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HOW CORE STIFFNESS AND POISSON RATIO AFFECT
ENERGY BALANCE ROLL STRUCTURE FORMULAS

J. D. Pfeiffer and W. Y. Hamad
Department of Mechanical Engineering
McGill University, Montreal
Quebec, Canada

ABSTRACT

The stiffness of the core determines how much support it will offer for the initial
wraps of web material, and whether this support will be maintained as internal pressures
are developed. An expression is developed for calculating the effective modulus of the
core for isotropic and anisotropic material. The linear solution is carried further to predict
how this core modulus is reflected in local radial hardness of the roll when additional
material is wound onto the core. The radial modulus parameters of a roll winding model
based upon energy balance are adjusted to account for the stiffening or yielding effect of
the core. under given winding conditions. The effect of different Poisson ratios on core
stiffness and roll formation is discussed.
WOUND ROLL STRESSES
FROM DISPLACEMENT MEASUREMENTS

David R. Roisum, Ph.D
Kimberly-Clark

ABSTRACT

Previous wound roll models required a known Wound-In-Stress boundary condition that is easily obtainable only for the restrictive case of pure centerwinding with measured incoming web tension and caliper. A new boundary condition and model were defined that allows wound roll stresses to be predicted for any winding case from roll diameter and web caliper measurements. These measurements are made during winding using an instrument similar to a density analyzer but extended to include web caliper. These measurements as well as material properties are input into winding models which have been extended to also calculate displacements. The net result is a measurement technique at least an order of magnitude more sensitive that previous methods, as well as fundamental outputs of radial and tangential stresses and strains at any point in the roll and at any time during the winding process.
ABSTRACT

The Force Sensing Resistor (FSRTM) is a device which changes resistance in a predictable manner with the application of force on its surface.[I] The FSR has been used in a variety of applications since its invention in 1986, including position sensing, traffic counting, pressure sensing in wind tunnels and sensing in numerous security devices. This publication presents the results of a study in which the FSR was implemented as a tool for measuring the radial interlayer pressures in wound rolls.

The FSR exists in two primary forms: the shunt mode FSR, and the through-conduction mode FSR. The focus of this study is concentrated entirely upon the shunt mode form of the device. The term “FSR” will refer to this form of the device throughout this publication.

The FSR consists of two polyester sheets sandwiched together. One sheet contains a screen printed pattern of discontinuous conductive fingers. The other sheet contains a sensing film consisting of a number of organic and inorganic ingredients suspended in a polymer matrix. The sensing film acts as a shunt resistance to the printed conductor on the opposing polyester sheet. The shunt resistance of the sensing film decreases proportionately with the applied normal force by means of microscopic contact mechanisms in the sensing film. Very small conductors and semiconductors, ranging from fractions of microns to microns in size, are present in the sensing film. The intimate contact of these particles with other particles and with the conductive fingers on the opposite sheet produces a relatively uniform resistance that changes as a function of pressure. In Figure 1, the mechanical form of the FSR is illustrated.

Since the FSR is manufactured by a screen printing process, any size or shape of FSR can be manufactured. The FSR used for all of the work in this study is shown in Figure 2. This pattern can be used not only to measure interlayer pressures at various radii in the wound roll, but it can also be used to measure the pressure variations across the width of the web in the cross machine direction.

This publication will first present a technique by which the FSR can be calibrated for experimental studies of the radial pressure profile in wound rolls. The results of wound roll studies which have led to the discovery of a new boundary condition for wound roll stress models are also presented. The development of this boundary condition allows models previously constrained to center-winding to be applied to center-winding with an undriven nip roll pressed against the wound roll.
ABSTRACT

Roll structure measurement is presently done with destructive and intrusive measuring devices, such as FSR’s or with specially instrumented winders. These methods are generally limited to research and development applications. Prior to this paper, there was no method of non-destructively determining the structure of a roll with unknown winding conditions.

This paper presents a measurement technique that uses thickness acoustic time of flight measurements to determine roll structure, an extension of the work done by J. David Pfeiffer [1] and alluded to by L. Eriksson [Z] and D. R. Roisum [3]. A measurement is made of the time required for an acoustic wave to travel through the roll. This time of flight measurement is used as an extra degree of freedom in a winding model such as Z. Hakiel’s [4] to replace an unknown or questionable model input, such as radial modulus or winding tension. The roll structure is determined by adjusting the model input until the calculated time of flight matches the measured time of flight.

The measurement technique was verified by comparison with two other independent methods. Each method was used to map the radial pressures in the left and right sides of six different wound rolls. Excellent results were obtained with the Acoustic Gage, when winding tension was used as the adjustable parameter. The excessive pressures predicted by winding models, the excellent results obtained by adjusting winding tension in the Acoustic Gage and the indication that stack tests produce accurate radial modulus data, cast doubt on the validity of the hoop stress boundary condition.
ABSTRACT

This paper presents a method of predicting the internal stress states in rolls simultaneously wound with independent supply spools of dissimilar material. The method is based on linear, orthotropic behavior of the mandrel and web materials, and is sufficiently general to allow an arbitrary choice for web materials and their respective winding tensions. The generality of the method also permits the introduction and termination of additional webs of arbitrary material at any time during the winding process. The method is analytical, and utilizes an elasticity solution with rigorous satisfaction of boundary conditions between each ply of the wound roll. A prototypical wound capacitor is used as an example to provide for numerical results of the internal stress states induced during the winding process. Differences in the winding tension loss of the two dissimilar web materials is discussed and explained, as are other mechanical threats to roll stability and performance. The influence of winding tension variations on internal, wound stress states is also discussed.
ON THE EFFECT OF WIDTH DIRECTION THICKNESS VARIATIONS IN WOUND ROLLS

Z. HAKIEL

Eastman Kodak Company
Rochester, NY USA

ABSTRACT

A first order model has been developed, which predicts the widthwise variability in wound roll diameter and stresses. This model has been verified experimentally on wound rolls of film and qualitative agreement between the predicted and measured results was found. The theoretical model and experimental techniques used in its verification are described.
USING A TWO DIMENSIONAL WINDING MODEL TO PREDICT WOUND ROLL STRESSES THAT OCCUR DUE TO CIRCUMFERENTIAL STEPS IN CORE DIAMETER OR TO CROSS-WEB CALIPER VARIATION

D. M. Kedl
3M Company
St. Paul, MN USA

ABSTRACT

This paper describes a model for estimating the stresses throughout a wound roll as a function of both radius and width. Width direction stresses are influenced by non-uniform winding tensions created through stacking layers of film with cross-web caliper variation. The model computes the effects of cross-web non-uniformity by dividing the roll into an arbitrary number of cross-web segments, treating each as a separate wound roll with its own winding tension, and tension taper. In order to compute tension, segment diameters are first determined. For this, a special model based upon stacking thick walled cylinders with orthotropic properties is used. Computations of the wound-in pressure and tension are then computed from any existing model that allows the compressive roll modulus to be a function of pressure.
ABSTRACT

The prediction of bobbin stresses generated by wire winding is now possible by combining a finite element structural code and a rigid body motion code. In this combination of computer codes, the bobbin and the individual wire wraps are considered to be axisymmetric. Each wire wrap is modeled with a single one-node element that has stiffness, mass and radius. The distributed radial load that a wire wrap exerts on the bobbin or other wires is calculated by using a relationship developed for a thin ring with a circular cross section.

In this analysis, a layer of wire wraps with a specified tension is applied to a bobbin. The bobbin contracts radially until an equilibrium position is reached. When a second layer is added, the bobbin and each wire in the first layer reach a new equilibrium position. The tensions and the distributed radial loads associated with each displaced wire in the first layer change accordingly. As additional layers are added, the tensions and the distributed radial loads for all the previously applied wires are adjusted to reflect their new positions. The stresses in the bobbin can be determined for any number of wire layers. Bobbin fixturing during winding can be simulated by imposing suitable boundary conditions on the bobbin’s finite element mesh.

A simple test problem is presented, providing a comparison between the finite element results and a closed-form solution. Quantitative results for bobbin stresses and wire tensions are then presented for more realistic coils. The impact of bobbin fixturing and wire packing structure on the stresses in the bobbin are also discussed.
STRESSES WITHIN ROLLS WOUND IN THE PRESENCE OF A NIP ROLLER

J.K. Good, Z. Wu and M.W.R. Fikes
School of Mechanical and Aerospace Engineering
Oklahoma State University
Stillwater, OK USA

ABSTRACT

Models which can be used to calculate the internal stresses within wound rolls of web material have all been confined to the center winding technique to date. In this publication a new boundary condition is presented which will allow existing models to calculate the internal stresses within a wound roll which has been center wound with an undriven nip roller impinged upon the outside of the roll. Experimental verification of the new boundary condition is presented. The mechanism by which a nip roller can increase the wound in tension in the outer layer of the wound roll is presented.
MECHANICAL STATES IN WOUND HETEROGENEOUS TAPES
BY THE FINITE ELEMENT METHOD

R. K. Thomas
Applied Mechanics Division 1544
Sandia National Laboratories’
Albuquerque, NM USA

ABSTRACT

The problem of predicting the mechanical stress and deformation states in wound tapes that result from the winding process addressed by application of the finite element method. The generally heterogeneous tape construction is approximated by continuum finite elements each of which represents many tape plies. Material behavior within the finite element continuum is assumed to be orthotropic elastic. The actual winding process, in which stressed plies are added to an already stressed but partially wound tape, is simulated by sequentially activating layers of finite elements which have initial stress equal to the average winding stress. This model has been implemented in the three-dimensional code JAC3D. Numerical results are presented for the case of a regular two-dimensional circular geometry, for which analytical solutions have been reported in the literature. The favorable comparison between finite element results and analytical results for this example problem validate the finite element approach.
WINDING PROBLEMS WITH ROTOGRAVURE JUMBO-ROLLS

E. G. Welp
Jagenberg AG
Geschäftsbereich Maschinenbau
Düsseldorf, Germany

ABSTRACT

The production and conversion of jumbo rolls presents a challenge to all involved in the production process. This presentation shows that as reel dimensions continue to increase, limits are being reached with regard to engineering and production. This applies to the paper, the core and particularly to winders and printing machine unloads. The two problems areas, on the one hand crepe wrinkles and bursts in the reel centre when rewinding and unwinding and on the other hand the danger of the core disintegrating in the winder machine unwind, which can have serious consequences, can only be solved jointly by those involved in the whole process. One effective measure will be to use 150 mm cores instead of the 76 mm core for extremely heavy jumbo reels. This will represent an initial decisive break-through to improve the situation. Further optimisation in paper making and converting, in core geometry, strength and stiffness as well as in the design of winders and printing machine unloads will ensure that the manufacture and conversion of jumbo reels meet the requirements posed.
MEASUREMENT AND CONTROL OF THE TENSION DISTRIBUTION ACROSS THE WEB IN A NEWSPAPER PRINTING PRESS

L. G. Eriksson
Swedish Newsprint Research Centre
Djursholm, Sweden

ABSTRACT

A bending moment in a newsprint web caused by unevenly distributed tension across the web leads to disturbances in the production. Measurements in a printing press during newspaper production showed large variations in the bending moment. The cause was found to be variations in mechanical properties of the paper, variations induced by the printing process e.g. reel changes, variable press speed and different amounts of fountain solution in different parts of the web. It has been found that the moment can be eliminated by an adjustment of the angle of the axis of a roller in the press.

A control system has been developed to eliminate the moment of the web in the printing press. The bending moment and the forces in the machine and cross-machine directions are measured by a roller mounted on load cells. The same roller can be used both as a sensor and as the controlling adjustable roller.

In the first section of this paper, the manner in which adjustments of a control roller will influence the stresses in the paper and the stability of the web has been theoretically studied. Based on the Timoshenko beam model, a mathematical model of the web has been established. Numerical calculations of forces, moments and lateral displacements in the web have to be made. The model is formulated in such a way that the stress characteristics in a web span are governed by only two dimensionless parameters, $K_sL$ and $g$. These parameters depend on the tension in the web, the free length and width of the web span and the bending and shear stiffness of the web.

The model can also be used to draw conclusions about the optimum design of the web lead when a control roller is to be installed in a printing press. The lengths of the spans on both sides of the control roller and the wrap angle can be changed to diminish the lateral displacement downstream of the control roller to negligible values. The design of the web lead must also fulfill the condition that the load on the upstream span from an adjustment of the control roller is smaller than the load on the downstream span. Measurements in the laboratory with 300 mm wide webs confirmed these theoretical results. It was also experimentally found possible to change the moment in the web without any permanent lateral displacement of the web at the rollers downstream of the control roller.

In the second section of this paper, the development of a closed loop control of the moment in a newspaper printing press based on measured values of the bending moment, the web tension and the web speed is described. The largest disturbances
occurred during the automatic reel changes, especially when two papers subjected to a flying splice had different elastic properties. The time constant of the control-roller response was chosen to be of the same order as the rise time of the change of the moment from the automatic reel change. Recorded data showed that the control system was able to suppress the fast variations of the moment which occur during the automatic reel change at full press speed.

Analysis of data from a large number of printed reels also showed that the correction signal from the control system reflected inherent properties of the reels. The device can therefore be used to map paper and reel properties.

Several hundreds of reels have been printed in a production press with the automatic control system in operation. A considerable improvement in runnability has been observed.
WEB TENSION MEASUREMENTS IN THE PAPER MILL

H. Linna¹, P. Moilanen¹, I. Koskimä²

¹Graphic Arts Laboratory
Technical Research Centre Of Finland (VTT)
Espoo, Finland

²Valmet Paper Machinery
Jyvaskyla, Finland

ABSTRACT

Web tension measuring methods and corresponding instruments have been evaluated at the Graphic Arts Laboratory of the VTT. Together with Valmet Paper Machinery, cross-web tension profiles have been studied in different paper machines and they have been compared to other profiles measured by the process control system in the paper machine. The role of the paper machine tension profile in winding and in paper customer rolls is outlined.

The measuring techniques developed seemed to be practical and are from now on available to analyze the paper machine performance. The realized field measurements have shown quite even profiles in basis weight, dry weight and moisture, which are normally measured at the dry end of the paper machine. Web tension can show drastic variation across the web and especially web edges used to be problematic.
CAUSE AND EFFECTS OF TENSION IN A
DRAW-CONTROLLED WEB PROCESS LINE

John J. Shelton
School of Mechanical and Aerospace Engineering
Oklahoma State University
Stillwater, OK USA

ABSTRACT

There is a common belief, supported by several technical papers and bulletins, that the tension in a web increases with velocity by the addition of the term $mV^2$ to the tension in a stationary web. This concept of a tension which increases with velocity is assumed to be a partial explanation of the increasing breakage of webs at higher velocities.

Certain effects of tension, such as the angle of release of a web which has been nipped to a roller and the depth of the catenary of a horizontal span, have been mistakenly believed to cause tension.

This paper shows that the web tension is not affected by the web velocity, if the tension is controlled by strain (draw ratio) as in a papermaking machine, nor is a catenary or other cause of a steady deviation in the path of the web the source of tension.
VARIABLE-GAIN CONTROL OF LONGITUDINAL TENSION
IN A WEB TRANSPORT SYSTEM

K. N. Reid and K. H. Shin
School of Mechanical and Aerospace Engineering
Oklahoma State University
Stillwater, OK USA

ABSTRACT

Fixed-gain and variable-gain PID control of longitudinal tension in the winding section of a simple web transport system were evaluated. An open-loop mathematical model for the web transport system was derived and used for the design of the PID controllers. The winding roll radius is a time-varying parameter in the model.

The fixed-gain PID controller designed for a particular winding roll radius did not meet the desired specifications, whereas the variable-gain PID controller compensated for the time-varying parameter and produced accurate tension control. In comparison with other controllers, the variable-gain PID controller is easy to implement and shows promise for applications where the time-varying parameters are easily measured.
ABSTRACT

Biaxially oriented web manufactured by the tenter method is first wound into a mill roll as the middle stage of the product roll manufacturing process. It is well known that mill roll winding quality greatly affects final product roll quality and productivity when finished by a slitter-rewinder. The key determinant of rewind quality is of course the basic performance of the winding system itself and its operation technique. However, another point which is rarely mentioned, yet is perhaps more important, is that of the tension control function which has an effect on web take-up as it comes out of the tenter. My paper introduces and explains some examples of practical facilities technology, focusing on this point.
ABSTRACT

Basic study has been conducted on sheet flutter which becomes an obstacle to the operation of printing machines and paper making machines in higher speed. Following three topics are presented in this paper.

(1) Fluctuating pressure causes sheet flutter. This fluctuation occurs as the vortex separates at the leading edge of the sheet and grows toward the downstream corresponding to the sheet movement.

(2) Characteristics of sheet flutter were clarified with respect to the following points.
   (a) Flutter mode, (b) Flutter amplitude, (c) Flutter frequency, (d) Influence of damping factor

(3) The critical velocity of sheet flutter is determined by the following three parameters.
   (a) Aspect ratio (b/c), (b) Rigidity parameter (Eh^3/12ρ_Ac^3), (c) Mass ratio (ρ_p h/ρ_Ac) (where b = sheet width, c = sheet length, h = sheet thickness, E = Young’s modulus, ρ_p = Sheet density, ρ_A = Air density)
ABSTRACT

A persistent problem in paper machines and other webs subjected to drying air flows is edge flutter. The resulting stresses can damage the edges, initiate tears and breaks in paper machines, or spoil coatings near the edges of polymer webs.

Analytical and experimental studies showed that the interaction of the web with the surrounding air is an important part of the problem, especially if there is a cross-machine flow component. This interaction has been investigated in wind tunnel tests. The results have been plotted to separate the influence of each design parameter on the incidence and severity of flutter. Semi-empirical equations have been developed to assist in the prediction of critical conditions. They should be helpful in selecting operating conditions, and avoiding either excessive or insufficient tension.

A number of practical suggestions are made for managing the drying air flow in order to minimize flutter damage.
ABSTRACT

Explicit finite difference schemes for modeling one-dimensional, transient web dynamics are designed, developed and tested. A sequence of numerical experiments are performed to ascertain the effects of various parameters on the stability and accuracy of the numerical results. Refinement of the numerical grid led to results which converged to analytical results for stable computations. For a particular web running speed and computational duration, there exists a time-step limit for stability. Longer computational time durations as well as higher web running speeds require reduced time-step size for stable numerical results. Upstream differencing of the Coriolis term to procure stability leads to numerical damping in the computations. A combination of upstream and central differencing yields stable results at larger time-steps than that required using full central differencing as well as less damping than that produced using full upstream differencing.
USING FINITE ELEMENT MODEL TO DEFINE HOW WRINKLES FORM IN A SINGLE WEB SPAN WITHOUT MOMENT TRANSFER

H. Gopal & D.M. Kedl
3M Company
St. Paul, MN USA

ABSTRACT

This paper describes a finite element model that successfully predicts the formation of troughs and shear wrinkles in plastic webs for a single span bounded by two idler rollers. For this model, wrinkles are created when the down-stream roller is out of tram with the up-stream roller, and there is no moment transfer across the up-stream roller. Variables considered are the span length web width, caliper, and tension.
SENSORS AND SIGNAL PROCESSING

AN OPTICAL EDGE SENSOR FOR TRANSPARENT FILM APPLICATIONS

D. Gronquist
Fife Corporation
Oklahoma City, OK USA

ABSTRACT

Sensing the edge of transparent film webs has always been somewhat difficult. Optical sensors typically see through the low opacity webs while pneumatic, ultrasonic and other sensors have their own sets of unique problems.

In transparent film applications, the typical usable optical sensor output can be as low as 10% of that obtained from a normal opaque web. Any error or thermal drift will be amplified through the system electronics along with the desired small control change. If a web were 10% opaque, a 5% thermal drift would become 50% of the usable output signal. Light emitters and sensing elements both have quite dramatic temperature characteristics.

By using modulated infrared “IR” techniques along with careful circuit design and stabilization, a sensor and companion amplifier have been developed that is usable with most transparent film web applications. Being low intensity IR in nature, it is useful in some photosensitive film applications. Its temperature drift of less than 1% across the 0 to 50 °C range is the key to transparent film applications.

This precision sensor is made possible by utilizing modem design techniques, some of which were borrowed from the aerospace industry. Constructed using Surface Mount Technology (SMT), the carefully selected circuits were fine tuned for stable and predictable operation.

The temperature-compensated mini sensor is small in size, low in power consumption, has excellent power supply stability, and temperature stability. The new sensor exhibits good plane change tolerance, ambient light immunity, electrostatic discharge immunity, and an excellent linear proportional control range.

The companion X10 amplifier provides the operator with a manual adjustment or control knob to compensate for web opacity. When properly adjusted, this control position relates to the opacity of the web material being used. The primary purpose of the amplifiers is to provide the controller with full-scale or typical sensor levels regardless of web (10% m 100%) opacity. The operator adjustment procedure is quite simple and easily mastered.
ABSTRACT

In order to initiate programs in web handling, it is necessary to understand the technical vector that has developed in the field. In this paper we have investigated 1784 Japanese patents on web handling technology that were issued from 1971 to 1988, 227 patents have been classified into several categories and as a result, we have found that Japanese patents concentrate on hardware (e.g., splice, tension control and edge position control) and phenomena. Phenomena include improvement of winding quality and recently, several patents to increase yield percentage and to improve storage quality.
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AIR SUPPORT CONVEYANCE OF UNIFORM AND NON-UNIFORM WEBS

Ronald P. Swanson
3M Company
St. Paul, Minnesota

ABSTRACT

A web span model and solution technique have been developed to determine the stresses and deflections of uniform and non-uniform webs, subject to side loading from an air support system. Formulas are given to calculate the magnitude of these side forces. An experimental air support system was used to verify the model, and serves as an example to determine the cause of lateral displacement problems.
ABSTRACT

Although the prevention of lateral instability on continuous processing lines called “strip walk” is important in achieving high productivity and improving quality for steel industry, empirical systems have been applied to specific problems for many years. To meet various requirements, a general-purpose numerical simulation model based on spring-mass system was developed, which can predict the unsteady-state walking behavior of strip on a multiple-pass continuous processing line.
ABSTRACT

Lateral control of a web through a process line involves the use of web guides and control systems at different points in the process. There are three general areas for guiding. Guides are typically located at the terminal ends of the process and in the process section. Guides located at the terminal ends are referred to as unwind and rewind, uncoil and recoil, payoff and tension reel, and other terms that may be specific to certain industries. In between the terminal guides is the process section. Guides in this section are referred to as intermediate guides.

This paper concerns the practical application of terminal guides (unwind and rewind), the control system loop, the control system types, sensor configurations, sensor locations, and response of the system and equipment.
ABSTRACT

Draw control is defined as changing or maintaining web tension by controlling surface speeds of consecutive driven rollers. Even though draw control is commonly used in web handling applications, there remains some misunderstanding of the relationship between machine draw and the resulting web elongation and tension. Fundamentals of draw control and a new analytical solution will be presented.

Draw control is commonly used downstream of a constant tension zone. The strain at any point in the process is dependent on the upstream tension and the added web strain from the machine draw. Recent experimental studies of draw control have revealed a previously unknown influence of nip roller load, similar to pack rollers at winding. Models for nipped pull roller slip conditions, and nip induced draw and tension will be presented.

THEORY AND APPLICATION OF DRAW CONTROL FOR ELASTIC WEBS WITH NIPPED PULL ROLLERS

Thomas M. Spielbauer and Timothy J. Walker
3M Company
St. Paul, Minnesota
EFFECTS OF PID GAINS FOR CONTROLLER WITH DANCER MECHANISM ON WEB TENSION

P. Lin¹ and M. S. La²

¹Rockwell International Corporation
Westmont, Illinois

²Rockwell International Corporation
Thousand Oaks, California

ABSTRACT

A dancer mechanism is widely used in connection with a tension controller in the tension control systems for web printing presses. The common tension controllers perform proportional, integral, and/or derivative (PID) control. This paper investigates the effects of PID gains on the web tension under various operating conditions, such as variations of paper roll size, various desired web tension levels, various web speeds, and other parameters. A mathematical model representing the unwind and the infeed sections of a printing press is used to simulate web tension in connection with various controllers and operating conditions. Effects of the individual gain in various controllers using proportional (P) control, proportional-derivative (PD) control, proportional-integral (PI) control, and PID control are discussed and compared.
CONTROL OF LONGITUDINAL TENSION IN MULTI-SPAN WEB TRANSPORT SYSTEMS DURING START UP

Karl N. Reid and Ku-Chin Lin
School of Mechanical and Aerospace Engineering
Oklahoma State University
Stillwater, Oklahoma

ABSTRACT

The control of longitudinal tension in a multi-span web transport system during start up is studied using first-principles modeling and digital simulation. Since start-up problems normally involve large variations of system roller velocities, nonlinear models (rather than linearized models) are used for the analysis.

Examples of systems using load cells and dancer subsystems for tension measurement are presented to demonstrate the effects on web tension of changes in the start-up conditions.
NEW DECENTRALIZED CONTROL IN PROCESSING MACHINES WITH CONTINUOUS MOVING WEBS

W. Wolfermann and D. Schroeder
Technical University of Munich
Munich, Germany

ABSTRACT

Web-products are manufactured in sections of rollers which transport the web according to specific technological demands. To achieve the required final product, the transport of the web has to be successful without material defects and losses. To fulfill these demands, the tension in the web during transport must be kept on a desired value within close limits. Therefore, electrical and mechanical quantities of the drives have to be controlled by closed loop control systems.

The rollers in such processing machines are coupled by the web and are driven usually by electrical motors. So the processing machines are multi-motor drives and from the view of control a multi input - multi output system.

To improve the dynamic behavior of the controlled system, new concepts with decoupling state space control are considered in this paper. The goal of the control are non-interacting, decentralized control-loops. Two decentralized control methods were developed and are described.

The first method is called DECENTRALIZED DECOUPLING. The state space controller of low order for each subsystem makes the controlled subsystems approximately unobservable and uncontrollable from the neighbouring subsystems. The second method is FUZZY-CONTROL which is in examination just now.

The new control methods are applicable for both, DC- and AC-drives. The identification of the process variables and the calculation of the control algorithm is performed by a microcomputer system.
ON THE DYNAMICS OF WEB TRANSFER
IN AN OPEN DRAW

Pekka Pakarinen\textsuperscript{1}, Risto Ryymin\textsuperscript{1}, Matti Kurki\textsuperscript{2}, Pekka Taskin\textsuperscript{3}

\textsuperscript{1}Technical Research Center of Finland
Jyväskylä, Finland

\textsuperscript{2}University of Jyväskylä
Jyväskylä, Finland

\textsuperscript{3}Valmet Paper Machinery, Inc.
Jyväskylä, Finland

ABSTRACT

A paper web running in an open draw of a high speed paper machine is subjected to various internal and external forces which stretch it and which can ultimately rupture it. The forces arise from speed differences between various web transfer elements, from pressure loads transmitted through the surrounding air and from the effects of gravity, friction and drag. Since the web travels in a curved path, it is also subjected to centripetal forces, which can reach very high magnitudes.

This study is concerned with the dynamics of paper web in an open draw. The constructed model takes into account external and internal forces acting on the web. There is provision in the model for determining variations in web tension caused by occasional external disturbances.

The sensitivity of web tension to small external disturbances is shown in simulations. The length of the open draw is an important variable in web transfer dynamics. Another essential parameters which must be included are the aerodynamic drag forces, as they contribute to damping the resonance events during web transfer, and therefore to web stability.
ABSTRACT

A dancer subsystem may be used as a tension measurement or as a disturbance attenuator depending on its design. The design of a dancer subsystem to accomplish a desired result requires the development of a dynamic model for the subsystem. This paper presents the results of a generalized dynamic model of a dancer subsystem. Examples are presented to illustrate the behavior of an unwind-rewind web transport system which incorporates a dancer subsystem, and which has periodic disturbances from an out-of-round unwinding roll.
ADVANCED WINDING MACHINE DEVELOPMENT
AT SANDIA NATIONAL LABORATORIES*

Charles B. Richardson
Sandia National Laboratories
Albuquerque, New Mexico

ABSTRACT

Sandia National Labs, New Mexico is designing and testing an improved version of its state-of-the-art capacitor winding machine. The new CL1610 winding machine is based on the mechanical design of three previous Sandia designed winding machines using a precision tool plate and guide roller design to provide very accurate material alignment and minimum roller drag. It features closed-loop tension control, precise material acceleration and velocity control, programmable logic controllers, and an improved and expanded operator interface.

The new machine will increase Sandia’s capacitor fabrication capability by applying the tension control accuracy we now have for narrow width films and small diameter windings to films up to 0.2 m in width and windings up to 0.25 m in diameter. Tension control of ±0.05 N will be maintained on the new machine through a range of 0.25 to 4.90 N. The machine will implement variable tension control with the goal of optimizing the electrical performance of the wound capacitors. The tension variation will be based on a model developed at Sandia that calculates internal mechanical stresses and will serve to specify all mechanical stresses in a finished capacitor. The new machine will also have the capability to wind non-cylindrical capacitors while maintaining the tension control of ±0.05 N we currently have for cylindrical capacitors.

The capability to wind two to sixteen ply extended and buried foil capacitor designs with the widths and diameters mentioned above will be available with the new machine. Take-up mandrel velocity and acceleration will be controlled using a stepper motor that can be programmed to operate between 0 and 60 RPM and 0 and 3000 rev/min/min. In addition, the number of active turns, the number of pre- and post-insulating wraps, and the number of turns to the foil termination can all be programmed.

Operator errors will be reduced by automation techniques and instruction sets built into the PC interface. The machine will be controlled with a Macintosh computer that communicates with both the stepper motor controller and the programmable logic controller (PLC). Using a Sandia designed software interface on the Macintosh, all of the process parameters are entered by the operator before winding begins. Variable tension will be controlled through the same interface. The operator will enter the material properties and geometric characteristics of the capacitor and the computer will generate the tension variations necessary to achieve the desired mechanical stresses. The PLC will control winding tension and spindle braking, while the stepper motor computer will control take up spindle velocity, acceleration, and material travel distance. All of the
process parameters obtained from the fabrication of a capacitor are entered into the computer automatically, or by the operator, and can be stored for later analysis.

*This work was performed at Sandia National Laboratories supported by the U.S. Department of Energy (DOE) under contract number DE-AC04-76DP00789.
A STUDY OF THREE-DIMENSIONAL NONLINEAR NIP MECHANICS

Ted Diehl\textsuperscript{1,2}, Kenneth D. Stack\textsuperscript{2}, and Richard C. Benson\textsuperscript{2}

\textsuperscript{1}Eastman Kodak Company
Rochester, New York

\textsuperscript{2}University of Rochester
Rochester, New York

ABSTRACT

An understanding of nip pressure and deformed nip geometry is of vital importance to the design of web handling equipment. Axial variations in nip pressure and deformed nip geometry can lead to poor product performance and customer dissatisfaction. This study evaluates these axial variations for two general cases: an identical-hollow-drum design and a classic calendaring design. Both cases include the effects of elastomeric coverings. Comparisons between modeling the resulting axial variations in nip parameters by beam effects or shell effects are evaluated. Evaluations of nip pressure and overdrive/underdrive are performed. Approximate boundary conditions for the study of web wrinkling are proposed based on deformed nip geometry.
INSTRUMENTING ROLLING NIPS FOR VIDEO RECORDING AND STRAIN RECORDING

J. D. Pfeiffer
Department of Mechanical Engineering
McGill University, Montreal
Quebec, Canada

ABSTRACT

An apparatus has been constructed to study the effect of a rolling nip on multiple layers of paper or other material. The use of a roller in contact with the surface of a winding product roll excludes air and produces higher levels of winding tension than when the web is brought into contact with the roll without nip contact. However, rolling nips are suspected of producing a number of side effects such as crepe wrinkles, torsional twisting within the roll body leading to roping and corrugations, and possible generation of bursts within the roll on weaker sheets. In this apparatus it is possible to measure the tension on each end of fifteen strips of material to study the effect of web tension and nip force on the residual tension distribution within the sheets. The roll body remains stationary while the nip travels around it, and this has allowed the installation of a continuous-focus microscope and closed circuit television camera to view the behavior of the webs as the nip passes by. Observation of differential motion between web layers is possible but difficult, as the total displacement is small. The strain gages have detected strain differences between the webs and results are reported for testing 15 webs of newsprint under different nip loading forces and web tensions.
A MATHEMATICAL AND EXPERIMENTAL INVESTIGATION OF
THE STACK COMPRESSION OF FILMS

Albert W. Forrest, Jr.
DuPont Company
Circleville, Ohio

ABSTRACT

An analytical model has been developed which predicts the stack stiffness of multiple layers of films with rough surfaces. Film surfaces are approximated by asperity distributions measured using commercially available equipment. Comparisons were made with stack compression measurements made in a vacuum. It was found that measurements taken in a vacuum were quite different from those taken in air. Approximate correlations are included for PET films. The results are suitable for approximating the radial elastic modulus in rolls of film.
ABSTRACT

Historically wound roll models have required the input of a radial modulus of elasticity. Heretofore this modulus has been measured using material testing systems which have shown the radial modulus to be dependent upon radial pressure and that it is typically much less than the in-plane moduli of the web. This paper focuses upon a method in which the radial modulus can be predicted based upon surface roughness characteristics. The advantage of this method is that wound roll stresses can be predicted prior to the manufacture of the web. Thus winding strategies can be developed prior to the production of the web. An application of this theory will be presented on polymer webs with experimental verification.
NEWSPRINT ROLLS WITH A DIAMETER OF ABOUT 125 CM HAVE BEEN RUN SIX TIMES THROUGH AREWINDERS. THE CHANGES IN THE CD WEB TENSION PROFILE HAVE BEEN RECORDED DURING THEREWINDINGS. THE ROLL HARDNESS HAS BEEN MEASURED BEFORE AND AFTER EACH REWINDING. PAPER SAMPLES HAVE BEEN TAKEN OUT AND MEASURED IN ORDER TO DETERMINE THE CHANGE IN PAPER PROPERTIES SUCH AS SURFACE ROUGHNESS, SURFACE COMPRRESSIBILITY, THICKNESS, AIR PERMEANCE, AND FRICTION COEFFICIENT. TENSILE TESTING HAS ALSO BEEN MADE AND VALUES OF TENSILE STIFFNESS, TENSILE STRENGTH, TENSILE ENERGY ABSORPTION, AND STRAIN TO FAILURE HAVE BEEN DERIVED.

THE CD WEB TENSION PROFILE REMAINED ALMOST THE SAME. THE TENSILE PROPERTIES CHANGED ALSO VERY LITTLE. THE ROLL HARDNESS INCREASED AFTER THE FIRST REWINDING, BUT IN THE FOLLOWINGREWINDINGS IT DID NOT CHANGE VERY MUCH. THE THICKNESS, SURFACE ROUGHNESS, AND SURFACE COMPRESSIBILITY DECLINED SIGNIFICANTLY.

SIGNIFICANT CHANGES OF THE PAPER PROPERTIES ARE RECORDED AFTER THE FIRST REWINDING. THEREAFTER VERY SMALL CHANGES TAKE PLACE WHEN THE ROLL IS REPEATEDLY REWOUND.
THE EFFECT OF AIR ENTRAINMENT IN CENTERWOUND ROLLS

J. K. Good, Oklahoma State University

M. W. Holmberg, Graphics Technology International

ABSTRACT

Internal stress models for centerwound rolls have existed for over thirty years but no model to date has accounted for air which is entrained due to the web velocity and the viscosity of air. This paper reports the results of an experimental investigation in which the entrained air thickness was monitored on a centerwinding roll. The results confirmed that the air foil bearing theory was adequate for describing the amount of air entrained to a centerwinding roll. Knowledge of the amount of entrained air allowed the derivation of a reduced radial modulus of elasticity for the wound roll which when used with a wound roll model yielded results which compared well to experimental pressure data.
IRREVERSIBLE REDUCTION OF FOIL TENSION DUE TO AERODYNAMICAL EFFECTS

F. Bouquerel and P. Bourgin

1Rhône-Poulenc Films
Miribel, Cedex, France

2Ecole d’Application des Hauts Polymères
Strasbourg, France

ABSTRACT

Computation of the residual stress generated during the winding of B plastic film has been coped with by many authors. These studies are based on the assumption that the residual stresses mainly depend on two winding factors: (i) nominal foil tension and (ii) foil mechanical properties. Recently, several authors have introduced the effects of a third winding factor: nip force. But, in all the existing studies, the influence of the entrapped air layer and more generally, the aerodynamical effects are neglected.

Such an assumption is reasonable in the case of thick plastic film (thickness about 100 µm) or thin plastic films (thickness about 10 µm) wound under low velocities (about 1 m.s⁻¹). However, in the case of industrial winding conditions in which film thickness is typically about 10 µm and velocity about 5 m.s⁻¹, the effects of aerodynamical phenomena are experimentally known to be as important as the effects of foil tension itself.

From a more general point of view, the industrial winding conditions suffer from a lack of theoretical analysis since they are mainly based on empirism, which is not quite satisfactory.

We recently proposed a model in order to predict the residual stresses generated under realistic industrial conditions, including the effect of nip roll. This model is based on a new global approach in which the winding process is seen as a mechanism of air entrainment and air exhaust. To set this model in order, we were faced with several problems: (i) computation of the thickness of the entrained air layer, (ii) analysis of the air exhaust phenomena, (iii) analysis of effects due to film toughness... All the main parameters which govern the winding process (velocity, foil tension, nip force, foil bulk and surface properties...) are taken into account.

In the present paper, we propose to recall the basis of this new global approach and to focus our attention on one of its most important consequences: the irreversible reduction of foil tension during and after winding. Experimental check is presented for a large set of winding conditions. Comparison is based on the average air layer thickness and on the foil residual tension value.
AIR FILMS BETWEEN A MOVING TENSIONED WEB
AND A STATIONARY SUPPORT CYLINDER

S. L. King, B. A. Funk, and F. W. Chambers
Oklahoma State University
Stillwater, Oklahoma

ABSTRACT

Web quality and web processing efficiency depend upon maintaining a proper lubricating air film between the moving web and the driving and supporting rollers. As web line speeds are increased, the film can become too thick, reducing traction between the web and roller. A common means to improve traction when this “web flotation” is encountered is to roughen the roller surface. While flexible foil bearing theory may be applied to predict the thickness of the air film between a non-porous web and a smooth roller, empiricism must be applied for textured, roughened rollers. The mechanisms through which these surfaces work have been unclear and models to predict their performance have been unavailable. This paper presents the results of research conducted to identify the traction improvement mechanism through measurements of the air film thickness between a web and roughened rollers. The principle objective of this work was to determine how the addition of surface roughness changes the air film from that which can be predicted with foil bearing theory.

The effects of surface roughness on the air film were evaluated experimentally by measuring the height of a tensioned smooth web moving over a stationary cylinder with three alternate surface roughness segments. The 152 mm (6 inch) wide web was a spliced continuous loop of 36 µm (1.4E-03 inch) thick polypropylene with vacuum deposited aluminum on the upper surface. The stationary cylinder was aluminum with a diameter of 203 mm (8 inches) and alternate surface roughness segments of 0.76, 2.0, and 4.3 µm rms (30, 80, and 170 microinches rms). Web speeds ranged up to 12.7 m/s (2500 ft/min) and web tensions were 219 N/m (1.25 lbf/in.), 314 N/m (1.79 lbf/in.) and 460 N/m (2.62 lbf/in.).

The measured air film heights were compared with those predicted by the foil bearing equation. Good correlation was achieved for the web moving over the smoothest surface only. The rougher surfaces did not produce air films that followed theory for the complete speed range. In some cases, the air films followed foil bearing theory at lower speeds but then became nearly constant and independent of speed at higher speeds, significantly below foil bearing predictions. The air films for the highest roughness surface were constant and independent of speed throughout the tested speed range, remaining far below the predictions of foil bearing theory. The reasons for this behavior and the implications for web-roller traction are discussed.
ABSTRACT

Lateral compressive buckling of a web is often evident in troughs along a tensioned span and in corrugations in a wound roll or in the web wrapping a roller.

The lateral compressive forces are not evident from elementary free body diagrams, but arise from microscopic displacements caused by such phenomena as steering of edge tape elements by deflected rollers and an increasing width as the web passes over a driven roller or is expanded by heat, moisture, or viscoelastic memory.

The theory that buckling of webs is caused by lateral compressive forces is supported by comparisons of wavelengths of troughs and corrugations to predictions by classical buckling theory.

The theory of buckling of webs implies that, for inherent avoidance of harmful wrinkling, rollers should be stiff and as smooth as practical, tensions should be as constant as possible throughout the processing machine, and the web should be as dimensionally stable as possible.
WEB TENSION AND WRINKLES IN THE PRINTING PRESS

Hannu Linna¹, Pertti Moilanen², and Markku Parola³

¹Manager, Materials Section
²Research Scientist
³Research Scientist

Technical Research Centre of Finland (VTT)
Finland

ABSTRACT

In a modern paper mill the web handling in way process stage is optimized to fulfill productivity demands. The same kind of demands also exist in the printing plants. Smooth production without runnability disturbances is a must in both cases. But in practise several problems still exist. Uneven paper profiles together with long web leads in 4-colour printing can be problematic. The shape of the web tension profile is often known but the variation across the web needs careful measurements. Because of differences in tension distribution, rolls cut from several positions on a paper machine reel can be totally different when printed in a 4-colour web.

Web tension measurements from paper machines to printing presses were carried out by the Graphic Arts Laboratory of the VTT. The same paper machine reel was measured with a portable set of measuring equipment both in a paper machine and in a winder. Laboratory analysis of the paper was carried out. The tension profiles of customer rolls were again measured in printing plants. The printed sheets were evaluated and the wrinkling phenomenon across the paper machine web was analysed. The results show that the profiles measured in printing presses originate from paper machines. Also the limitations of modem printing presses and paper itself must be taken into consideration when an optimum combination of tension and other paper profiles are aimed at in every process stage.
INTRODUCTION

It is often observed that flexible membranes are prone to wrinkling when passed through a roller “nip”, when transported over a guide, or when wound onto a roll. This is due to an unfortunate design incompatibility between the web’s inability to withstand compressive stress, and the sensitivity and variability that exists in many transport devices.

Figure 1 illustrates a problem familiar in web transport. Nonuniform conditions along the length of the nip cause variability in the transport speed of the web. This will cause a gradual build-up of loading on the web until finally the imbalance is relieved. For thick webs, the imbalance may be relieved through a complicated stick-slip behavior in the nip itself. For thinner webs, the imbalance may cause buckling. Buckling, or wrinkling, is highly undesired as the wrinkle will often be drawn into the nip, and then creased and made permanent. Figure 1 shows two commonly observed wrinkling patterns colloquially called “rivers” and “lakes”. Figure 2 shows three photographs of a web with dimensions 148 mm × 114 mm × 6 µm (5.8 in × 4.5 in × 0.25 mils). From top to bottom, the three wrinkling patterns are of the “rivers”, “lakes”, and shear-induced type.

It is the goal of this paper to examine a very thin web under different edge displacement conditions, and to assess the consequences on wrinkling. Three of the edge loading patterns will be chosen for their basic nature. Two other test cases will be based on nip transport conditions predicted in a companion paper in this conference by Diehl, Stack and Benson [22]. A geometry exhibiting shear wrinkles will be used in three final cases to compare different modelling approaches.

The basic tool for our analysis is “tension field” theory which has been developed over the past 60 years to analyze a number of flexible structures that can support tension, but have virtually no ability to withstand compression. Application areas include airplane wing coverings, human skin, cloth, paper sheets, and polyethylene terephthalate (PET) webs. References [1-13, 16-22] provide a sampling of the work that has been done in the past. The details of “tension field” theory, and more about individual references will be discussed in the next section.
TWO TYPES OF WRINKLING PATTERNS

“Rivers”

“Lakes”

Figure 1: “Rivers” and “Lakes”
THE MECHANICS OF WEB SPREADING

David R. Roisum, Ph.D.
Finishing Technologies, Inc.
Neenah, Wisconsin

ABSTRACT

Web spreading systems are governed by a universal set of web handling principles such as bending, minimal energy path, normal entry and traction. These laws, which apply for all web materials and spreading systems, can be used to understand the influences which affect spreader operation.

This report covers the mechanics of spreaders such as: bowed rollers, dual bowed rollers, concave rollers, expander rollers, D-bars, Pos-Z™ bars and more. Also covered are spreader design considerations and troubleshooting techniques.
ANALYSIS OF WEB SPREADING INDUCED BY THE CONCAVE ROLLER

R. D. Delahoussaye and J. K. Good
Oklahoma State University
Stillwater, Oklahoma

ABSTRACT

This paper describes the development of a model for predicting the elastic deformations and stresses in a web crossing a concave (or negative crown) roller. The Finite Element Method was used to compute web displacements, forces and stresses. A preprocessor was developed to automatically convert the web material properties and roller geometry into a FEM mesh and a set of boundary conditions. The boundary conditions which produce web spreading were developed and incorporated into the model. The principal boundary conditions in this model are derived from the assumption that there is sufficient friction between the web and the roller to prevent slipping. Because of the nonlinear nature of the traction between the web and the roller, an iterative Finite Element solution technique was used. The model was used to perform a study of the effects of variations in geometry, material properties and operating conditions on the spreading behavior of the web/roller system. The results of this study are presented.
ANALYSIS OF WEB SPREADING INDUCED BY
THE CURVED AXIS ROLLER

R. D. Delahoussaye and J. K. Good
Oklahoma State University
Stillwater, Oklahoma

ABSTRACT

This paper describes the development of a model for predicting the elastic deformations and stresses in a web crossing a curved-axis roller. The Finite Element Method was used to compute web displacements, forces and stresses. A preprocessor was developed to automatically convert the web material properties and roller geometry into a FEM mesh and a set of boundary conditions. The boundary conditions which produce web spreading were developed and incorporated into the model. The principal boundary conditions in this model are derived from the assumption that there is sufficient friction between the web and the roller to prevent slipping. Because of the nonlinear nature of the traction between the web and the roller, an iterative Finite Element solution technique was used. The model was used to perform a study of the effects of variations in geometry, material properties and operating conditions on the spreading behavior of the web/roller system. The results of this study are presented.
ABSTRACT

A web is a material that is produced as a continuous sheet and stored in wound roll form. Mechanics of web material handling in production, coating or conditioning, and winding operations affect web uniformity and the material stress/strain state, thus affecting roll quality. In an effort to improve all aspects of web handling procedures, much attention has been focused on acquisition and utilization of on-line web handling process information such as web tension. Tension is a quantity basic to web production and processing yet historically has been difficult to measure except in an average sense. Improvements in on-line tension measurement accuracy have foreseeable application to automated tension control systems and winder maintenance used in modern day web production/processing facilities. This paper describes a new means of noncontacting, local web tension measurement through use of a point source pneumatic excitation coupled to signal acquisition and processing schemes. Advantages of this new system include variable web excitation rate, variable system tuning for different applications, high lateral tension distribution resolution, and compact, easily serviceable transducer head assembly. This work was sponsored through the Web Handling Research Center (WHRC), an NSF funded research facility located at Oklahoma State University in Stillwater, Oklahoma.
WEB TENSION PROFILES AS MEASURED IN A REWINDER AND IN A PRINTING PRESS

P. Hellentin¹, L. G. Eriksson¹, P. Johnson¹, and G. T. F. Kilmister²

¹Swedish Newsprint Research Centre
   Djursholm, Sweden

²Davy International
   Poole, England

ABSTRACT

The web tension profile has been measured with an equipment called the CTSensor (Cross Tension Sensor) during ordinary production-runs both in rewinders and in newspaper printing presses. The measuring roller was placed after the printing units.

The cross-direction (CD) tension profile from a paper machine does not vary much from time to time during normal conditions. From the measurements in the rewinder it is seen that higher moisture content gives lower tension. In the printing press the tension profile is changed, which is caused by the dampening with the fountain solution.

When one reel in the printing press is automatically changed in the flying paster, it is possible to record the changes in the tension profiles between the two rolls. Tension transients are sometimes found, but they are normally small, and should not alone cause web breaks. However, when web breaks occur it is often in connection with the flying paster. A control roller can be used to compensate the change in the bending moment, which reduces the risk for web breaks.
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FROM PREDICTIVE MODELS TO PROFITABILITY
IN THE WEB-HANDLING INDUSTRY

Z. Hakiel
Eastman Kodak Company
Rochester, N.Y.

ABSTRACT

This paper attempts to put some of the work being done by researchers in the web-handling field, including some of the papers to be presented at this conference, into a broader business context. Various ways of utilizing predictive models are discussed, ranging from troubleshooting to robust product-process design. A future-state vision for a highly effective web-handling predictive model is defined. An example consisting of the application of an analytical wound-roll stress model in conjunction with statistical methods to the robust design of a roll-winding process is described to illustrate the potential value of such an approach.
DEFORMATION OF HIGHLY COMPRESSED WOUND ROLLS

R. C. Benson, J. E. LaFlecbe and K. D. Stack
University of Rochester
Rochester, NY, U.S.A.

ABSTRACT

This study concerns the loss of lap tension and interlayer pressure in a wound roll due to the compression of the web. Compression of the web thickness also affects the amount of material that may be wound into a roll of a given diameter. Stress predictions are made using a new, nonlinear wound roll model developed by the Mechanics of Flexible Structures Project at the University of Rochester. Comparison to experimental data available in the literature is excellent. We find that for some materials such as polyethylene terephthalate (PET) the effect of web compressibility is relatively insignificant. For other materials, like paper, the effect is important.
A NONLINEAR MODEL TO CALCULATE THE STRESSED STATE OF A CENTER-WOUND ROLL

C. A. Piper
3M Company
St. Paul, MN, U.S.A.

ABSTRACT

This work develops a model to calculate the stressed state of center-wound rolled webs, such as film paper, or foil. The model is built on a lesser known linear model developed by Umanskii and accounts for the nonlinear stress-strain relationship of the roll in the radial direction as determined from uniaxially compressing a stack of the material. The main cause of this nonlinear behavior is inter-layer air entrapment and web surface roughness. The more popular published linear model developed by Altmann has been extended by Hakiel to include the roll’s nonlinear radial stress-strain relationship. However, recent published work shows the radial stresses predicted by Hakiel to be significantly greater than measured data using calibrated pull tabs for some webs.

Results from this nonlinear model are compared to published measured in-roll radial stress data for three materials: PET, newsprint and bond paper. After eliminating the softest portion of the stack test data, the model predicted in-roll radial stresses that agree well with the experimental data for PET. The predicted in-roll radial stresses were less than the experimental data for both papers. However, results from the Hakiel model and the new nonlinear model were found to provide bounds for the experimental data for paper.
THE EFFECT OF HIGH VELOCITIES, STARTUP AND SHUTDOWN ON WINDING

J. E. Olsen
Norwegian Institute of Technology
Trondheim, Norway

ABSTRACT

The effect of high velocities on wound rolls is analyzed by applying a winding model accounting for the centrifugal effect. Also realistic velocity functions with startup and shutdown are considered. The effect of high velocities, startup and shutdown and on winding is found to be significant.
A NONLINEAR ORTHOTROPIC VISCOELASTIC WINDING MODEL

W. R. Qualls and J. K. Good
Oklahoma State University
Stillwater, Oklahoma, U.S.A.

ABSTRACT

A realistic and adaptive viscoelastic model for prediction of transient wound roll stress distributions is presented. The web material is taken to be orthotropic with a nonlinear radial creep compliance dependent upon interlayer pressure. Viscoelastic behavior is represented by a generalized Maxwell model for creep written as a convolution integral. Numerical solutions to the resulting integral boundary value problem give both initial and transient stress distributions within the mound roll. The model is successfully compared to the exact solution for a simple case of isotropy as well as to published works on this topic. In contrasting the solutions, the advantages and adaptability of this nonlinear formulation will be readily seen.
AIR ENTRAINMENT DURING FILM WINDING WITH LAYON ROLLS

A. W. Forrest Jr.
DuPont
Circleville, Ohio, U.S.A.

ABSTRACT

Excessive air entrainment has long been recognized as a cause for telescoping and other forms of wound roll defects. To eliminate a portion of the air, exclusion devices such as layon rolls are often used. Air entrainment calculations in the literature generally do not consider this geometry. When layon rolls are employed, the high pressures under the nip make consideration of the surface roughness necessary. Here, the contact pressure is supported by a combination of the surface roughness and the entrained air pressure. After the nip passes, the entrained air expands and a final winding condition is achieved. This paper describes an analytical procedure that calculates the amount of entrained air considering these effects.
AIR ENTRAPMENT AND RESIDUAL STRESSES IN ROLLS WOUND WITH A RIDER ROLL

J. K. Good and S. M. Cove11
Oklahoma State University
Stillwater, Oklahoma

ABSTRACT

Air is entrained during the process of winding webs. Rider rolls are often employed in an effort to reduce the amount of air which enters the wound roll. This paper presents the results of an experiment which allows the entrained air to be measured. With knowledge of the levels of entrapped air an algorithm was chosen to predict the amount of entrained air for various operating conditions. Finally the air entrapment algorithm was incorporated into a wound roll model such that the effect of the entrained air on the residual pressures within the wound roll could be studied.
WOUND ROLL STRESS ANALYSIS INCLUDING AIR ENTRAINMENT AND THE FORMATION OF ROLL DEFECTS

A. W. Forrest Jr.
DuPont
Circleville, Ohio, U.S.A.

ABSTRACT

Numerous procedures have been developed to determine the stresses inside wound rolls of film. These typically use factors such as winding tension, film thickness and film properties to calculate the stresses. The calculation presented here includes provisions for entrained air and methods to predict the formation of common roll defects. The entrained air pressure, the air gap and the winding tension are used to fully define the surface boundary condition during winding. Incipient buckling criteria are developed to predict deformations induced by transverse and circumferential stresses. The results include radial pressures, circumferential and transverse direction stresses, buckling defect formation indicators and the entrapped air pressure for the plane-strain case.
THE IMPORTANCE OF TORQUE CAPACITY IN PREDICTING CREPE WRINKLES AND STARRING IN WOUND ROLLS

J. K. Good and N. Vaidyanathan
Oklahoma State University
Stillwater, Oklahoma

ABSTRACT

Roll models provide information about the radial stresses and circumferential stresses that exist in a wound roll of web material. A derived quantity that is available from the radial stress profile is the torque capacity. The torque capacity is the ability of a wound roll to resist slippage when subjected to external torque. Crepe wrinkles that occur in wound rolls have been attributed to slippage. The literature available on crepe wrinkle formation is nebulous with respect to quantitative evidence available to identify parameters that contribute to the formation of the defect. A parameter associated with the winding machinery is the deceleration that rolls undergo. A method to predict crepe wrinkle formation due to slippage that results during deceleration will be presented with quantitative evidence. Starring has been attributed to negative circumferential stresses that exist in wound rolls. Slippage has never been identified as a factor that contributes to star formation. This study identifies the importance of torque capacity as a means to predict starring in center-wound rolls, and provide quantitative evidence from experimental data to support the fact that in some cases slippage is a precursor to star formation in center-wound rolls.
MODELING WEB TRACTION ON ROLLERS

N. Zahlan and D. Is. Jones
Imperial Chemical Industries plc
Wilton, Middlesbrough, Cleveland, UK

ABSTRACT

When web tension changes between entry and exit on a roller, the tension change occurs in a slip zone in the last part of the wrap, whose size is given by the well-known Capstan or Belt equation. A method for modelling moving film over rollers has been developed using the Finite Element analysis program ABAQUS. This has been used to reproduce the analytical results for the angular extent of the slip zone, and the relative movement on the roller surface of the web as it extends or contracts.

 Normally, the web has a non-zero Poisson’s Ratio, and therefore a tension change is accompanied by changes in stress and strain in the transverse (width) direction. As a consequence, the relative motion of the web has a transverse component in the slip zone. ABAQUS has been used to model this, as an analytic solution is no longer possible. The slip zone is larger at the edges of the web, and transverse movement changes continuously from zero in the centre of the web to a value similar to that in the machine direction at the edge. The effect of varying web modulus, entry and exit tensions, and friction coefficient has been studied.

More commonly, machines use sequences of rollers and it is desirable to know how web tension varies from one span to the next. If the roller surface speeds differ by only a fraction of a percent, large tension differences can be set up resulting in slip on some of the rollers. A scheme for obtaining a self-consistent solution for the tensions has been developed. An elementary system of rollers driven at set speeds with controlled unwind and rewind tensions has been modelled analytically at steady state. Common drive strategies increase roller speed through the machine, but the simulation shows this can lead to slippage on many rollers and tensions greatly exceeding the unwind and rewind values midway through the roller sequence.
STICK-SLIP BEHAVIOR OF PAPER DURING FRICTION TESTING

A. P. Penner
QUNO Corporation
Thorold, Ontario, Canada

ABSTRACT

Paper often exhibits oscillatory stick-slip motion during friction testing using a horizontal sled apparatus. The motion consists of a constant-amplitude oscillation in the force required to move the sled, which may occasionally turn into a heavily-damped oscillation. The transition between these two types of behaviour is discrete, not continuous. Depending on the operating conditions, either or both of the above motions can be seen in a single test. A theoretical framework is presented for the analysis of this motion, and it is shown that the distinction between the two classes can be made based on the sled speed and the difference between the static and kinetic coefficients of friction.

It has been found that two different grades of paper may consistently fall into different categories when classified according to the shape of their oscillation. It is suggested that stick-slip behaviour may provide a more reproducible test of the difference between samples than does the traditional friction test which is based only on the measurement of the first peak in the friction curve.
TENACITY, FRACTURE MECHANICS & UNKNOWN COATER WEB BREAKS

D. Swinehart\textsuperscript{1} and D. Broek\textsuperscript{2}

\textsuperscript{1}Mead Central Research
Chillicothe, Ohio, U.S.A.

\textsuperscript{2}FractuREsearch
Chillicothe, Ohio, U.S.A.

ABSTRACT

A web break model, based on fracture mechanics, was used to investigate unknown coater web breaks. Runnability was defined as $L_b$, the length between breaks. The model includes the size distribution of defects (holes and light spots, for example), web strength and web tension. Defects, such as holes, were most detrimental to $L_b$.

Tenacity and tensile were used interchangeably, due to their high correlation on these grades. Tenacity is a simple, precise, valid toughness test that is easy to use. Strength correlated strongly with web breaks. A 10\% increase in tensile related to a 26\% increase in $L_b$. 

TENSION CONTROL OF WEBS - A REVIEW OF THE PROBLEMS AND SOLUTIONS IN THE PRESENT AND FUTURE

W. Wolfermann
Technical University of Munich
Munich, Germany

ABSTRACT

Production plants with continuous moving webs have a complex structure where mechanical and electrical problems are involved. To solve the problems of this systems, it is necessary to take into account the total system to find an optimum. In other words, we have to achieve an Integrated Design.

A global presentation of specific demands and problems referring to tension control is given. After an excursion to the modelling of such systems, we can study the steady-state and dynamic behaviour.

In industrial plants, usually the tension is controlled either in an open loop system with a speed control of the driven rollers or the tension is controlled in 5 closed loop cascade control with PI or PID controllers. The optimization of the control is often done without the influence of the coupling of the rollers with the web. Under special conditions, if the parameters of the system fulfill particular conditions, such a control leads to an acceptable tension control.

Nowadays the demands on a tension control increase because of higher speed in the plant. In many cases the limits of the cascade control are reached and new solutions are demanded. The goal in the future is to realize non-interacting, decentralized control loops. In the control science, the state space control is an effective tool to solve complex problems and to improve the dynamic behaviour of the control. As a state space control of the total system is complex and often unpractical in industrial plants, decentralized control methods are discussed. As the measurement of the tension causes sometimes more problems than solutions, observers which estimate the web forces are used.

Nevertheless, some problems of tension control cannot be solved by using this methods. In the reality, we do not have linear systems. Therefore some new methods as Fuzzy Control and Neural Networks are discussed which may be able to solve such non-linear problems.
ON THE WEB TENSION DYNAMICS IN AN OPEN DRAW

M. Kurki\textsuperscript{1}, K. Juppi\textsuperscript{1}, R. Ryymin\textsuperscript{1}, P. Taskinen\textsuperscript{2}, and P. Pakarinen\textsuperscript{2}

\textsuperscript{1}Technical Research Center of Finland  
Jyvaskyla, Finland

\textsuperscript{2}Valmet Paper Machinery Inc.  
Jyvaskyla, Finland

ABSTRACT

Increasing productivity of paper machines, i.e. speeds, and requirements on decreasing basis weights of paper grades demand a deeper insight of the web tension behavior in the open draws. Runnability of a paper machine is often determined by the web’s sensitivity to breaks in the press and dryer sections, where the wet paper web has not yet reached its full strength. Often the measurement of variations in web tension is possible, but determining the factors causing these tension changes is difficult. Mathematical models offer an efficient way to study qualitatively time-dependent physical phenomena in the web.

The aim of this paper is to study web dynamics in an open draw with the help of an advanced mathematical model by including flexural rigidity of the web and geometrically having rolls at both ends of the open draw. The model is based on two-dimensional finite element method (FEM), and both longitudinal and transverse forces have time-dependence in the open draw. FEM implementation of the model makes it possible to study phenomena of the moving web in a detailed manner. Different portions of the total forces affecting the web (inertial and external forces) can be calculated at desired points of the web. As a result, we obtain temporal tension distribution and web deflections. The FEM method offers versatile possibilities to study the responses of different external disturbances at different velocity levels and with different open draw lengths.

The results show that the radius of the roll has a significant effect on the web’s behavior in terms of temporal length variation of the open draw. In this case, the open draw has non-constant boundary conditions, and thus the natural frequencies of the web depend on the length and tension distribution of the open draw. This phenomenon is accentuated especially in cases where the effect of the added mass (air mass) has been included in the model and in cases where the velocity of the web is high. One of the important dynamic phenomena revealed by the model is the rapid changing of web-roll contact points at both ends of the open draw. Due to this, longitudinal and transverse force components undergo rapid changes which could cause web breaks.

In the future, the main goal is to make experiments on the model in such a case where the web runs from roll to roll. One of our intentions is also to refine the model by a
more realistic material assumption by taking into account the nonlinear behavior of the paper and also expanding the model in a third dimension. With aid of these steps, it is possible to obtain further information of time-dependent stress distributions on the web.
REAL-TIME TENSION CONTROL IN A MULTI-STAND ROLLING SYSTEM

K. H. Shin and W. K. Hong
Kon-Kuk University
Seoul, Korea

ABSTRACT

The problem of real-time tension control in a metal-strip processing line is addressed. The tension in a metal strip changes due to not only the speed difference but also thickness changes at the ends of a span. The mathematical dynamic model which describes relationship between the tension change and the roll-speed change is improved to include the effect of the strip thickness change on tension variation.

Through the computer simulation of this model, the parameter sensitivity analysis and the static and dynamic characteristic study are carried out. The tension variation in the metal strip turned out to be very sensitive to the thickness variation as well as to the speed difference at the ends of the metal strip.

In the rolling process, the master speed drive is usually located at the last stand. The speeds of rollers in upstream stands are adjusted with respect to the speed of the last stand to compensate the speed change for the tension regulation. A new tension control strategy in a multi-stand rolling process is suggested. The tension transfer phenomena is used in the design of the suggested controller. The developed mathematical model is used to design a controller for the real-time control system. A real-time software for the tension control in a multi-stand system is designed by using the VxWorks real-time scheduler and the Force Target board.

The suggested control strategy needs less control efforts and shows better performance than those of the existing control method in a rolling process.
LONGITUDINAL DYNAMICS OF A WINDING ZONE?

J. P. Ries
DuPont Company
Wilmington, Delaware, U.S.A.

ABSTRACT

The longitudinal dynamics of a moving web in a tension controlled winding zone was modeled and analyzed. The dynamics of the zone included the effects of idler roll inertia, web elasticity, package inertia and feedback control. A computer simulation program was used to solve the system of equations for the natural frequencies and transfer functions. It was found that a typical production type winding zone can have several natural frequencies in the operating range of the winder. The predicted natural frequencies were found to depend significantly on package diameter and feedback gain. As a result, resonant conditions can occur at different times during the winding cycle because the angular velocity of the spindle continually changes. Resonance can also occur with the second and third harmonics of the spindle frequency or any other rotating elements in the winding zone.
MATRIX INTERPOLATION BASED SELF-TUNING WEB TENSION REGULATION

B. T. Boulter\textsuperscript{1} and Z. Gao\textsuperscript{2}

\textsuperscript{1}Reliance Electric
Cleveland, Ohio, U.S.A.

\textsuperscript{2}Cleveland State University
Cleveland, Ohio, U.S.A.

ABSTRACT

A self-tuning control scheme is proposed for tension regulation in a web transport system. A matrix interpolation based computationally efficient self-tuning method is first described. The frequency domain model of the plant is then derived. Simulations of the on-line tuning are presented and a comparison is made with current tension regulation methods. The paper closes with a discussion of cognizant implementation issues.
ABSTRACT

Rapid changes of the web tension take place at the roll change in the printing press. Variations in the machine direction depend on the tension control system and variation in the cross direction is strongly affected by paper and roll properties. The web tension profile can be measured with a single sensor scanning across the web or with a special beam equipped with several sensors. In this paper findings from the studies carried out with different tension measurement systems are presented. In the long-term study the effect of paper machine reel position as well as the changes within the roll and between the rolls on the web tension profile are underlined.
NON-INTERACTING TENSION CONTROL IN A MULTI-SPAN WEB TRANSPORT SYSTEM

K. H. Shin¹, K. N. Reid² and S. O. Kwon¹

¹Kon-Kuk University
Seoul, Korea

²Oklahoma State University
Stillwater, Oklahoma, U.S.A.

ABSTRACT

A non-interacting tension control algorithm is proposed to reject the disturbance due to the interaction between neighboring processing sections. An ‘auxiliary dynamic model’ is derived. And an ‘auxiliary controller’ is designed with the concept of feedback and feedforward control using the auxiliary dynamic model such that it can reject disturbances from the upstream as well as downstream web span. The performance of this controller is compared with that of an existing controller. When the proposed controller is used, the tension in each span is successfully regulated even in a highly interacting multi-span system with less control effort than that of an existing control method.
ABSTRACT

Strip floating system is effective to avoid strip wrinkles and defects caused by roll contact, and to keep high quality of steel strip in the continuous processing lines.

In development of the floating system, challenging point is its controller against lateral instability of the floating strip supported by air cushion devices. We developed the electromagnetic control system, whose response is much quicker than that of the conventional center position control (CPC) system using rollers. This paper shows validity of our new control system.
COUPLING BETWEEN OUT-OF-PLANE DISPLACEMENT AND LATERAL STABILITY OF WEBS IN AIR-SUPPORT OVENS

P. M. Moretti and Y. B. Chang
Oklahoma State University
Stillwater, Oklahoma, U.S.A.

ABSTRACT

In drying ovens where the web zigzags over and under air-support bars, the web sometimes drifts to one side or the other until it runs into the oven wall. This divergence is shown to be coupled to out-of-plane displacements in the form of lateral tilting of the web where it curves over the air-support bars. Limiting these out-of-plane displacements is necessary in order to prevent excessive lateral divergence and the resulting damage to the web and its coating. Air-bar characteristics which control out-of-plane displacements are identified.
GROUND-EFFECT THEORY AND ITS APPLICATION TO AIR FLOTATION DEVICES

Y. B. Chang and P. M. Moretti
Oklahoma State University
Stillwater, Oklahoma, U.S.A.

ABSTRACT

The ground-effect theories, originally developed for air cushion vehicles (or ground-effect machines), are re-examined and compared with the air bar test results. The geometries of the tested air bars are different from that of the basic ground-effect model. It is shown that the ground-effect theories can be applied to the air bars by using properly defined equivalent values of the ground-effect variables. The ground-effect theories are applied to a tilted flexible web, and the equations for lateral aerodynamic force are derived. The discussion in this paper is limited to the pressure-pad-type air bars.
WRINKLE DEPENDENCY ON WEB ROLLER SLIP

J. N. Dobbs and D. M. Kedl
3M Company
St. Paul, MN, U.S.A.

ABSTRACT

The shear forces in a web introduced from an untrammed roller create wrinkles that are affected by web twisting or slipping on the upstream roller. The web span bounded between the untrammed and upstream rollers behaves like a beam when bending in the web plane (2). If the bending stresses exceed the capacity of the friction forces holding the web on the upstream roller, strain will migrate over the roller transferring a portion of the moment to the upstream span. A model is presented that predicts the onset of moment transfer based on equilibrium equations for a beam in bending, and web roller traction.
THE EFFECTS OF NIP PARAMETERS ON MEDIA TRANSPORT

K. D. Stack, J. E. LaFleche and R. C. Benson
University of Rochester
Rochester, NY, U.S.A.

ABSTRACT

The mechanics of a web being transported through a set of elastomeric rollers has been investigated. Three general classes of roller materials are identified. These nip materials are then characterized by the speed at which they transport a web, and how that speed changes due to a number of design factors. The issue of media skew is also addressed, and examples are given of how different nip materials will or will not cause skew. Finally, design tradeoffs are discussed for the three classes of materials.
DEFLECTION AND CRITICAL VELOCITY OF ROLLERS

J. J. Shelton
Oklahoma State University
Stillwater, Oklahoma, U.S.A.

ABSTRACT

A coordinate system with its origin at the center of the roller, and with the origin moving as the roller deflects, is used for solution of the fourth order differential equation of beam mechanics. The result is a continuous polynomial in terms of x, the distance from the center. The form of the equation is adaptable to further analyses such as finding the profile of a nip roller, predicting wrinkling of a web, or predicting the natural frequency of a live-shaft roller as demonstrated in this paper.

The natural frequency of a live shaft roller is predicted by substituting values of deflection, caused by the weight of the roller determined either experimentally or analytically as in this paper, into a relationship derived by Rayleigh’s method.
THE 10 COMMANDMENTS OF WEB MACHINE DESIGN

D. R. Roisum
Finishing Technologies, Inc.
Neenah, WI, U.S.A.

ABSTRACT

This paper describes the most important aspects of roller design selection and maintenance necessary for a smooth running web process. Included are discussions of alignment, deflection, geometry, surfaces, traction, and tension control. Design criteria for sizing and tolerancing rollers will be given which are based on web handling mechanics. Also given are simple field checks for a quick evaluation of existing machinery.
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ABSTRACT

What changes constantly, is optimized with difficulty, and cannot be bought or sold; yet without it, making web based products is impossible? The answer: Web Handling Technology. Ten years ago 3M established a Web Handling Research Group to convert the art of web handling into a science. Since then, we have determined many of the engineering principles governing the control of flexible media, established connections with several research centers, and published papers. However, subsequent to our success in gaining understanding, we have had to face the additional challenge of translating our knowledge into a form that will be useful in equipment design and production. This presentation will concentrate on the tools and processes we have used to effect this translation.
ABSTRACT

Crepe wrinkles are created during reeling and winding of paper rolls against a rolling drum. These defects are associated with interlayer movement of paper within the body of the roll. To study this movement, rolls made from five different papers were loaded against a rotating drum under controlled conditions and the layer-to-layer movement quantified by means of “J”-lines marked on their face. The interlayer movement of paper is directly related to frictional stress; the coefficient of friction multiplied by the radial compressive stress in the paper roll, and the shear stress created by rolling friction of the paper roll.

The amount of interlayer movement can be reduced by lowering the nip load, increasing the drum diameter, or covering the drum with a soft material. Interlayer movement increases sharply when the coefficient of friction falls below a critical value, which explains why crepe wrinkles can appear after a seemingly imperceptible change in coefficient of friction.
ABSTRACT

The trend in winding in the paper industry can be simply characterized by: wider and faster with more dense webs with a lower level of accepted defects. This is valid for paper production and printing, especially in rotogravure.

Europe’s rotogravure industry is investing in wider printing machines: 3.08 m - 3.18 m - 3.48 m - 3.52 m - 3.60 m. These machines are already ordered and the widest will start up end of 1997. In the unwinding process the techniques of fiber cores is running to the edge of physical limits: vibrations. Experimental natural frequency analyses and trials on a core rotational test stand demonstrate limits and potentials of cores and unwind stands.

Jumbo reels in roto are exceeding masses of 5 tons. In the unwinding situation bunk near the core occur - the more often, the wider and heavier the reels are. A systematic winding test on a production winder with a modified unwind stand demonstrate the creation of bursts and leads to a method to avoid center bursts in jumbo reek for rotogravure.

In paper production there is an idea to produce machine wide reels with high diameters for a high efficiency and a minimum of paper losses. Limits in winding of LWC base paper are observed because of center bursts. Investigations of thermal phenomena in the center of big reels show characteristic temperature structures during winding. Bursts can be detected because they produce a local temperature “hot” spot. From this ideas can be created to develop a new winding test or inspection system to detect winding structures and winding failures.
ABSTRACT

The primary defect for thin films (< 25 µm ) consists of sinusoidal ridges that run around the wound roll of film. Previous work has shown that these defects are buckles caused by compressive stresses in the transverse direction and that their formation can be minimized by adjusting winding conditions. The work presented here shows that the film surface also has a critical role in controlling this defect. The effort includes (1) measurements of properties for films with differing surfaces, (2) calculations to determine whether buckles will occur, and (3) winding experiments to verify the conclusions. Recommendations are included to design surfaces that are resistant to internal buckles and their related defects.
TWO-DRUM WINDER RUN SIMULATION MODEL

M. Jorkama¹ and R. Von Hertzen²

¹Valmet Corporation
²Helsinki University of Technology
Finland

ABSTRACT

A dynamic, analytical model for winder run simulations is presented. The model consists of elastic drums, deformable paper rolls and a rigid rider roll beam. A paper roll nip flexibility model is derived and a profound influence of paper roll properties on winder dynamics is demonstrated. The origin of winder vibrations due to specific vibrating paper grades is explained in detail. Winder drum design aspects against vibrations are studied. Finally, some practical measures to reduce winder vibrations are presented.
ANALYSIS OF THE KINEMATIC AND DYNAMIC PROCESS DURING WINDING BASED ON A SYSTEMATOLOGY OF MODELS FOR WINDING MECHANICS

E. G. Welp and B. Goldenburg
Ruhr-Universitat Bochum
Germany

ABSTRACT

The winding process of web materials with low bending resistance is composed of several partial processes whose single effects are influenced by specific machine, process and material parameters. The interaction of these processes causes an essential increase in the difficulty of modeling the total process. Up to now there are numerous mainly experimental investigations concerning the particular effects of the winding process. But they are not sufficient to describe the total process regarding all influences of the machine technology and material properties.

In this regard our institute has developed a systematology of models for winding mechanics which starts with the real winding process of the different winder classifications and resolves the complex total process step by step into partial models. Subsequently it is possible to study the effect of different parameters on the derived partial models based on various degrees of idealization. By coupling different partial models the modelling of any partial process becomes possible.

The fundamental knowledge of theoretical research work is the mechanic of solid bodies with its analytical methods for highly idealized [simple] models and numerical methods (finite element-method (FEM), finite-difference-method (FDM) for complex, more realistic models.
ASPECTS OF TWO DRUM WINDING

J. E. Olsen$^1$ and F. Irgens$^2$

$^1$Norwegian Pulp and Paper Research Institute

$^2$Norwegian University of Science and Technology

Norway

ABSTRACT

Two drum winding is not yet described by any model due to the lacking expression for the so-called wound-in-tension. Through dynamic analysis equations for winding velocity and first-drum-tension, which is related to wound-in-tension, are established.
A SYSTEMS APPROACH TO REDUCING WINDING DEFECTS AT ALCOA-WARRICK OPERATIONS

B. J. Becker
Alcoa
USA

ABSTRACT

When processing coated aluminum, coil winding defects can be a major detractor to recovery, flow time, and customer satisfaction goals for coil coating and slitting operations. Over the past several years, extensive studies have been performed at Alcoa on individual parameters in an attempt understand their effect on coil collapse and other winding problems. These studies improved understanding, but did not fully explain the collapse defect. Recent work has concentrated on the analysis of all important variables together as a “system.” The focus of this paper is to explain interactions between variables which influence coil collapse, and how this defect can be minimized by optimizing the system of winding a coil.
READING A ROLL

D. R. Roisum
Finishing Technologies, Inc.
USA

ABSTRACT

Web or winder defects often leave a visible record of themselves in the wound roll that can be read much like the rings of a tree. Varying strains in each layer as it is wound will cause changes in geometry that can be observed visually or with simple tools. These cylindricity deviations are a fingerprint of the cause of the defect.

This paper shows how to read a roll’s history by diametral variations across its width, by radial variances around the periphery, and by variations in width or CD position. Additionally, the winding mechanics that produced the cylindricity deviations will be discussed. Defects covered include corrugations, dishing, ridges, starring, telescoping, and many others.
A MODEL FOR THE PREDICTION OF WOUND ROLL DISHING

K. A. Cole
Eastman Kodak Company
USA

ABSTRACT

Historically, wound-roll models have been used to predict stress levels which develop within winding and wound rolls. To gain maximum benefit from these models, stresses must be incorporated into defect or failure models. This paper focuses on the development of a wound-roll dishing model. Caliper nonuniformity in both the width and the length direction is incorporated into the model. The effect of some of the important conveyance issues is also included in the model. An experiment is described and the results compared to the analytical predictions. Finally, the model is used to study the effects of process parameters on the level of wound roll dishing.
ABSTRACT

The elastic nature of plastic films and the rotational inertia of rolls, spindles and drives cause a film handling line to exhibit the characteristics of a dynamic system. This dynamic response can be observed by measuring on-line variables such as tension, roll velocity or dancer motion. Because of the dynamic behavior, a variety of control systems are employed to keep tensions and velocities in bounds. For purpose of control and isolation, a film line is divided into separate zones. One of the most difficult zones to control is the winding zone.

This paper describes an experimental study conducted on an existing film line where the winding zone was experiencing large tension variations at certain speeds. An experimental technique was developed to measure the natural frequency of the zone. The natural frequency was found to vary with package diameter and film thickness. Using FFT analysis on the winding tension signal, the resonant excitation was identified as the winding spindle frequency. A computer model was used to predict the transfer functions and natural frequencies for the zone. Very good agreement was obtained between the predicted and measured natural frequencies.

In addition to explaining the source of the large tension variations during winding, this study also provided a better understanding of the dynamics of the winding zone and the possibilities for resonant conditions. With these tools, alternate solutions to the problem could be evaluated.
AIR ENTRAINMENT IN WEB HANDLING: TO BE AVOIDED OR MASTERED?

P. Bourgin
Universite Louis Pasteur
France

ABSTRACT

The presence of ambient air is of prime importance in various industrial processes involving web handling. This paper is an attempt to answer the following questions: how does air influence the quality of the final product? How is it possible to cope with such a situation?

After a brief description of a few basic problems of fluid mechanics, namely: (i) the development of boundary layers on moving webs and (ii) the flow structure and pressure generation in wedges (i.e. « corner flows »), several illustrative examples are presented.

(1) When a flexible web passes over a spindle, a thin air layer is formed between the two surfaces. This is typically a foil bearing configuration, which is important to master in order to reduce wear reduction or to avoid any misfunction at the head-tape interface. A brief survey of the historical works on this topic will be given.

(2) In wound roll models, the stress field generated in the roll depends on the winding conditions (i.e. geometry and processing parameters) and on the flexible media bulk properties (elasticity or viscoelasticity) and surface properties (topography). It is well known that there is a strong link between the roughness of a surface (resulting from microparticles added to the resin) and its behavior in terms of air entrainment and evacuation. A first attempt to study the complex mechanisms governing this link is proposed.

(3) In high velocity coating flows which are present in numerous processes (magnetic tape manufacturing, paper industry, ...) some air can be entrained between the solid substrate and the liquid layer being coated on it. After a qualitative description of the complex phenomena owning in the vicinity of the three-phase junction, the amount of air likely to be entrained is evaluated on the basis of a theoretical model.

As a conclusion, a few recommendations for practical applications will be tentatively drawn.
ABSTRACT

In this paper, in order to estimate an air film thickness between moving web and wide roller (web spacing height), the air film thickness formula was derived based on the finite width compressible foil bearing theory. In the derivation of air film thickness formula, the two-dimensional Reynolds equation and foil equilibrium equation were discretized by the finite difference method and solved iteratively to obtain the pressure and air film thickness distributions for various parameters. Based on the numerical results, the simplified convenience formula for the estimation of air film thickness between web and guide roller was obtained. On the other hand, the air film thickness between web and guide roller was measured by the optical sensor, and the experimental results were compared with the calculated results. Moreover, the variation of air film thickness between layer and layer in winding processes of web was analyzed by making use of the air film thickness formula. From the theoretical and experimental results obtained, the effects of air film thickness on the web transporting systems were clarified.
ENTRAINED AIR FILMS IN CENTER WOUND ROLLS - WITH AND WITHOUT THE NIP

R. M. Taylor and J. K. Good
Oklahoma State University
USA

ABSTRACT

Development of analytical expressions predicting the thickness of fluid layers in the area of a foil bearing has been ongoing for nearly forty years. These expressions have been adapted to include air as the lubricating medium for use in predicting layer separation in wound rolls or for predicting the floating height of a web over a roller. An experimental technique has been perfected to study the air entrainment in wound rolls of web material. This paper will focus on providing proof regarding what expressions should be employed and how they are used to model the amount of air which is entrained in centerwinding, with or without an impinging nip.
COMPUTATIONS OF AIR FILMS AND PRESSURES BETWEEN WEBS AND ROLLERS FOR STEADY AND UNSTEADY OPERATING CONDITIONS

S. S. Kothari, K. Satheesh and F. W. Chambers
Oklahoma State University
USA

ABSTRACT

Numerical computations have been performed to predict the lubricating air film thickness and pressure for the entire region of smooth rotating support rollers wrapped by moving impermeable and permeable webs. Results have been obtained for both steady and unsteady web tensions for a range of operating parameters and web properties. The numerical predictions required the simultaneous solution of coupled partial differential equations. One equation is the dynamic motion equation for the finite length web and the other is the transient Reynolds lubrication equation for the air film. In these two-dimensional computations, the web is assumed perfectly flexible and infinitely wide, with negligible air escape at the edges. A finite difference formulation was developed for the two governing partial differential equations. Spacing and pressure between the moving web and the support roller were obtained as a function of both time and distance along the roller for cases of constant tension, step changes in tension, and sinusoidal fluctuations in tension. For constant tension, the transient solution converges to the steady state solution from approximate initial conditions. For the unsteady tension cases, computations are started from a steady state solution. The effects of the web velocity, tension, permeability, mass per unit area, roller velocity, radius, and slip flow on the air film thickness and pressure distribution were predicted.
ABSTRACT

The present paper is concerned with experiments which consist in squeezing an air layer between a rigid, smooth surface and a flexible, rough one.

The experimental rig is composed of a smooth glass plate, with a circular slit allowing air aspiration to be done around it. A thin (few microns thick) plastic film is laid on the glass plate and air separating the glass and the film surfaces is removed by means of a vacuum pump. A circular front appears on the film surface, and moves towards the centre, as the film is pressed onto the glass plate.

A monochromatic lamp is used to insulate the surfaces from above and Newton rings can be observed as the front moves. The duration of this operation is measured by a chronometer.

Typically, the measured time depends on the plate diameter, the sub-ambient pressure exerted, the film flexural rigidity (or its thickness) and its surface roughness.

A set of experiments have been carried out for several values of the sub-ambient pressure and of the slit diameter.

The results are well reproducible: for a given sample, the characteristic time is proportional to the squared value of the diameter. The dependence on the sub-ambient pressure is more complicated. A simple model using a semi-empirical formulation is suggested on the basis of the experimental data.
THE EFFECT OF DUAL ACTUATING STRIP GUIDANCE SYSTEMS IN A CONTINUOUS STEEL ANNEALING LINE

J. B. Otten, C. H. L. Limpens, R. A. Boots, and H. Michel
Hoogovens
The Netherlands

ABSTRACT

In the past, Royal Hoogovens, a main primary steel and aluminum manufacturer in the Netherlands, used pre-shaped rolls and sophisticated tension tables to guarantee good ship tracking for all strip geometry’s in both their Continuous Annealing lines. However: with an increasing product mix (wider range of geometrical dimensions: widths between 800 - 1200 mm and thickness between 0.15 - 0.30 mm) in combination with high annealing temperatures of approximately 1000 K, these methods were not sufficient anymore. The steel strips became too vulnerable for wrinkles. To prevent wrinkles and tracking problems, Hoogovens Packaging Steel improved the flexibility of a processing line by partly substituting the pre-shaped rolls by flat rolls and new steering rolls. Before this process was started, a lot of time was spent developing a suitable new steering roll type. This steering roll, it is called the DUal Actuating strip guidance System (DUAS), has a minimal influence on the ship tension distribution, basically consists of a flat roll and two hydraulic actuators mounted on a small frame and fits in an existing installations without large modifications. In December ‘95 the first system was placed in the furnace of one of the Hoogovens annealing lines and in November ‘96 another two.
EFFECTS OF WEB CAMBER ON HANDLING

J. J. Shelton
Oklahoma State University
USA

ABSTRACT

The definition of camber and a laboratory method of measurement of camber are presented. Common problems caused by camber and methods for avoidance of these problems are discussed.

Analysis of the behavior of al web on a tapered roller is applied to a cambered web for explanation of tests run in 1969 and 1971, as well as a recent test of the lateral behavior of a cambered belt. In these tests, steeping was toward the long side. The lateral steering toward the short side of the web caused by tilting of a complaint carriage of an accumulator because of the off-center tension inn cambered web is analyzed.

Although a precise prediction of the effects of camber on lateral behavior is seldom practical, a qualitative understanding of basic phenomena will aid in avoidance and correction of problems caused by camber.
SHEAR IN MULTISPAN WEB SYSTEMS

J. K. Good
Oklahoma State University
USA

ABSTRACT

Wrinkling research has been concentrated in past years on understanding web wrinkling in isolated spans in web lines[1]. It is expected that some of the fundamentals which govern single span behavior will also apply to multispan wrinkling problems. For instance it has been found that predicting the shear in the web is necessary to be able to predict shear wrinkles, which are wrinkles due to roller misalignment. Earlier works Young[2] and Dobbs[3] have concentrated on determining shear and moments in moment transfer conditions where the coefficient of traction was assumed constant. It has also been found that knowledge of the traction capacity between webs and rollers allows the calculation a lower bound in web tension below which wrinkling becomes impossible. The focus of this paper is to show how shears in multispan web systems can be predicted. How these shears are impacted by the complications of traction capacities which vary as a function of entrained air and by web edge slackness will be treated.
THE EFFECT OF SPEED LOOP BANDWIDTHS AND LINE-SPEED ON SYSTEM EIGENVALUES IN MULTI-SPAN WEB TRANSPORT SYSTEMS

B. T. Boulter
Rockwell Automation
USA

ABSTRACT

Web transport systems are composed of multiple tension zones. These zones are separated by driven rolls such as calenders, briddles or nipped rolls whose speed is regulated by a closed loop controller. Given that tension regulators regulate tension by trimming the reference to the closed speed loop controller, the designer of the tension regulator cannot ignore the effects of closing the speed loop, and line speed, on the Web transport system (WTS) natural frequencies. These natural frequencies are typically computed as the eigenvalues of an equivalent translational cascaded spring-mass system. This paper discusses these effects.
ABSTRACT

A new tension control system is described, which allows the simultaneous control of up to four actuators, such as drives, brakes or clutches. It incorporates four speed/torque control modules and three tension control modules and is referred to as Multiple-Tension-Controller (MTC). All modules can be configured individually for different control schemes and can be interconnected to accommodate any type of application due to their formal and universal character. A significant advantage of such a structure is that it allows the sharing of all related process variable values. This is used to decouple the individual controllers in order to improve the overall control behavior of the web machine. This proposed MTC shows how both simple and complex tension control systems can be configured and optimized in a global manner.
SENSORLESS TENSION CONTROL OF WEBS

W. Wolfermann
Technical University of Munich
Germany

ABSTRACT

Production plants with continuous moving webs have a complex structure where mechanical, electrical and control problems are involved. To solve the problems of these systems, it is necessary to take the entire system into account.

In many processing machines in the plastic-, textile- and paper industry only the speed of the roller is controlled. The web tension is a function of the speed relation. The disadvantage of only controlling the speed is that the changes in the tension of the web during the technological process cannot be controlled. Therefore some nip sections are equipped with a sensor to measure the tension so that a closed loop control of the web tension can be used.

The sensor is a roller which is able to measure the web tension by transforming the mechanical signal to an electrical signal. But each roller in the plant is able to cause problems in the lateral control of the web or generate web wrinkling. Therefore it would be better to get the web tension sensorless. This would save problems and money.

In this paper observers to estimate the web tension are discussed. But there are some problems to realize observers in plants with continuous moving webs. The first problem is that all rollers and drives are coupled in the plant. Therefore, we have to design decentralized observers. The second problem is unknown and sometimes nonlinear parameters in the plant or not measurable inputs, for example disturbances that change while the process is running. Therefore observers have to be designed to estimate the tensions without a steady-state error.
DIFFERENTIALLY DRIVEN S-WRAP ROLLS FOR IMPROVED TENSION ISOLATION

A. W. Forest, Jr.\textsuperscript{1}, A. N. Bennett\textsuperscript{1} and M. R. Jones\textsuperscript{2}

\textsuperscript{1}DuPont Company

\textsuperscript{2}Fluor Daniel Engineering

USA

ABSTRACT

Achieving adequate tension isolation is necessary in both the manufacture and subsequent processing of webs of all types. Several techniques currently are available including nips, vacuum rolls, driven rolls and S-wraps. From a combination of low cost and simplicity, S-wraps are the attractive alternative. They also are the best choice if the web is susceptible to surface damage. However, current S-wraps have deficiencies which are related to (1) torque loadings on the roll pair, and (2) problems controlling the web tension between the two rolls. These deficiencies can make it difficult to achieve good tension isolation. The differentially driven S-wrap system described here eliminates these problems and offers additional benefits. It provides a means to control the torque split between the driven rolls. This split makes it possible to shift the torque to the high tension side of the S-wrap where the available friction forces are higher. It also fixes the tension between the driven rolls without additional equipment. Finally, the differential action allows the rolls to operate at different speeds to adjust for differences in the roll diameters or web elongation.
ABSTRACT

Paper machines operate continuously. When a machine reel is full, the paper web is transferred to an empty spool. The disturbances in the web which occur during the reel change period are wound-in and later released when the machine reel is unwound, causing disturbances in the winder and in the quality of the shipping rolls.

A measurement system was built to capture and to characterize the disturbances in web tensions and rotation speeds during the reel change period. To measure the rotation speed of the machine reel during the whole change sequence at different positions along the periphery of the pope drum, a transducer with infrared transmitting of data from the machine reel to the measurement system was developed.

Large disturbances occurred due to acceleration and deceleration of the angular winding velocity of the machine reel when it moved along the periphery of the pope cylinder from the starting position to the normal winding position. The interaction between the pope and the calender section introduced rapid disturbances of the web tension. The deviation between results of measurement and simulation of an ideal winding was used to characterize the disturbances. The method can be used to study results of different ways to improve the winding. This has been demonstrated.
NON-LINEAR TENSION CONTROL IN A WINDING PROCESS BY USING THE CONTACT ROLL

K. H. Shin, K. T. Kim, and S. M. Cheon
Kon-Kuk University
Korea

ABSTRACT

In a web winding process, the contact roll plays many important roles including air-entrainment control and WIT (Wound In Tension) regulation. The behavior of the contact roll significantly affects the winding tension characteristics specifically at the time of contact and separation when the tangential velocities of contact roll and the winding roll are not synchronized. A new mathematical model which includes the behavior of the web tension, the winding roll, carriage and the contact roll is derived for the control of the winding tension. By using the model derived, a non-linear PID (NPID) controller is designed to control the winding tension at the time of contact and separation between the contact roll and the winding roll. Computer simulation study showed that the performance of the winding system with the NPID controller was significantly improved compared with that of a system with PID controller.
ABSTRACT

Tension transients in a moving web can be described and predicted adequately from first principles. The resulting mathematical models are very useful for designing and debugging web conveyance machines and their controls. The basic equations involved will be reviewed. Examples will be presented, including an optimally robust stock roll controller and a balanced inertia float arm. These examples demonstrate the advances which can be accomplished through the application of mathematical modeling.
WEB TENSION IN A FLOTATION DRYER

J. P. Ries
DuPont Company
USA

ABSTRACT

In a flotation dryer, the web rides on a cushion of air and typically takes a “sine wave” path over the air bars. The non-straight path and the elastic effect of the air cushion interact with the normal tensioning of the web in the dryer zone. Equations were developed to describe the geometry of the web path, air pressure effect and the tensioning of the web in the zone. Computer simulation was used to solve the Equations simultaneously. It was found that the air cushion and pressure have no effect on the steady state tension. On the other hand, the dynamic response showed that the air cushion increased the time constant for the zone. Thus, the dryer zone appears to be much longer than the actual web length. Results also predict bow riding height decreases as tension increases in time. Several cases were run at different air cushion pressures.
ABSTRACT

There are many web spreading and anti-wrinkling techniques and devices. A few have been analyzed, but most have not been tested with a uniform scientific method. Currently the decision of when and where to use such a device is based on personal experience, vendor advice or trial and error. This paper presents a test method, simple analysis and test results, for ten different techniques or devices.
ABSTRACT

In order to set the mechanical characteristics to the target of the customer, cold rolled steel strips are annealed at high temperature in batch or continuous annealing furnaces.

In a continuous annealing furnace, the strip passes over thermally deformed rollers. The shape of the furnace rollers at high temperature depends on this thermal deformation and on a mechanical profile on the roll. An accurate setting of the mechanical roller profiles is of major importance in order to avoid tracking problems, specially in the first park of the furnace, or buckling problems when the strip is wide and processed at high temperature.

Since the last 15 years, the part of the strips processed in the continuous annealing lines is dramatically increasing in the world, the products are also getting thinner and wider and the processing speeds higher, causing lateral strip displacement and strip deformations, like buckles, more critical.

In this context it was important to accurately estimate the thermal deformation of the rollers and the critical conditions for buckling. IRSID and SOLLAC developed calculation models of roller thermal expansion, and wrinkling criteria. Those models were used to set new values of mechanical profiles for rollers in the annealing furnaces of SOLLAC.
A NONLINEAR FINITE ELEMENT MODEL FOR WEB SPREADING

K. Stack¹, J. Perconti², A. Jeans³, J. LaFleche¹, and R. Benson¹

¹Penn State University
²Eastman Kodak Company
³Hewlett Packard Corporation

USA

ABSTRACT

This study concerns the modification of a commercial finite element code (ABAQUS) to efficiently model webs moving over stationary, frictional guides. This modification will allow the user to refine the mesh in areas of interest (i.e. in the contact zone) while using a coarser mesh in other areas. The model was used to investigate web spreading using three different geometries - a straight bar, a bowed in-plane bar and a bowed out-of-plane bar (D-Bar). The effects of the Poisson ratio of the web and friction on web spreading will be investigated.
SHEAR WRINKLING IN ISOLATED SPANS

J. K. Good, D. M. Kedl, and J. J. Shelton

1Oklahoma State University

23M Company

USA

ABSTRACT

Web wrinkling is a problem which plagues the web process industry. Most webs are quite thin, on the order of 4-150 µm, and became subject to lateral shear during transport either by misaligned rollers or by guide rolls. It is proven herein through analyses verified by experiments, that classical instability theory does apply to this case. The dependence of wrinkles on the available traction between the web and roller surfaces is also modeled and verified experimentally. A verified model is presented which yields the traction as a function of entrained air.
PRINCIPLES OF WEB SLITTING

J. D. Pfeiffer
JDP Innovations, Inc.
Canada

ABSTRACT

The slitting arrangements used in the paper, plastic film, and metal industries have evolved into machines that use a variety of principles to sever the webs longitudinally. This presentation looks at a variety of ways for accomplishing this task, pointing out problems that are sometimes generated by these solutions. Such difficulties range from the tendencies of the cutting members to become dull, to the production of undesired dust and slivers, or the failure to maintain accurately trimmed widths. Wherever possible the reasons for the defects are explained with recommendations for avoiding further difficulty.
WEB FLUTTER AT CIRCULAR-TUBE AIR-TURN BARS

P. M. Moretti and Y. B. Chang
Oklahoma State University
USA

ABSTRACT

Circular tubes having air-emitting holes are often used for non-contact handling of photographic and magnetic media and for printed paper webs. One of the problems of circular-tube air-turn bars is their tendency to cause flutter, sometimes accompanied by a buzzing sound. An experimental study of such a flutter problem is discussed in this paper. Vibration of a web supported by air-turn bars was measured for different values of supply pressure of air, web tension, and wrap angle. It is shown that different types of flutter can occur at different operating conditions. This study resulted in parameter maps which show the regions of operating conditions for different types of flutter.
ADVANCED SURFACE DESIGN OF POLYESTER FILMS AND ITS APPLICATION TO MAGNETIC RECORDING MEDIA

M. Handa
Teijin Ltd.
Japan

ABSTRACT

This paper briefly overviews the recent surface design for the purpose of achieving the good windability of polyester films and its application to the substrate films for the magnetic recording media.

One example is concerning the application to the films for VHS video tapes. The authors found it is quite important to remove the air layer from between each layer of the wound films in order to get a good roll formation in the VHS tape production process and we were successful in solving the roll formation problem by introducing a unique technology.

The other is concerning the application to the films for high density magnetic recording tapes such as 8 mm video or professional video, for which one of the requirements to the substrate films is to achieve quite a smooth surface and a good windability at the same time. The authors made it possible and were successful in reducing cost by introducing the dual surface film manufacturing technology and a technology to form fine and minute protrusions on the surface of the film and their combination.
THE EFFECT OF WEB RHEOLOGY AND PEELING ON WEB TRANSFER IN OPEN DRAW

M. Kurki¹, J. Vestola¹, P. Martikainen², and P. Pakarinen¹

¹Valmet Corporation
²Technical Research Center of Finland
Finland

ABSTRACT

To achieve higher productivity in papermaking, the increasing of web speed is the most efficient way. However, velocity increase will also immediately cause greater demands according to the web strength.

In normal papermaking process, the form of the web changes gradually through the forming and press sections loom suspension to solid form. After the press section, the basic fiber structure of the paper has already been created, but its rheological properties are in the beginning state of their development. Due to the water removal method by pressing the wet fiber network against a press roll surface, an adhesion force is generated between the web and the surface.

At the end of the press section, the strength of the web is still very low due to the web’s great moisture content. At this point, the mechanical properties of the paper can be affected or even deteriorated by wrong web peeling methods. For this reason, the understanding and controlling of the adhesional behaviour of the web is essential especially in the cases of high velocity levels.

This paper studies the adhesional behaviour of the open draw, which is usually the first time during the papermaking process when the wet web is stressed mechanically in the longitudinal direction. This behaviour is studied by a quasi-dynamic mathematical model, which includes force balance and continuity models and also a rheological model for the open draw and material properties of the web respectively.

The model consists of steady-state and nonsteady-state portions. Time-dependency is applied through mass flow and rheological equations, force balance equation is in static form. The solving method for this coupled equation system is to first solve the ideal steady-state situation and, after this nonsteady-state equations which can be solved by using the steady-state situation as an initial condition.

The qualitative behaviour of this model is correct, for example the increase in peeling angle between the surface and the web can be observed in cases of both velocity increase and adhesion energy increase even if the relative speed difference of the open
draw has remained constant. Limitations appear mainly in the correctness of web material, adhesion and external pressure parameters. However, by using this model, also the effects of such external disturbances as adhesion and pressure disturbances can be studied efficiently.

One of the main results is also an exponential increase in the peeling angle as a function of velocity. In this paper, it is caused by the centripetal force affecting the web.

As a conclusion, the peeling behaviour of the wet web in an open draw is a very sensitive system. The main advantage of this system is its capability to self-adjustment through changes of the mass flow rate and peeling angle. However, also the rheological properties of the web and the adhesion force itself play a significant role in the optimization and stabilization of the web transfer in an open draw.
DETERMINATION OF LINEAR VISCOELASTIC MATERIAL PROPERTIES OF PAPER FOR WEB MECHANICS IN PRINTING PRESSES

J. 0. Lif¹, S. Ostlund² and C. Fellers

Swedish Pulp and Paper Research Institute
¹also Stora Corporate Research
²also Royal Institute of Technology
Sweden

ABSTRACT

Analysis of multispan web handling systems such as printing presses requires that viscoelasticity is considered. Guided by the plane and anisotropic nature of paper webs and the relatively small strain levels in a printing press suggests the use of a two dimensional anisotropic linear viscoelastic constitutive model for a first order analysis of the web behavior.

In the present paper a novel procedure for determination of the material functions in such a model, based upon biaxial measurements during small uniaxial sinusoidal excitations of paper strips symmetrically around zero stress, was presented. The drawbacks of buckling of the paper strip during the compressive part of the load cycle was avoided by supporting the paper specimen between glass plates. The method enables in-plane viscoelastic characterization of paper grades in the frequency range 0.000238-10 Hz. The experimental set-up was tested for newsprint and paperboard. The results showed that the method offers the determination of the material functions during a steady-state response which is not the case in conventional set-ups using a static pre-strain in order to avoid buckling.

The experimental data were used for determination of appropriate material functions. The usefulness of the material model was verified by comparing model simulations with different driving stimuli in a tensile tester. The time dependent transverse strain response of paper due to stress relaxation was demonstrated. The comparison between model and experiments indicated that newsprint and paperboard exhibit some non-linear material behavior at the strain amplitude of 0.075 % chosen for obtaining the material parameters. The linear viscoelastic model described the Behaviour of the tested papers within the requirements of engineering accuracy for strain levels typical for many printing applications.
Idler roller bearing drag plays a critical role when modeling web tension in a web line system. Lubrication, line speed, radial and axial loads on bearings can influence drag, which is directly reflected as a tension load on the web. An in-situ method has been devised for measuring idler roller bearing drag. Empirical models, fit to the data, provide bearing drag predictions under operating conditions. A relatively simple Spin Down test on an idler roller was used to predict the steady state drag from bearings as a function of line speed. Bearings were cleaned and lubricated with both oil and grease to test the contribution of lubricant to bearing drag.
ABSTRACT

Machines that manufacture photographic web products use rollers to convey the web. Product imperfections, like scratches and scuff marks, are caused by loss of traction between these rollers and the web. Loss of traction is due to a variety of well-known conditions and always has the characteristic that the roller surface speed is not identical to the web speed. In typical photographic manufacturing processes, imperfections like these cannot be seen until the product is completely through the machine, and then only by well-trained operators in lighted areas and/or expensive automated scanning equipment.

The existence of the imperfection means the product must be scrapped; the machine time used to make the product is “lost”. Additional machine time is necessary to search for the responsible roller(s). The search compromises operator safety in that in order to take many of the measurements necessary to locate the responsible roller, using handheld contact and non-contact tachometers, and prony brakes, the operator is placed in dangerous proximity to the moving web.

To address these machine and operational problems, many have suggested installing roller speed sensors on the rollers. This would allow operations personnel to identify responsible rollers more quickly and safely. However, the high cost of installing traditional single-point roller speed measurement systems has, until now, kept us from monitoring every roller. One recent single-point roller speed installation cost nearly $25K and these rollers number in the thousands in a typical machine. The goal of this development effort was to design an inexpensive multipoint roller speed monitoring system for photographic product manufacturing machines.

The method we used is composed of (1) single magnets affixed to each roller, (2) magnetic field sensors, (3) custom printed circuit boards (PCB’s) for multiplexing a multitude of sensor signals from the field to a remote location for processing, (4) high-speed counter/timer electronics, and (5) digital output electronics. The design of the field sensors and electronics satisfies low-power electrical code requirements, which reduces the cost of conduit usually required to protect field cables.

The final costs were roughly $100K for an installation of about 450 sensors ($220/point) after initial development and design. That cost did not include the control computer or programming.
PROCEEDINGS OF THE FIFTH INTERNATIONAL CONFERENCE ON
WEB HANDLING

June 6-9, 1999

Web Handling Research center
Oklahoma State University
Stillwater, Oklahoma

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Closed Solid-State-Fluid Mechanical Model for Calculating the Transferable Torque on Wrapped Rolls
D. Schüler, E. G. Welp and O. Kopp
ABSTRACT

Mathematical modeling of film winding has progressed to a point where it can offer much insight into the mechanics of this process. However, experience and testing on the actual hardware are still necessary to maximize yields. The purpose of this work is to describe the practice of using both modeling and testing in consort to optimize winding. Modeling is the first step. For the best results, this is done before the winding hardware is fabricated. The use of models for roll stresses, air entrainment, buckling, air leakage and roll aging are discussed. Films are divided into categories based on the predominant defect type. Winding hardware and film surface design requirements are discussed for each of these film groups. An example of this approach is included that describes the process from the concept to on-line testing phases to optimize the process conditions.
QUANTITATIVE ANALYSIS OF NIP-INDUCED TENSION
BY USE OF DIGITAL IMAGE PROCESSING

B. Gueldenberg and E. G. Welp
Ruhr-University Bochum
GERMANY

ABSTRACT

Winding paper in contact with a drum leads to the production of nip-induced tension which, to a high degree, influences the structure of the roll. Thus, comprehending the processes in the nip, including each parameter involved, is desirable to avoid roll defects.

This paper deals with a new measurement technique that is able to observe the process of building up nip-induced tension in the outer layers of a roll. With the use of digital image processing, this method ensures the registration of the two-dimensional displacement field of the outer layers with fairly high precision. Based on the first principal of the equations of mechanics, it is possible to derive the stress and strain in the layers from the displacement field. Thus, it succeeds to calculate the tangential stress in the outer layers of a roll taking the compression as well as the slippage of the layers into account.

In all experimental test series the tangential stress increases within the first 4 to 15 layers to a maximum value. Afterwards, there is still a considerable displacement of the layers relative to the core, but the layer-to-layer slippage is so small that the change in strain is negligible. Furthermore, it is shown that there is a reduced increase of nip-induced tension in the first approximate 50 layers near the core. Comparing the nip-induced displacement of different type of papers, there are clearly differences noticeable concerning the amount of displacement, as well as the rapidness of increase to the final displacement.
CONTACT MECHANICAL APPROACH TO THE WINDING NIP

M. Jorkama\textsuperscript{1} and R. von Hertzen\textsuperscript{2}

\textsuperscript{1}Valmet Winders

\textsuperscript{2}Helsinki University of Technology

FINLAND

ABSTRACT

A contact mechanical model for the winding nip, consisting of the wound roll, winding drum and the intervening sheet, is presented. The roll and drum are modeled as linear, orthotropic, homogeneous cylinders with a rigid core. The elastic solutions for the cylinders are derived analytically in a series form. The sheet is modeled as a linear and orthotropic material as well. An approximate elastic solution for the sheet is obtained by assuming an internal stress distribution compatible with the boundary conditions (thin sheet approximation). The governing contact mechanical equations are presented and the appropriate form of the wound-on-condition of the sheet is presented.
MODELING OF EDGE ROLLS DEFECTS

J. E. Olsen
Norwegian Pulp and Paper Research Institute
NORWAY

ABSTRACT

Based upon Hakiel’s nonlinear orthotropic model for wound rolls, a model has been developed which takes into account widthwise variations in web properties. The model includes widthwise variations in the elastic modulus in the machine direction and it includes the effect of slack edges which is modeled as a widthwise variation in initial strain. Both variations can typically be found in paper and they are possible causes of soft outer edges on wound rolls. The variations are included by modifying the outer boundary condition in Hakiel’s model. Calculations show that in-roll pressure decreases towards the edge if there is a slack edge or the elastic modulus has a lower value at the edge than elsewhere. This is consistent with empirical observations.
ABSTRACT

The compression testing of stacks of sheet materials is done to learn the behavior of the group of sheets, a behavior that is quite different from that of a solid, or even one single thick sheet of the same material. Many interfaces are present at the sheet contact, consisting of soft fibers, asperities, or minor surface protrusions, and these cooperate to make the stress-strain relationship of the package nonlinear. Reasons for doing the testing are presented, with models for estimating the pressure versus strain curves, and implications for roll structure prediction based upon these models. The concept of strain loss in compression is reintroduced, and techniques are presented for improving curve-fitting when strain loss exists. A list of alternative ways for evaluating wound roll structure is given, with comments on the relative merits of these methods.
A FULLY NONLINEAR SOLUTION TO THE
STRESSES INSIDE WOUND ROLLS

A. W. Forrest Jr.
DuPont
USA

ABSTRACT

The Hakiel approach has been the accepted method for calculating stresses in wound rolls. It determines the stress in rolls by summing the stress induced by wraps of film applied to the roll surface. This approach is called linear superposition and it is strictly valid only for linear differential equations. The radial properties of film in a roll make the equations highly nonlinear and this presents a problem. Test results have supported the general accuracy of the Hakiel method. The method described here obtains a fully nonlinear solution for the stresses which occur during winding and any roll deformation that may occur afterward. The subsequent roll deformation can be a result of air leaking out or plastic deformation of the film both in the stack and in-plane directions. Only the case involving air leaking is presented. It reproduces the Hakiel approach for linearized conditions and differs to varying degree for the nonlinear cases. The approach presented here is more suitable for highly nonlinear cases and for making roll-aging calculations.
ABSTRACT

Pfeiffer first defined the wound-in-tension measurement in 1968[1]. This technique requires the outer layer of web to be pulled away from a winding roll and a measure of the web tension is made prior to returning the web to the surface of the winding roll. In this manner the wound-in-tension can be studied as a function of winder type and as a function of winder and web line operating parameters. In this paper the use of the WIT measurement as a non-interfering method of evaluating roll structure will be examined. WIT will be used to compare surface winding and center winding with a nip. The nip-induced-tension components of the WIT will be determined as well and compared for the different winder types.
LIMITATIONS TO SENSING OF WEB TENSION
BY MEANS OF ROLLER REACTION FORCES

J. J. Shelton
Oklahoma State University
USA

ABSTRACT

Classical frequency response analysis of a dancer or a roller mounted on load cells reveals that such devices are severely limited in their ability to sense the dynamic tension in a web. The response of a tension control system may therefore be limited by the dynamics of the sensor instead of the drive motor and its controller.

Natural frequencies of rollers in translation and rotation are shown to limit the bandwidth of tension control systems. Dancers are shown to often increase dynamic tension variations when compared to a simple span of web, instead of performing their intended function of reducing or eliminating these variations.

Transfer functions of web dynamics reveal that a tension control system may appear to be one “type” (as defined by the number of pure integrations in the open loop), but the tension output does not benefit from the integrations, yet the control system suffers the difficulty of stabilization associated with integration(s). A dancer which controls a torque device (contrasted with control of velocity) is particularly difficult to stabilize because of the double integration (type 2) and the great variations of important parameters.

Dimensionless groups of parameters were developed for evaluation of the performance of roller-reaction sensors of tension. Performance is shown to depend upon the stiffness and velocity of the web, as well as such parameters of machine design as the number of the idlers between the driven rollers, mass and radius of each roller, stiffness of the load cells, and lengths of spans between drive stations. A subgroup of parameters (not dimensionless) is the inertia of a roller divided by the square of its radius. Because this subgroup is never separated into its two components, the inertia by itself is unimportant.
COMPENSATION OF DISTURBANCES IN THE WEB FORCE CAUSED BY A NON-CIRCULAR RUNNING WINDER

W. Wolfermann
Technical University Munich
GERMANY

ABSTRACT

In many plants of the steel-, paper-, printing-, plastic- or textile industry the first section is an unwinder. But during storage and transport of the rolls, the rolls are often non-circular. If such a roll is unwinded, the radius is variable around the circumference. Therefore a changing web velocity is caused depending on the variable radius and big oscillations of the web forces are the consequence, if the winder speed is constant.

To solve the problem, it is necessary to use new methods to compensate the disturbances without additional mechanical systems. To do this, there are to solve two fundamental problems. The first is to get the unknown, nonlinear changes of the radius and the second is the design of a fast speed control of the winder which is able to compensate these changes.

Therefore a neural network is proposed to identify online the unknown, nonlinear variable radius with respect to the angle position continuously during running. The advantage of neural networks is that they do not need any information about the nonlinearities, they are able to handle unknown nonlinearities. So the neural network is like a “learning” observer.

To compensate the disturbances in the web force, the output of the neural network is fed into the speed control of the winder to change the motor speed of the winder in this way that the web velocity is nearly constant. This reduces the oscillations of the web force in a big range. But the requirement is a fast speed control of the winder. A conventional PI-controller is not able to fulfill that condition. Therefore an adaptive state space control of the motor speed was designed.

The advantage of this method is that no additional mechanical equipment is necessary. The identification of the unknown eccentricity of the roll and the compensation are done only in the digital control system.
ABSTRACT

State feedback has become a widely used method of controlling dynamic systems such as moving webs. In a state controller the present value of all states (i.e. tension, motor speed, and motor torque for each web span) are used to calculate the output of the controller. Since it is not cost effective to measure all of these states, state observers are often used to estimate some of the states. Typically, the state to be controlled (tension in this case) is measured, and observers estimate the other states. It is possible, however, to measure a state other than tension (e.g. motor speed) and generate an estimate of the tension using the state observer. Tension sensors are not needed if this estimated tension is controlled instead of the actual tension.

This paper compares tension control using estimated tension versus tension control using tension sensors. Simulations were run for machines having several nominally identical web spans and nominally identical controllers, motors, and sensors. Since all web spans, motors, etc. are assumed to be identical, tuning parameters were held constant for all simulations. Parameters such as sensor gain were varied from their nominal to study the effect.

Integral feedback was used in all cases. Using tension sensors, the steady state error is dependent only upon the accuracy of the tension sensors. For the sensorless case, steady state error was directly dependent on the accuracy of the torque-measuring device (i.e. torque sensor or torque estimated by the observer), but integral action could not remove all steady state errors.

It is highly desirable that the individual web spans and their associated controls be decoupled from one another. A decentralized control can then be used for each span. If completely decoupled, additional web spans will not affect the dynamics of the other spans. Tension control with sensors accomplished this much better than sensorless control. With sensorless control, steady state errors introduced in one span are also seen in all preceding spans. Tension sensors successfully removed such errors. With sensorless control adding more web spans (and their associated controls) eventually resulted in an unstable system. This was not observed using tension sensor control.

A robust system is one that can tolerate large changes in parameters. Here again, for most parameters control with tension sensors was superior to sensorless control.
THEORETICAL COMPARISON OF WINDING TENSION CONTROL METHODS

J. P. Ries
DuPont
USA

ABSTRACT

Several methods are used to control tension in the winding zone. The two most common methods use either a tension signal from a loadcell or a position signal from a dancer system. Both techniques control tension, however, the insertion of a dancer roll also affects the dynamics of the web transport line. The moving mass of the dancer roll and the fact that it can move add another degree of freedom to the system.

The method used in this analysis to compare the two control techniques was the closed loop transfer function. Differences between the two systems can be clearly seen in the frequency domain. Two excitations were considered. The first was an upstream disturbance from the in-feed roll velocity. The second was a torque disturbance on the winding spindle. The output variables of interest were the winding tension and the package velocity. Two identical zones were analyzed.

The closed loop transfer functions were obtained using an in-house, software program. Results showed that the loadcell system was better for low frequency disturbances because of the additional natural frequency created by the dancer roll. The dancer system provided better control in the mid-frequency range. Both systems were identical in the high frequency range because the dancer roll could not respond fast enough. The conclusion was that the successful use of a dancer system requires knowledge of the excitation frequencies and a good design for the dancer system.
ABSTRACT

A set of sub-optimal Extended Kalman Filters (EKF’s) are described. The filters are used to estimate web tension, modulus of elasticity, and loss torque for all sections in a small web processing line located at Rockwell Automation’s Euclid Research Facility. Conditions necessary for observability, and estimate convergence are discussed.
ABSTRACT

Friction plays a critical role in many web handling and winding problems in the paper industry. Although these problems can often be reduced to simple mechanical models, the models require the coefficient of friction of the material as an input. However, coefficient of friction of paper can be an elusive measurement which depends on measurement conditions, handling and even on previous measurements on the same sample. This paper looks at how friction should be measured for different applications. Fundamental principles are used to explain the chemical nature of friction which is essential for understanding and controlling friction in the paper industry.
THEORETICAL ANALYSIS OF SHEAR SLITTING OF PAPER ON THE BASIS OF A THREE-DIMENSIONAL MATERIAL LAW

E. G. Welp and E. Wolf
Ruhr-University Bochum
GERMANY

ABSTRACT

The slitting and cross cutting as one of the substantial manufacturing methods in paper equipment and paper processing are characterized in many applications by practice problems, which lead to productivity and quality losses.

Analysing the knowledge of shear-slitting shows that there are great gaps in the fundamental understanding of the slitting procedure as well as in its conversion to mechanical engineering. For this reason our institute carries out a research project to analyse the slitting procedure on a theoretical and experimental basis. The aim of this project is to clear up the correlations of shear-slitting and to derive measures for the improvement of slit quality and blade durability in practice.

Because of the complex, three-dimensional state of stress during the slitting process, the problem cannot be solved analytically and the finite-element-method is used to calculate the states of stress and strain. For the modelling of the material behavior of paper, a three-dimensional material law is deduced. The influence of the material law and the cutting tool geometry on the shear slitting process is studied. The achieved results of the FEM analysis shall be compared to experimental results in later research work.
THE STRESS FIELD IN A WEB DURING SLITTING -OPENING MODE

H. Lu¹ and C. Liu²

¹Oklahoma State University
²Los Alamos National Laboratory
USA

ABSTRACT

The dynamic stress field in a web during slitting is presented for the opening mode appropriate for razor slitting in the steady state. The integral equations for the general stress and strain fields in a web near a razor blade are solved for the in-plane stress components for a homogeneous, isotropic and linearly elastic web. A wedge-type razor blade profile is used in the analysis. A Coulomb type of friction relation between the shear and normal traction at the interface between the razor and the web is assumed. Analysis is performed to determine the stress components and the contour of effective stress. It is found that the stress distribution in the web can be separated into two parts. One part depends only on the web speed and the other part depends only on the slitter profile. A parametric study is carried out to determine the dependence of the contour of effective stress on the slitter blade profile, the friction coefficient at the web-slitter interface, the web speed during slitting, as well as the web tension. In the parametric study, it is assumed that the web material properties such as Young’s modulus, yield strength and fracture toughness are independent of the strain rate or the web speed. The results on the dependence of the contour of effective stress on the slitting parameters reveal that the size of the permanent deformation zone in the slit edge becomes larger when any one of the slitting parameters among the web tension, the razor wedge-angle and the web speed increases while all the other slitting parameters and web material properties are fixed.
ENGINEERING PAPER TUBES TO IMPROVE WINDING PERFORMANCE OF VARIOUS MATERIALS

T. D. Gerhardt, Y. P Qiu, C. G. Johnson, and D. E. Rhodes
Sonoco Products Company
USA

ABSTRACT

Over the past 10 years, Sonoco has conducted fundamental, solid mechanics research concerning structural behavior of spirally wound paper tubes. The scope of this program has included experimental, numerical, and analytical mechanics approaches as documented in references (1-7). For recent non-linear finite element research, we have used ABAQUS and developed user-defined material subroutines. These subroutines feature a proprietary 3D constitutive model for paperboard. The model uses non-linear stress-strain properties of Sonoco paperboard measured in 3 principle directions. An important research objective is to develop innovative tube designs that enable our customers to improve their winding operations. To achieve this objective, we have developed several patented test devices that measure tube properties fundamental to winding applications. Tests to measure core radial stiffness on the inside and outside $(E_c)$ with respect to an external pressure and radial strength have been developed. This paper describes the test methods and presents data to verify mechanics research findings by way of two core applications. These are examples of where cores were engineered using mechanics technology to improve winding capability: (1) development of an extremely high $E_c$ core for winding low friction, coated aluminum, and (2) cores for winding textile yams based on radial stiffness of inside diameter.
ABSTRACT

The tube performance requirements critical to a manufacturer’s needs are dependent on such parameters as the manufacturer’s processes, winding media, packaging, and equipment. Two important strength requirements for paper tubes include flat crush strength and radial crush strength. Flat crush strength is an industry standard test method and thus an understanding of this strength parameter is important for any user of paper tubes. This paper will present a description of flat crush strength as well as basic parameters related to flat crush. We will also present a patented approach to optimize flat crush strength. This patented approach is based upon experiments and finite element analysis. Another important paper tube performance property is radial crush strength. Radial crush strength is a critical strength parameter for manufacturers of films and textiles or other media that have high recovery rates in the machine direction. This paper will present a Sonoco patented tester for radial crush strength as well as basic parameters related to radial crush. Finally, this paper will present some basic information on tube behavior with changes in tube moisture content.
MACHINE DIRECTION LAMINATE CURL CONTROL

P. Werner
Rockwell Automation / Drive Systems
USA

ABSTRACT

Machine Direction Curl is a phenomenon that develops sometime after a finished laminate is allowed to relax. The root causes of this eventual curl are due primarily to the recovering of strain, in either or both Strips A and B, which were stress induced prior to and during the laminating process.

This paper reviews the Laminating process parameters that effect the development of Machine Direction Curl. It then presents Soft Roll Drive configurations and empirical procedures to provide effective influence in correcting for Machine Direction Curl.
THE FACTORS THAT CONTROL RUN-AHEAD ON PRINTING PRESSES

J. Hamel, A. Menard and D. McDonald
Pulp and Paper Research Institute of Canada
CANADA

ABSTRACT

Run-ahead is a problem that occurs on printing presses where the paper rolls are braked by metallic bands applied to their periphery. Run-ahead occurs when the web in contact with the band decelerates faster than the roll, or when the web stops completely but the roll continues to rotate. This leads to a bubble, or bunching of paper layers, on the ingoing side of the bands. This breaks the web. A model has been developed to characterize run-ahead that takes into account press operating conditions, as well as paper and roll properties. The model shows that run-ahead depends on the press parameters of wrap angle, deceleration rate, and unwinding tension. It depends on paper parameters such as paper-to-paper coefficient of friction (COF), paper-to-band COF, wound-in tension, and the mass of the roll. We found that the paper-to-band COF increases significantly due to contamination of the band from the paper, and could be a determinant in the run-ahead problem. The probability of run-ahead can be reduced by increasing the wrap angle between the braking band and the paper roll, reducing the rate of deceleration, reducing the web tension on the press, or by increasing the wound-in tension. The key factors are the static paper-to-paper COF and the dynamic COF between the paper and the band material. Increasing the paper-to-paper COF will not be effective if there is also a proportional increase in the paper-to-band COF, so care must be taken when evaluating possible additives or treatments.
A DYNAMIC MODEL FOR MONITORING
AND CONTROL OF A WINDING PROCESS

P. Kabore\textsuperscript{1}, H. Wang\textsuperscript{1}, H. Jaafar\textsuperscript{1} and W. Hamad\textsuperscript{1,2}

\textsuperscript{1}Paper Science Department UMIST
\textsuperscript{2}International Paper Corporate Research Center
USA

ABSTRACT

In this paper, a dynamical model for an on-line monitoring and control strategy design is proposed. It describes the dynamic behaviour of in-roll stresses as the roll is being built. The distribution of in-roll stresses is in fact a key issue to tackle the problem of avoidance of in-roll stresses. By acting on boundary variables such as tension and torque, one can drive the in-roll stresses to a non-defect inducing on.
ON-LINE CONTINUOUS MEASUREMENT OF ROLLS’ COEFFICIENT OF RESTITUTION

H. Jaafar¹, W. Hamad¹⁻², P. Kabore¹, and H. Wang¹

¹Paper Science Department UMIST

²International Paper Corporate Research Center

USA

ABSTRACT

This paper reports on the development of a novel technique to measure on-line rolls’ coefficient of restitution or “springiness”. The ratio of speed of separation to speed of approach in an elastic collision is termed the coefficient of restitution (Cr). The Cr sensor is based on the concept of an elastic collision of a steel object being freely dropped onto the web, as a roll is being wound, from a known height in the direction normal to the contact surfaces and rebound to a measured elevation. An important feature of this is the relationship between the rebound height and the in-roll stresses. The sensor returns the value of Cr as a function of roll radius. The latter can accurately be calculated from the data acquired via the sensor. The results indicate that the Cr values are complex and produce dramatic changes near the roll core. Further investigations are underway to verify the results and their interpolation in terms of the direct relationship with the in-roll stress and other parameters that may contribute to changing the roll springiness.
A NEW PARAMETER FOR DYNAMIC CHARACTERIZATION OF PET FILM SURFACE TOPOGRAPHY

M. Boutaous and P. Bourgin
University Louis Pasteur
FRANCE

ABSTRACT

It is well-known that handling and winding flexible media involve aerodynamic phenomena which are crucial for the process. Among those parameters which govern the final thickness value of the air layers separating the film layers in a roll of film (for example PET), surface roughness plays an important role. In order to characterize the surface topography of such materials, in a dynamic way, an original experimental set-up was built. It has been described elsewhere, and only its basic features are recalled here. It consists in a polished glass disc with a circular slit connected to a vacuum pump. Having displayed a sample of PET film onto the glass plate, sub-ambient pressure is applied. The air layer which initially separates the film from the plate is partially reduced due to air aspiration: a circular front starts from the slit and propagates towards the center. For prescribed values of the film thickness, the total propagation time depends on sub-ambient pressure and slit diameter (i.e. squeezing surface) through relationships which involve a single parameter characteristic of film roughness.

Here the same experimental set up is used to carry out further investigations dealing with the kinetics of both air layer thinning and front propagation. Using a monochromatic light to insulate the film from above, Newton rings are generated allowing the air gap thickness variation to be measured by means of a CCD camera associated with image processing. The main experimental result is that the air layer at the center decreases linearly versus time, the slope being characteristic of the film surface roughness. A simple theoretical model based on the concept of “equivalent smooth surfaces” is developed in order to predict the circular front propagation. Excellent agreement is observed with the experimental data, namely the front propagation kinetics. These results are extrapolated to the configuration of winding, leading to significant improvement of the existing model for lateral evacuation of the air layers confined between the film layers in a roll of film.
PERMANENT OUT-OF-PLANE-DISTORTIONS OF PAPER
PRINTED IN HEAT-SET WEB OFFSET

R. Bosse
Consultant
GERMANY

ABSTRACT

Paper, a flat material, frequently with a coated surface, is made out of fibres. In heat-set offset printing a permanent out-of-plane distortion, the so-called washboard effect, occurs quite frequently, which is clearly visible in a lot of web printed products. In the last few decades, manufacturers of heat-set dryers have tried to eliminate this washboard by different constructive measures without any real improvement. Views on this washboard have shown a dependency on various physical properties of the web. In printing practice it can be shown that the washboard is caused by the combination of tension, heating and cooling the paper. The washboard occurs when the paper is not flattened when cooled.
MEASUREMENT AND PREDICTION OF THE CENTERING EFFECT OF A PROFILED ROLL ON STEEL STRIPS

F. Onno\textsuperscript{1} and J. C. Petit\textsuperscript{2}

\textsuperscript{1}Sollac Florange

\textsuperscript{2}Irsid

FRANCE

ABSTRACT

In a steel continuous processing line, the strip passes over an important number of rolls and strip walking can occur due to strip defects, roll profile or roll misalignment. Since decades, two solutions are used in order to keep a strip centered in the line: deflection rolls are profiled (with crowned or tapered shapes) and steering rolls are implemented, in different part of the lines.

As in other industries, the constant challenge for a line manager in the steel industry is to increase the productivity of the line and to adapt the lines to new products.

To achieve these goals on pickling lines or continuous annealing lines, it is necessary in some cases to know precisely about the centering effect of profiled rolls on the strip. This data can be used either to improve the strip centering by increasing the roll profile or to avoid other defects as wrinkles, by reducing the crown without increasing strip walking.

In order to quantify the centering efficiency of a roll, Irsid and Sollac developed a theoretical model for calculating the strip position after a profiled roll and compared it to experimental data measured on two pilot lines.
ABSTRACT

To date, most of the theoretical work on longitudinal web behavior has been directed at the problem of controlling average tension. Very little attention has been given to the subject of this paper – propagation of tension within a span.

The model presented here is based on the one-dimensional wave equation, modified for a moving medium. Boundary conditions are developed that, for the first time, incorporate tension and mass transfer on rolling supports. The P.D.E. is solved analytically using Laplace transforms.

A number of phenomena are described that will be of interest to process designers and troubleshooters. These can be used to explain existing tension problems, whose causes may have been unrecognized in the past, and to anticipate problems that will appear as line speeds are increased. Among these are:

1. Propagation of strain discontinuities when draw is increased suddenly.
2. Amplification of repetitive strain disturbances due to strain reflection and reinforcement.
3. Damping of solitary strain disturbances.
4. Alteration of longitudinal resonant frequencies by transport motion.

Another important use of the model is to serve as a necessary step toward more advanced models that include out-of-plane motion, viscoelasticity and aerodynamics.

The model is tested by comparing it to the currently accepted O.D.E. model. At large time scales, where propagation phenomena are imperceptible, the two models are in good agreement.
WEB TENSION CONTROL IN AN INDUSTRIAL ACCUMULATOR

H. Koç1, D. Knittel1,2, M. de Mathelin1, G. Abba1 and C. Gauthier3

1Strasbourg I University
2Institut Professionnel des Sciences et Technologies
3Institut Charles Sadron

FRANCE

ABSTRACT

This paper presents the study of an industrial accumulator used in a web transport system. In order to understand the main characteristics of the accumulator and the causes of problems appearing during transient phases, different models based on physical laws have been built.

Different approaches are tested to calculate the web tension between two rolls. The selected approach uses an empirical law to express the web tension as a function of the downstream span tension and the difference of velocities between consecutive rolls. The empirical law aims to respect the mechanical behavior and the tension and velocity conditions imposed at the entry and the exit of the accumulator, which is not realized in classical web transport modeling.

One actuator is available to maintain the web tension approximately constant in the whole accumulator during the accumulator descent. Experiments and simulations have permitted to show that the existing industrial PI control of the web tension is not very satisfactory. The comparison of the PI control with a multivariable control (H∞ robust control) is presented. To improve the accumulator operation, new approaches are suggested, such as modifying the input parameter or introducing a mechanical tension regulator.
ABSTRACT

A conventional accumulator with no driven rollers and all rollers identical is studied for avoidance of excessive tension, slackness and slippage on the rollers. The total force imposed by the web spans on the carriage is derived for the case of a constant acceleration of the web.

For the usual case of several rollers on the carriage, the translational kinetic energy of the carriage (including the moving rollers) is shown to be negligible in comparison to the rotational kinetic energy of all the rollers in the accumulator. This discovery allows design and analysis of the control scheme of an accumulator with knowledge only of the parameters of the rollers.

The time required for a constant acceleration of the carriage is shown to be a simple function of the acceptable difference of tension across the accumulator, the total change of velocity, the number of rollers, and $J/R^2$ of the rollers.

Equations are derived for the ratios of tension across each roller, allowing the choice of a rate of acceleration for avoidance of slippage on a roller. The first or last roller was found to not always be the critical one for slippage.

Equations are derived relating the balancing force on the carriage to the number of rollers and an acceptable magnitude of tension.
ABSTRACT

This paper lays the groundwork in an effort to determine appropriate boundary conditions and basic principles that can be used to extend current web mechanics models to include webs that are not “initially straight and uniform.” A method to design, manufacture, measure and test non-uniform web is presented. Deflection, shear and moment equations are extended to include the effects of cambered web and non-zero curvature at the downstream end of a span. It is shown that the curvature at the downstream roller is not zero, as is the case with uniform web. The prediction of actual curvature, and consequently deflection, shear and moment, has been bracketed, but not quantified.
THE INFLUENCE OF WEB WARPAGE ON THE LATERAL DYNAMICS OF WEBS

R. C. Benson
Pennsylvania State University
USA

ABSTRACT

The transport of long flexible webs is of great importance in many manufacturing applications, including the processing of paper, textiles, magnetic tapes and photographic film. Beginning with the pioneering work of Shelton and Reid (1,2), analysts have had the ability to model the lateral dynamics of webs, and, thereafter, to apply control algorithms for accurate steering. See, for example, Reid, Shin and Lin (3); Sievers, Balas and von Flotow (4); and Young and Reid (5). Other analysts, such as Soong and Li (6) and Young, Shelton and Fang (7,8), have studied greater web-conveyance systems.

Each of these models assumes that the web is perfectly straight in its stress-free state, which is often a reasonable assumption. However, in some regions of a web, manufacturing flaws and splice misalignments can give the web a stress-free geometry that is warped in the plane of the web. As the imperfection travels between rollers it has an action equivalent to an applied, lateral load that moves with the speed of the web. This causes the imperfect web to deform differently than expected, which, in turn, affects lateral dynamics and control.

In a recent paper, Benson (9) added geometrical imperfections to the web steering analysis, and studied the special case of a splice moving between two rollers. The model utilized the “Timoshenko” beam theory, presented by Shames and Dym (10), to account for the elastic bending and transverse shear deformation of the web. Boundary conditions at the rollers were influenced by the stick/slip studies conducted by Johnson (11) and Smith (12). In the present paper the imperfect web formulation of Benson (9) will be used to examine the case of a sinusoidally warped web. Example results will be presented to show how this imperfection affects the lateral dynamics of the web, and can lead to what Sievers, et al. (4) called “weave regeneration” in downstream web spans.
INTRODUCTION

In her thesis, Sievers’ begins with fully-dynamic equations of motion for the potential and kinetic energy of moving beams. She applies Hamilton’s principle, and these equations result:

\[ -m\left(\ddot{y} + 2v\dot{y} + v^2y''\right) + \left(\frac{AG}{n} + T\right)y'' - \frac{AG}{n} \dot{y}'' = 0 \]  

(1)

\[ -J\left(\ddot{y} + 2v\dot{y} + v^2y''\right) + EI\dot{y}'' + \frac{AG}{n} (y'' - ?) = 0 \]  

(2)

By making the assumption of quasi-static behavior, the time derivatives drop out. The terms which include mass and inertia are negligibly small, and may be discarded. Manipulation of (1) and (2) gives (with the time dependence of the web shown):

\[ \frac{\partial^4 y(x,t)}{\partial x^4} - k^2 \frac{\partial^2 y(x,t)}{\partial x^2} = 0 \]  

(3)

\[ ?(x,t) = \frac{\partial y(x,t)}{\partial x} + f \frac{\partial^3 y(x,t)}{\partial x^3} \]  

(4)

where:

\[ k^2 = \frac{T}{EI\left(1 + \frac{nT}{AG}\right)} \]  

(5)

\[ f = \frac{Eln\left(1 + \frac{nT}{AG}\right)}{AG} \]  

(6)

Note that web shear causes the web centerline angle to differ from the web face angle. It is the web face angle that is continuous across a roller, rather than the web centerline angle.

To describe the transient lateral behavior of a web treated as a tensioned Timoshenko beam in a web conveyance system, an equation is added to describe the web lateral behavior at the downstream roller interface:
\[
\frac{\partial y(x,t)}{\partial t} = -v \left( \frac{\partial y(x,t)}{\partial x} - \gamma_r \right) + \frac{\partial z}{\partial t} \tag{7}
\]

Equation (7) introduces the assumption of no slippage on each roller.

These above equations are insufficient to determine the transient behavior of the web. Sievers, following Shelton\textsuperscript{2}, goes on to differentiate (7) with respect to time, substituting (7) for the time part of \( \frac{\partial^2 y(x,t)}{\partial t \partial x} \) which occurs, giving:

\[
\frac{\partial^2 y(x,t)}{\partial t^2} = v^2 \frac{\partial^2 y(x,t)}{\partial x^2} + \frac{\partial^2 z}{\partial t^2} \tag{8}
\]
ABSTRACT

In modern industrial process controls, web guiding is becoming very demanding due to variations in web materials, variable web widths, and the need for better guiding accuracy. Selecting the appropriate sensor for various types of web materials and repositioning the sensors for variable web widths can be very expensive and time-consuming. At present, some web guiding applications where wide web width variations are desirable require the sensor positioner to electromechanically reposition the sensors to accommodate the web width variations. With time, a system using electromechanical means suffers in terms of reliability and consistency in guiding accuracy.

To address these needs, a solid-state, laser-based, multiprocessing sensing scheme can be a viable option. This new sensing technique is based on a segmented, multiple transmit-receive pair scanning topology. A wide sensor field of view is achieved by staggering multiple sets of transmit-receive segments. On the transmitter side, a collimated light curtain is obtained by using a set of cross cylindrical lens-based optics with a semiconductor laser diode. Each receiver segment is made of a linear photodiode array that is independently scanned by a dedicated microcontroller. The main sensor synchronizes multiple segment scanning, processes segment information, delivers output based on web edge position.
WRINKLING OF WEBS DUE TO TWIST

J. K. Good and P. Straughan
Oklahoma State University
USA

ABSTRACT

Webs are often required to endure twisting in web process machinery. There is a limit to the degree to which the web can be twisted prior to wrinkling. The objective of this publication is to document a closed form technique that was developed to predict the twist limit of the web.
MECHANICS OF A CYLINDRICAL FLEXIBLE WEB
FLOATING OVER AN AIR-REVERSER

S. Müftü¹ and K. A. Cole²

¹Massachusetts Institute of Technology
²Eastman Kodak Company
USA

ABSTRACT

The mechanics of the fluid/structure interaction between a thin flexible web, wrapped around a cylindrical drum (reverser), and the air cushion formed by external pressurization through the holes of this drum is analyzed. The web deflections are modeled by a cylindrical shell theory that allows moderately large deflections. The airflow is modeled in two-dimensions with a modified form of the Navier-Stokes and mass balance equations, with non-linear source terms. The coupled fluid/structure system is solved numerically. The mechanics of the interaction between the web deflections and the air cushion generated by the reverser is explained. The effects of the problem parameters on the overall equilibrium are presented.
RESILIENCY OF AN AIR-FLOATED WEB

Y. B. Chang¹, R. P. Swanson² and P. M. Moretti¹

¹Oklahoma State University
²3M Company

USA

ABSTRACT

Air-flotation ovens are used for non-contact drying of coated web materials such as photographic film, magnetic media, and paper. In a typical air-flotation oven, the air bars are arranged in such a way that the path of web is nearly sinusoidal. When web tension fluctuates, the distance between the web and the air bars also changes. This phenomenon affects the longitudinal dynamics and tension control of an air-floated web. In some cases, tension fluctuations can cause the web to touch the air bars, resulting in damage to the coating and the web. This paper discusses an analytical model of the extensional resiliency of an air-floated web. The analysis shows that at low tension the machine-directional stiffness of an air-floated web is small, being dominated by the air cushion effects. At higher web tension, however, the effects of material deformation become more important than the air cushion effects. The analysis is compared with the experimental results obtained in a pilot air-flotation oven. The analytical and experimental results show the same trends, though the analytical model tends to underpredict the longitudinal stiffness of air-supported web.
ABSTRACT

In the manufacturing fields of plastic sheet, paper, magnetic tape, thin metal plate, photographic film, etc., the web transporting systems supported by guide rollers are often used. In such systems, it is of cardinal importance to control the web spacing between the traveling web and guide rollers. For example, when the guide roller is used as turn bar in the commercial web offset press or used as dryer in the coating processes of web, it is sometimes needed to keep sufficient air film thickness between web and roller for avoiding the web defects due to surface roughness, stain and lack of uniforming. On the other hand, when the guide roller is used as drag roller, it is desirable to remove the entrained air between web and roller for keeping enough level of traction.

In this paper, two types of guide rollers are presented to improve the web spacing characteristics, one of which is hybrid type hollow porous roller for keeping the sufficient web spacing, and the other is grooved type roller for removing the entrained air. In the hybrid type hollow porous roller, the pressurized air is added to the lubrication air flow between web and roller from inside the roller. Then, the web spacing characteristics are improved by the hybrid effects of hydrodynamic pressure due to web movements and hydrostatic pressure due to pressurized added air through the roller. The relations between web spacing and web traveling velocity are measured under various supply pressures. Moreover, the relations between web spacing and web tension are examined. The contactless optical sensor, which can measure the variation of the quantities of reflected light from the back surface of web according to the variation of web spacing, is used to obtain the web spacing under various conditions. In the grooved rollers, the method for the estimation of web spacing by using the concept of equivalent spacing between web and roller is presented, and the web spacing is measured by the same experimental apparatus used in the case of hollow porous roller. From the calculated and measured results obtained, the effectiveness of two types of guide rollers on the web spacing is clarified.
AN EXPERIMENTAL AND THEORETICAL STUDY OF WEB TRACTION OVER A NONVENTED ROLLER

B. S. Rice¹, K. A. Cole¹ and S. Müftü²

¹Eastman Kodak Company

²M.I.T. Haystack Observatory

USA

ABSTRACT

The traction developed between a thin flexible web, wrapped around a nonvented, rotating cylindrical roller is studied experimentally and theoretically. A series of eight webs representing a wide range of surface roughness characteristics are traction tested against the same roller over a wide speed range. A one-dimensional finite difference model that couples air film pressure (Reynold’s equation), web bending and solid-body contact using an asperity compliance function is used to model the experimental traction data. An optimization technique is used to estimate the asperity compliance function parameters. A new model for computing the asperity engagement height for non-Gaussian surfaces is presented when the roughness of both surfaces is taken into account. Results are presented which indicate the viability and utility of the new methods.
ABSTRACT

Idler roll slippage occurs when the roll surface velocity no longer equals the velocity of the web that transports the roll. In a web transport system, slippage will produce scratches in sensitive, coated web or cause process problems such as loss of lateral tracking. This paper presents the results of an experimental study on roll slippage with polyester film and several different roll surfaces at web speeds to 1000 fpm.

A test stand was installed in a laboratory based web transport line. This allowed for the control of tension and the continuous measurement of torque, tensions and speeds. Tests were conducted using four different polyester films. Roll surfaces that were tested consisted of ground metal, rubber covered, grooved and knurled. The effects of wrap angle and outgoing tension were also studied.

Slippage was found to vary continuously from 0.05 to 100% depending on the amount of applied braking torque. The parameter used to quantify the onset of slippage was “effective coefficient of friction”. It was determined experimentally when the difference between web velocity and roll velocity was 0.25% of the web velocity. Reasons for this definition are discussed in the paper. The standard belt equation was used to calculate the coefficient from the test results. The change in the coefficient with web velocity, roll surface, wrap angle and film surface are presented. A roughened knurled roll provided the most traction and had fewer tendencies to slip at higher speeds.
ABSTRACT

Higher velocities of webs at the same or reduced web tension require basic improvement of the existing machine technique. Concerning the transferable torque between a web and a roll common work is restricted either to the foil bearing theory at constant web tension without solid-state contact, or to the solid-state friction, including in some cases the influence of a constant fluid pressure. In this paper a model for calculating the transferable torque between a roll and a web is introduced which is more conform to reality. In the web mounting and in the web launching area the gap width and the pressure are calculated taking into account the web tension. In the intermediate area, where contact occurs between the rough surfaces of web and roll, it is assumed that the gap width can be substituted by an equivalent gap width between smooth surfaces. The transferable torque is calculated taking into account the local fluid pressure. The calculations show that, in the contact area, the compressibility of the fluid has a significant influence on the pressure profile and, finally, on the transferable torque.

A device reducing the air entrainment by means of the so called “gap throttle effect” is introduced. It needs no separate energy, works nearly without contact, and has our patent pending on it. The maximum velocity up to which torque is transferable, as well as the transferable torque at a constant velocity, can be increased by this considerably. The effectiveness could be verified at a test rig in our laboratory.
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BOPP FILM TRENDS; SOME TECHNOLOGY IMPLICATIONS

J. Howard
Applied Extrusion Technologies, Inc.

ABSTRACT

Biaxially oriented polypropylene (BOPP) is an extremely versatile film that has demonstrated enormous growth in commercial usage over the approximately 40 years since its first introduction. A combination of material, web handling and process technology developments has continued to expand the range of film structures that can be produced. This has enabled polypropylene to cost effectively replace competing materials in many applications. Other than those companies with a pure low-cost producer strategy, BOPP manufacturers must introduce new products and extend their product ranges in order to maintain or increase their competitive positions. As new markets are identified, product line extensions commonly involve the introduction of new technology (e.g. for the development of very thick films). At the same time as diversifying the product range, even those suppliers with a differentiated product strategy must identify ways to contain or reduce manufacturing costs, while also increasing manufacturing flexibility.

In order to continue to accomplish these conflicting goals, further developments are needed in web handling and film making technologies. Specifically our ability to quickly, easily and accurately model equipment performance and film-equipment interactions must be extended. The range of requirements is broadened as film manufactures produce more complex film structures and strive to increase overall equipment performance (line speeds, uptime, waste reduction, etc.) across a diversifying product range, and customers process BOPP using many more downstream technologies (metallizing, printing, sheeting, guillotining etc).

The objective of this paper is to further illustrate these issues and to describe some of the progress made while also indicating priority areas for further work.
ABSTRACT

Rolls of films are routinely stored under varying conditions before being unwound into downstream operations. During storage, interlayer pressures can change relative to the pressures generated during winding. These changes can lead to problems such as film blocking (increased interlayer pressure) and roll shifting/cinching (decreased interlayer pressure). To study the storage effect, a nonlinear wound roll stress model including air entrainment is first developed and applied to predict the in-roll stresses during film winding. Thereafter, a thermal stress model is used to study the temperature effect on wound roll stresses. Key inputs to the models are the stack modulus, contact clearance, and air film reference clearance. A method is developed to measure these key model inputs. Results of a parametric study show that among the processing conditions, storage temperature and thermal expansion coefficients of the core and the film are key factors that affect in-roll stresses during storage. Limitations of the models will also be discussed along with recommendations for future modeling development.
ABSTRACT

In a previous paper (Jaafar et al., 1999) we reported on the rudimentary development of a new technique for the on-line measurement of a roll’s coefficient of restitution (Cr) as it is being wound, and enunciated the theoretical underpinnings behind the development. In this paper, the Cr sensor has been used to evaluate the radial and tangential roll behavior as it is being built. Based on the experimental findings, numerical simulations are proposed for modeling, using energy-based formulations, radial modulus and tangential stress as a function of roll radius. The simulations take into account the additive effect of winding operations, and corrects for the use of such idealized setups as the stack experiment, first proposed by Pfeiffer (1966), by incorporating increasing number of layers.

In addition to basic structural assessment of roll quality in real time, a set of experiments have been devised to garner a fundamental understanding of the in-roll stress variations, based on which new insight into the constitutive relations is presented.
ABSTRACT

The quality of a wound roll is highly dependent upon the in-roll stress distribution, which is controlled by the operating parameters of center torque, nip and tension. With increasing demands for higher performance of paper winding machines in terms of higher speed of winding, wider width of web and larger diameter of wound rolls, it becomes of vital importance to determine the optimum operating conditions of the machines.

In this paper, a numerical formulation for estimating the in-roll stress of a wound roll is proposed taking account of the effect of nonlinearity in web compressibility, air-entrainment and permeance. The proposed theory of winding is based on the assumption that the accumulation of the in-roll stress by a wound-in layer can be expressed as the superposition of the stress increments calculated from a mechanical model of a pressured thick cylinder. The theory of elasto-hydrodynamic lubrication with the compressibility of air is introduced to evaluate the effect of air-entrainment at the roll-inlet. Permeance of air is newly incorporated into the winding model, which is expressed under the assumption that permeance is proportional to the pressure difference of both sides of a web.

Winding tests were conducted in order to assure the applicability of the proposed theory by usage of the dry-end section of the paper-making pilot machine under the operating conditions of 200 ~ 2000m/min in winding speed, 765mm in web width and 1200mm in diameter of the wound roll. The numerical analysis and experimental observation shows the significant effect of the air-entrainment and permeance upon the in-roll stress.
ON-LINE CONTROL OF TENSION IN WEB WINDING SYSTEMS BASED ON WOUND ROLL INTERNAL STRESS COMPUTATION

P. Bourgin\textsuperscript{1}, M. Boutaous\textsuperscript{1}, and D. Knittel\textsuperscript{2}

\textsuperscript{1}Ecole Supérieure de Plasturgie

\textsuperscript{2}University of Strasbourg

FRANCE

ABSTRACT

One of the key challenges in the processing of flexible media such as plastic films is to obtain rolls without any aspect defect: if one considers that a “defect” (i.e. wrinkling or buckling) is due to the fact that the stress generated within the roll is greater than some “plasticity threshold,” then it is crucial to predict the internal stress. Several process parameters must be carefully mastered, among which the winding tension is very important. Offline optimization of the tension can \textit{apriori} guarantee the production of perfect rolls, with respect to the internal stress. Nevertheless, the industrial control systems never generate perfect follow-up of the tension reference value, because the tension which is actually imposed (i.e. measured) exhibits oscillations due to the imperfections of the winding system, including geometrical irregularities of the rolls. The fluctuations about the tension nominal value induce variations in the stress within the roll as compared to the value which would result from an ideal control. As a consequence, it is judicious to change the tension reference value during the winding process, according to some criterion defined from the stress computed within the roll, and then to apply this new “up-dated” reference to the forthcoming web layers. This new way of online tension control requires new concepts such as “robust multivariable control,” because distributed control may not work as well.

The first step consists in computing the internal stress generated within a roll of a wound web (for instance plastic film). For that purpose, a modified non-linear model is developed in the spirit of Hakiel’s. The web’s winding process can be considered as a continuous accretion process, in the sense that the stress components at a given point are continuously modified by the upper superimposed layers. In addition, the residual air films which separate the web layers are taken into account in an indirect way through the radial Young’s modulus of the roll which is a non-linear (polynomial) function of the compressive stress component. Several illustrative examples are presented and commented. Then, having prescribed an optimization criterion for the winding tension, an optimization algorithm based on the simplex principle is described. Finally, a new concept of \textit{online} tension control, based on prediction-correction is proposed. Dividing the roll radius into several segments, the tension reference is computed and corrected for each range of roll radius values, by using the predictive model for the stress within the roll. The adjusted tension is reactualized step by step, following the optimization
principle as described above and it will be considered as the new tension reference value for the coming layers. A comparison between offline and online tension controls clearly shows the improvement given by the new optimization technique (online).
ABSTRACT

Over the past 15 years, Sonoco has conducted solid mechanics research focused on structural behavior of spirally wound, paper tubes. The scope of this program has included experimental, numerical, and analytical mechanics approaches as documented in references (1-9). As is well known from published winding models, core outside diameter stiffness ($E_c$) is incorporated into the analysis through a boundary condition. We have previously published proper $E_c$ values for paper tubes (4) and, at the last OSU International Web Handling Conference, described a method to experimentally measure $E_c$ (9). However, all published $E_c$ data was collected on cores that were supported on the ends, but had minimal radial support in the test zone. In the field, many winding processes utilize an expandable mandrel that supports the core along its entire length. Our recent research suggests that these support conditions can have a significant impact stiffening the core wall and increasing $E_c$. As $E_c$ is changed, expected stresses in the wound roll are altered. In this paper, we describe a new experimental method capable of measuring $E_c$ data for cores supported by mandrels found in some field applications. To collect this data, we modified the test device described at the last conference. We also present a Finite Element model that quantifies core stiffening from mandrel support.
ABSTRACT

Web materials are wound into coils by a variety of winders. Some winders center wind only. In this type of winding, torque is provided to a core and web winds up on the core. Other types of winders have a roller, often called a nip roller, impinged into the outer surface of the winding roller. In this type of winding equipment, the torque required to wind the rolls of web may either be provided to the core or to the nip roller and in some cases torque is provided to both. When the winding torque is provided only or mainly to the nip roller, the winder is called a surface winder. When the winding torque is provided only or mainly to the core, the winder is called a center winder with an undriven nip roller. When substantial components of the winding torque are provided to both the core and the nip roller, the winder is called a combination winder.

It has been documented that the nip roller induces an increment in tension in the outer layer of a winding roll called the nip-induced-tension (NIT). The NIT combines with a component of the web tension to form the wound-in-tension (WIT) in the outer layer of a winding roll. The magnitude of the component of the web tension that becomes part of the WIT is dependent on whether the winder is center, surface, or combination driven. An objective of this paper is to show what wound roll and winder parameters affect the WIT based upon winding experiments. A second objective is to show the derivation of an introductory model whose output yields results that are consistent with winding tests.
DEVELOPMENT OF WEB TENSION IN A WINDING NIP

M. Jorkama¹ and R. von Hertzen²

¹Metso Paper, Inc.

²Helsinki University of Technology

FINLAND

ABSTRACT

Today practically all winding devices apply a nip to the wound roll. In this winding method, radial pressure is applied by a winding drum to the wound roll at the point where the web enters the roll. This reduces the air entrainment into the roll and increases the tension of the web entering the roll. The wound roll internal stress profile is determined by this Wound-On-Tension (WOT). If the WOT along with the elastic moduli of the web are known, the internal stresses of the wound roll can be calculated. A winding simulation model predicting the internal stresses of a wound roll would provide a valuable tool for the optimal selection of the winding control parameters. When the incoming web enters the nip area, its state of stress and strain changes significantly. An evaluation of these changes without any presumptions necessarily calls for a rigorous contact mechanical solution. The aim of the present paper is to calculate the surface tractions and the WOT due to the winding nip and, hence, provide means to predict the wound roll stresses as a function of the winding parameters.

The contact mechanical model is based on the plane strain elastic solutions of the wound roll, winding drum and the wrapping and intervening web, combined with the indentation, stick and slip equations. A homogeneous elastic orthotropic material law for the roll, drum and web is used. The incoming web may slip with respect to the roll and drum, whereas slippage of the layers in the roll is not allowed (solid roll model). The stick-slip pattern within the contact zone is iterated using a variant of the Panagiotopoulos Process. Numerical calculations revealed a typical mechanism for the development of the nip-induced tension when the winding drum is hard and the coefficient of friction between the drum and web is larger than that between the web and roll. Due to the appearance of a double-sided slip zone in the vicinity of the trailing edge of the nip, the web moves faster than the wound roll and winding drum and, hence, the web tension increases. It is also shown that for a winding drum covered with a thin rubber cover, most of the web tension increase occurs at the winding drum wrap. In addition, the dependence of the nip-induced tension on the winding force, layer-to-layer friction, wound roll and winding drum radii, drum cover compliancy and the elastic constants of the web was studied numerically. The calculated results were in good qualitative agreement with the experimental ones.
STUDY OF STRESS-STRAIN RELATION FOR PAPER ROLL

K. Ärölä¹, R. von Hertzen¹ and M. Jorkama²

¹Helsinki University of Technology

²Metso Paper, Inc.

FINLAND

ABSTRACT

In the present method a wound roll of paper is loaded against a nip roller and the measured values of the nip width and the roll indentation are compared with the corresponding calculated values of the nonlinear problem. The nip width is measured by a sensitive sensor film and the roll indentation by a laser displacement sensor. The nonlinear numerical problem is solved using the Finite Element Method with four-node isoparametric quadrilateral elements and Newton-Raphson-type iteration. A suitable form of the constitutive equation and the stress state dependence of the moduli of the incremental stress-strain law will be discussed. A least squares fit to the experimental results determines the values of the paper roll elastic moduli.
ABSTRACT

In wide paper machines, gravity forces may cause excessive stresses to the paper layers of the parent roll due to bending of the reel spool. Experimental and numerical studies of these effects will be described in this paper. Experiments done by strain gage measurements and numerical techniques involved will be described in the first part of the paper. In the second part, the same phenomena are studied by using FE modeling.

First, measurement techniques of reel spool bending strains is described. Measurements are done in static loading situations using several differently reeled parent rolls. Then, a method to estimate the contact pressure distribution between the parent roll and the reel spool from the measured bending strains is presented. Calculated experimental results are compared qualitatively and quantitatively to the FE modeling of the same situation. The unknown elastic orthotropic coefficients of the parent paper roll are estimated so that the finite element calculations give practically the same results as the experiments. Finally, FE model is used for further numerical studies of different reeling recipes etc.

The most essential result of the measurements and numerical studies is that the reel spool carries the parent paper roll almost entirely at the edges of the spool causing large stresses to the paper layers in this area. The well-known fact is that most printing roll defects are found from roll sets, which are made from edge and inside part of the parent roll.

Research results have changed the design philosophy of the reel spool for various paper grades, as machines are made for heavier and heavier reels. Experimental work is much more laborious and time-consuming than numerical studies, and therefore even a bit vaguely calibrated FE model is very effective design tool for new concepts.
MODELING RUBBER COVERED NIP ROLLERS IN WEB LINES

J. K. Good
Oklahoma State University
USA

ABSTRACT

Rubber covered nip rollers have a number of applications within web lines. Rubber covered rollers are often used to nip the web against a metal surfaced roller that is driven to achieve a certain web velocity or web tension. The lamination of webs is common in web process machinery where two or more webs are bonded together under nip pressure between rubber covered roll pairs. Rubber covered rolls are also used to wring liquids from webs and prevent contamination of downstream web processes.

The complexity of rubber covered rollers is the rubber itself. Rubber is nearly incompressible. Intuitively rubber appears readily compressible but changes in shape are often mistaken for changes in volume.

The purpose of this publication include to: (1) better document some properties of rubber and (2) to examine the usefulness of two dimensional algorithms that relate the force and deformations of rubber rolls in contact with other rolls and (3) to examine the potential for extending these algorithms for use in three dimensional modeling in which the bending deformations of the roll shafts become substantial.
TRACTION IN WEB HANDLING: A REVIEW

D. P. Jones
Emral Ltd.
UK

ABSTRACT

In web processes, at least one moving machine component must drive the material through a friction force at the interface. This force, or traction, inevitably falls as speed increases, and is accompanied by a degree of slip. As a result, traction often limits productivity through constraints on product output and quality. Although there are high traction elements available for web lines, such as nips, edge grippers and vacuum pull rollers, the majority of machines still rely on driven rollers wrapped by the web. Machinery manufacturers seek to optimise the design of the traction elements by specifying layout, drive and roller surfaces, whereas material manufacturers seek web surfaces that will perform well irrespective of machine. In other situations, low traction may be desirable. A roller imparts stability to the web if traction is high enough to ensure speed matching, or if the traction is low at all times so that roller has little influence on the web. It is important to avoid intermediate situations where intermittent slip occurs.

An understanding of traction, and design tools based on validated models, are clearly desirable. The reduction in traction with speed is dependent on roughness of web and roller. Current models tend to be based on statistical descriptions of the surfaces, rather than parameters suggested from the physics of the interaction. However, the models do permit a number of subtle effects, such as web permeability and the constriction at the exit point, to be included.

When applying traction theory to a web line, it is important to know where the web and roller speeds are matched, and this cannot be designated arbitrarily. Furthermore, adjustments of one roller speed can result in a remote roller moving from speed matched to a slip situation. A model, validated at low speeds, will be used to demonstrate these effects.

Traction also provides force perpendicular to the direction of web travel. Loss of traction may occur if the vector sum of lateral force and tension change is greater than the available friction force, causing web movement sideways. Also, lateral traction and slip are important in determining wrinkling and scratching on a roller.

Deviations from elastic web behaviour reduce available traction. The areas of speed matching no longer have constant tension, and extra zones of slip may appear. As an example, a model of a thermal vapour deposition on a film on a cooled drum will be described. The heat load causes thermal expansion, which tends to reduce tension in the machine direction and generate lateral compression. If the tension is too low, wrinkles form, and are set in as the material lifts off the drum and rapidly heats up.
REAL TIME DYNAMIC SIMULATION FOR CONTROL SYSTEM SOFTWARE VERIFICATION

R. Bettendorf
Metso Paper, Inc. (Valmet)
USA

ABSTRACT

It is a common practice in the paper industry to verify large portions of the control system software during machine commissioning. This is inefficient since the verification is done under production conditions when time is limited and delays are costly. The reason for this practice is that the machine, the drives, and other equipment are not integrated before installation and therefore no trial runs can be made with a web.

This paper describes a method for software verification using dynamic real time simulation. Primitive elements derived at the Web Handling Research Center are combined to form a system of simultaneous differential equations that model the behavior of the drives and the web. The system of equations is implemented in a programmable logic controller and solved in real time using a numerical integration algorithm. The outputs from the actual control software are used as inputs to the model and the simulated state variables are used as feedback for the software. This makes it appear to the software that all equipment has been integrated with the machine and a web is present.

Results are shown from a real time simulation that was successfully used on a winder rebuild to verify unwind brake tension control software. These results are compared with data from the actual machine. The differences and similarities are discussed with respect to the software verification process.
THE ROLE OF ACTIVE DANCERS IN
TENSION CONTROL OF WEBS

P. R. Pagilla, L. P. Perera, and R. V. Dwivedula
Oklahoma State University
USA

ABSTRACT

This paper investigates the role of active dancers in attenuation of web tension disturbances in a web process line. A general structure of the active dancer is considered; an input/output model is developed for analysis and controller design. Three types of control designs were investigated for the active dancer: proportional-integral-derivative controller, internal model based controller, and linear quadratic optimal controller. An open-architecture experimental platform is developed for conducting real-time control experiments using the active dancer system. Data collected from an extensive set of experiments using the three control designs validate the usefulness of the active dancers in a web process line. We present a representative sample of the experimental data in this paper.
CONSIDERATIONS IN THE SELECTION OF A DANCER OR LOAD CELL BASED TENSION REGULATION STRATEGY

D. H. Carlson
3M
USA

ABSTRACT

Two methods are predominantly used to control tension in web lines: a position regulated dancer roller strategy or a regulator based on tension feedback from a load cell. Dancers are most typically used on the unwind or rewind sections; sometimes they are applied on interior machine sections with special requirements, such as a rapidly changing web span lengths. Load cell control has predominantly been used on the interior machine sections, although it is also applied on unwind and rewind sections.

There has been much controversy and debate in the industry on the benefits and limitations of dancers as compared to load cell tension control. Web handling equipment suppliers offer varying and often contradictory reasons for making this selection. At the 5th International Web Handling Conference, J. J. Shelton of the Oklahoma State University published a paper that analyzed the performance of dancers and fixed span tension sensing rollers, and pointed out some limitations of dancers at higher frequencies. Another paper at this conference by J. P. Ries of DuPont suggested that load cells were better at low frequencies, dancers at mid frequencies, and they provided comparable performance at high frequencies. Other literature makes different claims on the drawbacks and benefits of these two methods.

This paper attempts to align and clarify this variety of viewpoints by presenting measured data on an actual webline. Comparisons are made between these measured results and the results predicted by these papers. In addition, this paper also presents some pragmatic considerations in the selection of either dancer or load cell tension regulators.
STRIP TENSION CONTROL CONSIDERING THE THERMAL STRAIN IN MULTI-SPAN SYSTEMS WITH TEMPERATURE CHANGE

K. H. Shin¹, J. I. Jang¹, and G. Y. Kim²

¹KonKuk University
²Research Institute of Industrial Science & Technology

KOREA

ABSTRACT

The mathematical model for tension behaviors of a moving web by Shin [1] is extended to the tension model considering the thermal strain due to temperature variation in furnace. The extended model includes the terms that take into account the effect of the change of the Young’s Modulus, the thermal coefficient, and the thermal strain on the variation of strip tension. Computer simulation study proved that the extended tension model could be used to analyze tension behaviors even when the strip goes through temperature variation.

By using the extended tension model, a new tension control method is suggested in this paper. The key factors of suggested tension control method include that the thermal strain of strip could be compensated by using the velocity adjustment of the helper-rollers. The computer simulation study was carried out to confirm the performance of the suggested tension control method. Simulation results shows that the suggested tension control logic not only overcomes the problem of the traditional tension control logic, but also improves the performance of tension control in a furnace of the CAL (Continuous Annealing Line).
MODELING AND H∞ ROBUST CONTROL FOR WINDING SYSTEMS

H. Koç¹, D. Knittel², M. de Mathelin², and G. Abba³

¹Siemens AG
   GERMANY

²University of Strasbourg
³University of Metz
   FRANCE

ABSTRACT

This paper presents the modeling and the H∞ robust control for an elastic web transport system including an unwinder, a winder and a traction motor. This model has been created using laws of Physics concerning elasticity of the web, friction between web and roll, and web speed between two rollers. In this paper, a novel linearization of this model allowed us to predict the relationship between web tension and speed more precisely than previous simplifications.

During the winding process the radius and inertia of the rollers change substantially. In order to eliminate system sensitivity to these variations, gain scheduling control was used. In addition, multivariable H∞ control in our linear model allowed us to effectively decouple web speed and tension. Multivariable control performance was compared with performance of the standard industry decentralized PID control. Results were validated on our experimental webline.
THE EFFECTS OF AIR ENTRAINMENT ON VACUUM DRIVE ROLLER TRACTION

J. N. Dobbs
3M
USA

ABSTRACT

Vacuum assisted drive rollers are commonly used to provide additional traction in web tension control schemes. Single-sided web contact makes them a natural choice between a coating station and an oven where lower tensions are often desired. Many vacuum rollers are designed by the manufacturer according to customer provided specifications, and very little is published on their effective traction capacity where air entrainment is significant. In this paper, an empirical study is carried out to measure the traction on a vacuum drive roller as a function of vacuum level, web tension and speed. Loss of traction is determined by measuring the differential velocity between the web and vacuum roller surface in conjunction with the inability to maintain a programmed tension differential across the roller. Comparison is made between experimental measurements and the traction that would be expected for a simply wrapped roller.
When web materials (paper, plastic films, or metal foils) are wound into rolls, excessive amounts of air can be entrapped between layers of the web, resulting in defective rolls. Entrapped air layer between a coated film and a heating/cooling drum can significantly reduce the heat transfer rate. The most widely adopted method for reducing the amount of entrapped air in winding rolls and at heating/cooling drums is to use a nip roller, which pushes down on the incoming web. A computational method was used to determine the amounts of air passing through the nip on the two sides of the web. The study model included the effects of air compressibility, but it was assumed that the two rolls are rigid. Main variables included the wrap angle of the incoming web, web speed, nip force, and diameters of the rolls. It was found that, when the nip force is not very small and the two rolls are rigid, the amounts of air on the two sides of the web are nearly the same and can be determined using a simple model which includes only a rigid roller and a flat surface.
ON-LINE TENSION PROFILE OPTIMIZATION VIA MOISTURE PROFILE CONTROLS ON THE NEWSPRINT PAPERMAKING PROCESS

J. Kniivilä
Metso Paper Automation, Inc.
FINLAND

ABSTRACT

This paper describes a novel multi-profile control, which can simultaneously optimize both moisture and elongation and/or tension profiles of newsprint grades. The controller can include tension profile measurement [1][2] in its optimization to be able to optimize elongation changes in the newsprint.

The relationship between tension, shrinkage and elongation will be explored to enable understanding of how elongation changes can be optimized. Furthermore, differences between tension profile as a property of the papermaking process and as a property of paper will be discussed.

This paper also focuses on an implementation of the new multi-profile control system for the newsprint machine. The implementation as well as experiences from the controller are explored, and mill results presented.

Additionally, the paper explores what is required from the newsprint machine and the automation to be able to have an elongation and/or tension and moisture optimizing profile controller.
MODELING THE TENSION OF THE PAPER WEB

S. Vuorinen and M. Parola
VTT Information Technology
FINLAND

ABSTRACT

The tension distribution of a paper web in a paper machine is typically uneven and the edges of the web are normally slacker than the middle areas. This contributes to many problems not only in the paper making process but also in the printing press. The formation mechanisms of the tension distribution are not well known.

The traditional approach in tension-related studies has been to handle paper as a one-dimensional string. However, this approach is not adequate to the study of three-dimensional moving webs. It is important for papermakers and printers to achieve good runnability and thus minimize the waste of paper. The improvement of runnability requires a better understanding of paper web dynamics and tension variations during the process in both the machine and cross directions. Stretching the paper web in the machine direction causes a non-homogeneous stress field in the web because the paper is subjected to mechanical shrinkage defined by the Poisson ratio of the paper. This typically causes a situation where the edges of the web are slacker than the middle areas. The cross directional tension is also an important factor that may have a crucial effect on the forming of wrinkles, for example. In this study factors affecting the machine directional tension were studied numerically and the known tension field theory distribution was examined.

Viscoelastic paper is a challenging material in terms of both modelling and web transport systems. In this study the finite element method (FEM) was applied to the modelling of the paper web. The models built were evaluated by tension measurements on a production scale. In the case of free open draw, the development of the tension field was studied.

The influence of mechanical conditions, such as guiding rolls, was modeled in press room conditions. Steady state analysis was performed for a moving paper web. The modeling results gave a better understanding of web transportation and FEM appears to be a promising tool for analyzing paper web behavior in different web handling systems.
WEB BAGGINESS: MAKING, MEASUREMENT AND MITIGATION THEREOF

D. R. Roisum
Finishing Technologies, Inc.
USA

ABSTRACT

Web bagginess is a defect so tenacious that few machines will totally escape its grip. It is so pervasive that it can be found on materials as diverse as tissue, writing paper, carpet, nonwovens, plastic film and steel. It is so chameleon-like in its appearance that it is given many aliases such as baggy lanes, camber, layflat, puckers and many more. Yet as common as this ailment is, objective measurements are tedious or fraught with uncertainty or both. This means that culling and rejection is typically done by subjective visual appearance. As common as this ailment is, few can take a specific baggy lane and point to the machine element that made it, much less how it was made.

This paper begins by defining bagginess in three entirely equivalent ways based on variations of flatness, stress and strain. It then develops a taxonomy of bagginess by classifying the general case into major groups depending on how the stress variations are distributed. Next, it discusses all of the common and most of the arcane means of measurement. Each is described by principle of operation, application and practical difficulties. Next, the more common sources of bagginess, such as nonuniform formation and yielding during handling are described. Finally, a methodology is developed for troubleshooting bagginess whose source is not certain.
A NEW OBJECTIVE METHOD FOR QUANTITATIVE ASSESSMENT
OF CUT EDGE QUALITY FOR PAPER AND BOARD

E. G. Welp, E. Wolf, J. Heindl
Ruhr-University Bochum
GERMANY

ABSTRACT

In the paper converting and finishing industry the cut edge quality is of particular importance to the manufacturing processes, e.g. the printing process. In this paper an objective method for the quantitative evaluation of the cut quality of thin, plane materials is presented. In a first part of this paper existing procedures for the evaluation of the cut quality are analyzed. Afterwards the own method, consisting of two essential elements, is presented. The first element is the measurement data logging by use of a CCD line camera and the second one, is the measuring data evaluation with a self-developed software. The capabilities of the developed method are demonstrated on evaluating cutting edges of four thin, plane materials. The results show that the procedure is suitable to differentiate cut results sufficiently and to transfer them into quantified quality grades in reproducible manner.
ABSTRACT

Shear slitting of a 25.4 µm thick polypropylene web was conducted on a laboratory slitter using a pair of rotary blades at a constant speed up to 5.08 m/s under controlled tension. The effect of web speed on the slit-edge burr height of the web is investigated for the thick polypropylene web. A profilometer was employed to measure the edge profile. Experimental results indicate that the burr height decreases with web speed when other slitting parameters are fixed. To overcome the difficulty in observing the in-situ shear slitting process of the polypropylene web, a rubber sheet was also used in the present study for the observation of the deformation process during shear slitting, and the surface deformation field of the rubber was measured by a digital image correlation method. The finite element simulation of the early stage of rubber slitting process was performed using commercial ABAQUS code and numerical results are in good agreement with those observed in experiments. The experimental observation and the numerical simulation show that shear slitting of rubber initiates with an indentation process, followed by deformation localizations around the slitter blades; the final stage is a tearing process.
ABSTRACT

It has always been problematic to accurately sense a nonwoven (spunbond) material edge by an analog photoelectric or ultrasonic means. A sensor based on analog photoelectric or ultrasonic detection determines the lateral displacement of the web by measuring the amount of signal the web blocks. For opaque materials, this sensing technique is sufficient with some concerns about the environmental effect on the detector, as well as the sensor linearity, depending on the size of the detector that is derived from the sensor proportional band requirement. However, for nonwoven materials with varying degrees of web opacity, the above-mentioned sensing scheme does not reflect accurate edge sensing by measuring the amount of signal the web blocks as seen by the detector. The light or ultrasonic signal from the transmit side can easily penetrate the nonwoven loosely bound area without any signal attenuation and can, therefore, cause the analog detector to see an average value of the signal it receives. The average received signal varies due to web opacity variations, and cannot be used to produce an accurate representation of the edge of the web. Also, frequency response of the analog detection circuitry dictates how much error it will generate based on the effect of web speed, as well as opacity variations. The slower the detector response, the less variation due to web opacity it sees for higher web speeds. Again, a slow detector response is undesirable in high-speed guiding and slitting applications.

Our goal is to design a photoelectric sensor for accurate edge sensing of nonwoven materials by disregarding the influence of web opacity variations. It also needs to be highly immune to environmental factors such as temperature and contamination, etc. The proposed method uses a digital linear image detector-based edge scan sensor in conjunction with collimated infrared light source. The light source is applied to the web in a retroreflective configuration by using a 180-degree light foldback prism. To prevent detection error due to opacity variation, this method uses a first edge detection technique. In this way, the sensor only responds to the true edge of the web and may avoid problems related to the light source passing through the material.
OBSERVATIONS ON THE VIBRATIONS OF PAPER WEBS

A. Raman\textsuperscript{1}, K.-D. Wolf\textsuperscript{2}, and P. Hagedorn\textsuperscript{2}

\textsuperscript{1}Purdue University
USA

\textsuperscript{2}Darmstadt University of Technology
GERMANY

ABSTRACT

Frequency clustering and edge vibration localization of thin, wide, high-speed translating webs are investigated using a linear, translating, tensioned Kirchhoff plate model with very small but finite bending stiffness to tension ratio. Non-uniform tensioning, and vibration coupling of the web with an incompressible potential flow are included in the model. Such webs are commonly found in paper, plastic, polymer sheet and metal foil processing, in gravure and offset web printing machines, and in magnetic and optical tapes. The presence of frequency clusters, its impact on free edge vibration localization, and its dependence on transport speed, and non-uniformity of tension are analyzed using a Galerkin discretization of the equations of motion. Experiments are performed on an acoustically excited, stationary, taut paper web. The experimental results demonstrate clearly the presence of frequency clustering and its dynamic effects. The results are expected to have significant implications for the further studies on the modal analysis and nonlinear mechanics of high-speed web systems.
ABSTRACT

This paper gives a brief description of the evolution of technical knowledge. The evolution of beam theory is given as an example from the field of strength of materials. Technical knowledge starts with information gained from early experiences. These experiences are enhanced with empirical data gained through experimentation. Theories are developed to help explain the observations and experimental results. First principle understanding (models) are developed and experimentally verified. Over time these principles prove valuable and gain acceptance.

Published web handling information is reviewed and evaluated on this evolutionary scale for the topics of: winding, longitudinal dynamics and tension control, wrinkling, lateral mechanics, traction, air support conveyance, measurement/sensors, air entrainment, slitting and nip mechanics. Direction is given for future research needs in these technology areas.
LATERAL MECHANICS OF AN IMPERFECT WEB

J. E. Olsen
Norwegian Pulp and Paper Research Institute
NORWAY

ABSTRACT

A model describing the lateral mechanics of an imperfect web has been derived which brings forward information on the much debated fourth boundary condition. The model is based upon a generalized beam theory. Calculations show that a web with CD profile in stiffness and/or frozen-in strain (camber) will shift towards the low tension side. The deflection increases with increasing tension and decreasing stiffness. The dependence upon tension is related to the stiffness profile. A web with a constant profile in stiffness, but with a varying profile in frozen-in strain, has a very weak influence of tension upon deflection.
A SIMPLIFIED MODEL FOR LATERAL BEHAVIOR OF SHORT WEB SPANS

J. J. Shelton
Oklahoma State University
USA

ABSTRACT

For ratios of L/W less than approximately 2.0, the effects of shear stresses on the shape of a web must be considered. In basic manufacturing and processing of webs, such ratios are very common. The analysis of a general Timoshenko beam is extremely complicated for some problems, such as the dynamic effects of the interconnection of spans, so that simplification may facilitate solution and enhance understanding.

The basis for the simplification is the fact that tension has no effect on the shape of the elastic curve if L/W is very low, so that the elastic curve of the web can be expressed as a polynomial in \(x\) instead of exponential or hyperbolic functions of \(x\) as necessary if L/W is large. Mathematical analysis thus becomes easier, and the results can be expressed in simpler, more understandable form.

Static problems, such as the critical angle of misalignment of a roller from the standpoint of slackness of an edge, are analyzed and the results are compared (for low L/W) to the solution of the Timoshenko beam (general L/W ratio) as presented in the Shelton thesis [1].

Superposition of the effects of translation and rotation of the upstream inputs and the downstream outputs allows analysis of the effects of interconnection of spans. A method of reducing “weave regeneration”, the downstream reappearance of an error which was corrected by a web guide as studied by Sievers [2], is shown to be the modification of ratios of L/W to uncommon values. Specifically, the guiding span should have a large ratio of L/W, and the exiting span of the guide should have a fractional value of L/W for reduction of weave regeneration.
EMPIRICAL INVESTIGATION OF WEAVE VERSUS WEB-TO-ROLLER TRACTION IN FLOATING LOOP DRYERS

R. L. Walton
Eastman Kodak Company
USA

INTRODUCTION

This report details the results of a laboratory experiment to better characterize the behavior of floating-loop dryers with respect to web-to-roller traction. The results show that roller traction primarily affects the frequency at which weave is amplified in a floating-loop dryer. Increased traction increases the frequency of weave amplification, which then requires more responsive web guiding equipment to control weave.
A multi-span model that predicts the lateral response of webs to changes in the upstream position of the web and any type of motion of the included rolls is presented. The model uses a beam approximation for the deflection in the web spans. The actual, rather than idealized, web spans, roll diameters, wrap angles and sensor locations are used. Equations are derived including web span interactions, roll motion such as occur in steering devices and feedback control systems. Example cases are included showing the value of this type of analysis and accuracy through comparisons with experimental results. Web steering devices of different types are used widely both to control the web in less than ideal circumstances and to accurately position the web for key operations in processes. The design of these devices is often based on idealized configurations that don’ t fully match the geometry of the equipment in question. As a result problems arise such as non -stable operation, web oscillation downstream of the guide system and the formation of shear wrinkles. The work presented here describes a method of analyzing an entire web path including steering devices and evaluating the respond of the system to all sorts of dynamic inputs. A computer program is described that can handle up to a 10 span system.
ABSTRACT

The focus of this paper is on lateral control of a web using estimated motor velocity feedback. A reduced state velocity observer is designed to estimate the motor velocity based on the measured lateral position of the web and the motor input. Estimated velocity is used for inner-loop motor velocity feedback instead of measured velocity from a tachometer. Two approaches are investigated in the design of the reduced state velocity observer; the first is based on the motor dynamics and the web lateral dynamics and the second is based on the motor dynamics and the static gain of the web lateral dynamics. The second approach results in a simple low-order velocity observer when compared to the first approach.

The proposed designs are experimentally investigated on a Fife remotely pivoted steering guide. The performance of the lateral control system with estimated motor velocity feedback is compared with the tachometer feedback and results are discussed. Representative experimental data from the two approaches indicated above is presented. Experimental results on the example considered shows that the observer can successfully replace the tachometer to close the inner velocity loop in lateral control systems.
ABSTRACT

A long web span supported by many, regularly spaced, alternating air-bars is studied. The focus is on the lateral forces on the web due to the interaction of lateral curvature with out-of-plane deflections. The effect of stretching of the elastic web material is included, and the effect of high web speed is handled by distinguishing between the tension in the material $T_{\text{mat}}$ and the apparent tension $T_{\text{app}} = T_{\text{mat}} - \mu v^2$.

The governing Partial Differential Equations for a continuous representation of the web’s lateral deflection, stability, and control is developed for both straight and cambered webs. The dimensionless parameters for web-tension effect, web-camber effect, and stretching effect are identified.

The influence of tilted air-bars is studied, towards developing a control mechanism to compensate for camber.
A REGULATION CONCEPT FOR WEB SPREADING EQUIPMENT IN WEB PROCESSING MACHINES ON THE BASIS OF NEURAL NETWORKS

E. G. Welp, D. Wang, and A. Kleinert
Ruhr-Universitaet Bochum
GERMANY

ABSTRACT

Web spreading systems are used in converting machines in order to guarantee a folding free web transport and a sufficient slit gap or slit separation. The adjustments, dependent on the respective application, are carried out manual before and during the operation. Wrong machine adjustments lead to productivity and quality losses. On this background a general regulation concept for web spreading systems, which is based on neural controllers is presented in this paper. The regulation concept is used for the regulation of the slit gap formation and applicated on the example of a dual spreader. The basic component of the controller is a controlling strategy which contains a mathematically describable, idealized operating range. All other, only qualitatively describable influence variables are declared as fuzzy data and included into the data base of the neural controller as training sets. First results show that neural controllers are suitable for the automatized operation of web spreading systems and can be drafted and simulated with passable operating expense.
ABSTRACT

Contraction of a web in the cross width direction while running over rollers can be traced to runability problems and wound roll defects. These defects may include troughing, baggy lanes, wrinkles and registration difficulties on the machine and creases in the wound roll. Web spreading devices have long been used in industry to restore the moving web to a taught width. At IWEB 4, Swanson [1] presented cases for the effectiveness of ten such devices along with simple models to calculate their ability to spread the web. This presentation extends the previous work by looking at two devices, the parabolic and the “bow tie” shaped rollers, and presents the mathematical derivations used to calculate the spreading ability of each roller. In each case, equations will be presented that, given a reduction in web width, a roller profile may be designed to restore the web to its original width.
Keynote Presentation

Strategies for Competitiveness .................................................................
J. Simons

Session 1 – Longitudinal, Out-of-Plane, & Lateral Web Mechanics/Dynamics

Robust Control Design Using H-Infinity Methods in Large Scale Web Handling Systems ............................................................................................................
D. Knittel

Real Time Dynamic Simulation of a Paper Winder ................................
R. Bettendorf

A Comparative Study on Active and Passive Dancers Used for Attenuation of Web Tension Disturbances .................................................................
R. V. Dwivedula, Y. L. Zhu, and P. R. Pagilla

Detection and Characterization of Web Vibrations by Artificial Vision ........
C. Doignon and D. Knittel

Vibration and Stability of Axially Moving Webs Coupled to Surrounding Air .................................................................
M. D. Vaughan and A. Raman

Installation and Performance of Classical Web Guides ................................
J. J. Shelton

Shear Effects and Dynamics of Imperfect Webs ................................
J. E. Olsen

Buckling of Orthotropic Webs in Process Machinery ..........................
J. K. Good and J. A. Beisel
Thinking Thin? .................................................................................................................................
D. R. Roisum

**Keynote Presentation**

A Future Online Concept for Roll and Sheet Production in Papermaking – Technology and Process Requirements for Web Handling .................................................................................................................................
E.G. Welp

**Session 2 – Air Entrainment & Traction**

Macroscopic Effects of Surface Roughness in Confined Air-Flow ........................................
P. Bourgin and M. Boutaous

A Simple Model to Predict Web-to-Roller Traction.................................................................
B. S. Rice and R. F. Gans

Prevention of Web Floating at Wrapped Transport and Guide Rollers ...........................
E. G. Welp, A. Kleinert, and D. Schuler

Traction Force Between Rotating Roll and Moving Web Considering the Effect of Air-Entrainment and Friction .................................................................................................
M. Sasaki, K. Tanimoto, K. Kohno, Sadamu Takahashi, and S. Suzuki

A Two-Dimensional Model for Web-to-Roller Traction at Small Wrap Angles..........................
B. S. Rice and R. F. Gans

Aerodynamic Forces of a Coanda Air Jet.............................................................................
E. Y. Hong and Y. B. Chang

**Session 3 – Slitting, Curl, & Idler Performance**

Issues in Modeling Slitting of Magnetic Tapes.................................................................
R. Andruet, R. Cook, and W. Qualls

Characterization of a Slit Edge Using Image Analysis ....................................................... 
H. Viswanathan and H. Lu

Optimized Slitting Parameters for the Shear-Slitting of Paper...........................................
E. Wolf and E. G. Welp

Finite Element Simulation of Shear Slitting of Aluminum Webs........................................
H. Lu, B. Wang, J. Ma, H. Viswanathan, and M. Li
Calculating Coilset Based on Curvature of a Web ...........................................................
R. Comeau

Practical Application of Idler Roller Performance Measurements and Models ...........................................................
T. J. Walker

Keynote Presentation

The Effects of Nonideal Webs on Roll Winding ........................................................................
K. A. Cole

Session 4 – Winding

Wound Roll Generated Unstable Vibration ............................................................................
M. Jorkama and R. von Hertzen

The Effect of Air-Side Leakage in Roll Winding ....................................................................
H. Lei and K. A. Cole

A Study of CD Elongation of Core in Winding ......................................................................
M. Ilomaki and M. Jorkama

Out-of-Round Paper Rolls ....................................................................................................
D. McDonald, J. Hamel, and A. Menard

A Method for Measuring Wound-On-Tension ......................................................................
J. Paanasalo

Strain-Inducing Mechanism of a Rolling Nip on a Paper Stack .............................................
K. Arola and R. von Hertzen

Wound-On-Tension for Two Drum Winders ..........................................................................  
J. K. Good, B. R. Cowan, L. E. Dolezal, and R. Markum
As technology has evolved and matured, we begin to see common practices or standard methods applied to solving problems. We can become very comfortable in the application of these methods because we know they work. There are many control system web handling techniques that are well proven. Today’s advanced drive technology makes these easy to apply and adapt to changing process requirements. There is little risk in using them because they have been proven again and again over time.

Risk aversion is natural but what are the long term effects on overall competitiveness? How much risk is prudent? How do you decide to apply new technologies while also economically minimizing the risk?

Obviously, when new technologies provide significant competitive advantage, it is clear that a company should invest appropriately to minimize the risk and offer the new solution to your customers. New innovative technologies are a clear way to provide market place differentiation. One could wonder, though, how often these opportunities are being missed in today’s economic environment.
ABSTRACT

This paper presents H∞ control strategies for elastic web transport systems. The aim is to reduce the coupling between web tension and web transport velocity. First of all, a multivariable H∞ centralized controller with or without gain scheduling is synthesized for a 3-motor plant composed of an unwinder, a tractor and a winder. This controller is then compared to a semi-decentralized weighted controller with overlapping. The influence of the weighting coefficients is shown on simulation results obtained from a non-linear model identified on an experimental bench.

Web handling systems are generally of large scale and it is not possible to synthesize a centralized controller for such scale. Therefore the global system is split in several subsystems (we have chosen 3-motor subsystems), each subsystem is controlled independently by its own H∞ controller. The subsystems can be overlapped or not. Simulation results are given on a non-linear 9-motor model.
REAL TIME DYNAMIC SIMULATION OF A PAPER WINDER

R. Bettendorf  
Metso Paper, Inc.  
USA

ABSTRACT

Typically, large portions of the winder control system software are tested during the commissioning process. This is inefficient since production is shut down and financial pressures limit the time available for testing. The reason for this practice is that it is not economically feasible to integrate the winder and the electrical drive system before the installation.

Recent advances in the computational capabilities of programmable logic controllers (PLCs) have made it possible to simulate the winder, web, and drive system dynamics in greater detail than was previously possible. Shipping roll build up, parent roll build down, additional web spans, mechanical brakes, and more sophisticated drive regulation algorithms can now be simulated in real time. The increased realism allows additional control system software features to be tested before winder installation.

This paper describes a winder simulator that was used to test control system software and train operators before a new winder was installed. The simulator consisted of a dedicated PLC that solved differential equations in real time in order to model the dynamic behavior of the winder and web. The web tension and speeds of the winder model were controlled by difference equations that simulated various drive regulation algorithms. The simulator PLC used these models to provide signals for the winder PLC that would normally be supplied by the drive system and sensors on the winder.

The simulator was verified by comparing the data it generated to data from a previously installed winder. A discussion of how the simulator was used before the installation of a new winder identifies the benefits of pre-installation software testing and training.
A COMPARATIVE STUDY ON ACTIVE AND PASSIVE DANCERS USED FOR ATTENUATION OF WEB TENSION DISTURBANCES

R. V. Dwivedula, Y. L. Zhu and P. R. Pagilla
Oklahoma State University
USA

ABSTRACT

A dancer mechanism, used in most of the web process lines, consists of a roller which is either connected to a fixed support by passive elements such as springs and dampers or is force loaded in opposition to the web tension. Dancer mechanisms are commonly used to attenuate web tension disturbances caused by uneven wound rolls, eccentric rollers, misalignment of idle rollers, and slacks in webs. A dancer mechanism is also used as a feedback element in a number of web tension control systems. The tension control system is driven by the variations in the position of the dancer mechanism as opposed to the variations in actual tension from the desired tension.

Since a substantial number of web process lines in web handling industries use. Dancer mechanisms, there is need for a systematic comparative study of different types of dancer mechanisms and their applicability; the focus of this paper will be on such a study. Active and passive dancers will be compared using analytical models; a representative sample of the most common dancer mechanisms will be considered. The results of this analysis will assist in the selection of the dancer mechanism and its components, design of the dancer mechanism, and the effectiveness of a particular dancer mechanism to reject different types of web tension disturbances. Also, to substantiate the fundamental analysis, results from experiments, for certain situations, will be shown and discussed.
ABSTRACT

In this paper, we address the problem of the detection of transverse web vibrations by means of a digital camera and a laser dots pattern device. For this purpose, we briefly present some video processings which yield an accurate location of the projection of laser dots in the image. However, the main contribution of this work is in the new approach developed for estimating, on-line, transverse web vibration frequencies with a geometrical method and without contact. To do so, some techniques commonly used in the computer vision field are extended to some classes of non-rigid objects suitable to account for a part of an elastic web. Finally, we compare the estimated frequencies with those provided by a simple vibrating elastic string model, in motion.
ABSTRACT

High-speed web flutter is of significant importance in a variety of paper, plastics, textiles, and sheet metal industries. The natural frequencies of vibration and the onset of flutter in thin, wide, high-speed webs are investigated by modeling the web as an axially moving, partially slack Kirchhoff plate with small bending stiffness, and coupled with surrounding air. The linear partial differential equations of the web are discretized using the Assumed Modes Method and analyzed for two different air models – incompressible and compressible flow. The solutions for the aerodynamic potentials and determined numerically and accurate reduced order models of the moving web with air coupling are generated.

In the absence of air coupling the web frequencies are grouped together in clusters and aeroelastic flutter occurs at supercritical speed. Addition of incompressible potential flow air coupling reduces significantly the web frequencies and separates the frequency clusters while modifying slightly the onset and frequency of flutter at supercritical speed. Compressible flow modeling adds radiation damping to the system and shifts the onset of flutter to the critical speed. Finally it is concluded that the prediction of web flutter at subcritical speeds requires the inclusion of base flows generated by air viscosity and web motion. These results corroborate previous results in the literature and suggest systematic analytical modeling approaches for web flutter prediction.
ABSTRACT

This paper depicts proper installations of conventional web guides and examines the theory of web mechanics and the theory of automatic control as foundations for the practice of web guiding. Conditions which would damage the web are quantified. The adverse effects of interaction of spans and avoidance of such interaction are discussed.

Limitations to accuracy of conventional web guides are discussed. Unusual but proven variations for satisfying special needs are presented.
A mathematical model describing the lateral dynamics of an imperfect web has been derived. The model includes the effect of shear forces. This was enabled by the development of a theory for beams of inhomogeneous materials. Calculations show that an inhomogeneous beam or a web with widthwise variations in material properties will bend towards the low tension side. The shear effect is significant.
ABSTRACT

Many webs in web process machinery exhibit out-of-plane deformations, defined as troughs, in free web spans between rollers. In other cases when the troughs become severe the out-of-plane web deformations will begin to transcend rollers. Any out-of-plane web deformations that transcend rollers are defined as wrinkles. Troughs and wrinkles in webs are often undesirable as they can interfere with web processes such as coating, they can result in web breaks and thereby decreased productivity, or these deformations may become permanent and result in quality loss.

Many plastic film, paper, tissue and nonwoven webs are highly anisotropic either by design or just as a result of the process by which the web is made. The first objective of this paper is to show how anisotropic web properties affect the buckling and wrinkling tendencies of these webs. Previously algorithms have been developed that show how roller misalignment can induce troughs and wrinkles. The second objective of this paper is to demonstrate how web orthotropy can affect the allowable roller misalignment in a web span and the web tension required to sustain a wrinkle upon a roller.
THINKING THIN?

D. R Roisum
Finishing Technologies, Inc.
USA

ABSTRACT

Markets drive us to ever thinner webs to reduce material costs and waste going to the landfill. The challenges for running a lighter basis weight or thinner caliper are at least as difficult for web handling as they are for web manufacturing. However, these challenges may not be as familiar as more commonly known machine limitations such as width or speed. Because they are not as familiar, they may catch us off guard. The challenges described in this paper include: wrinkling, air entrainment, tension control, roller design, problems associated with profile variations and others.
A FUTURE ONLINE CONCEPT FOR ROLL AND SHEET PRODUCTION IN PAPERMAKING TECHNOLOGY AND PROCESS REQUIREMENTS FOR WEB HANDLING

E. G. Welp
Ruhr-University Bochum
GERMANY

ABSTRACT

The process of on-line converting is discussed as a chance to increase the productivity and quality in roll and sheet converting in paper mills. In this article the technical and process related prospects will be presented on the basis of an exemplary production line (WFC Paper) and transferred into realizable concepts for continuity paper converting.

In the case of roll production, the segment of large rolls with standard sizes is very suitable for an on-line-production, and in the case of sheet production the segment of larger lot sizes. In both cases a new machine design with altered functions and a higher level of automation and process control is necessary.

These alterations yield diverse requirements for web and sheet handling, which have to be fulfilled for a continuous and high-quality production. All fundamental technologies such as transport mechanics of webs and sheets, winding and stacking mechanics, slitting in length and cross direction as well as measurement and control techniques for the monitoring of converting processes in particular belong to this category. These technologies will be discussed and further tasks for research work will be presented.
ABSTRACT

One challenge when processing flexible media such as plastic films is to obtain rolls without any aspect defect: if one considers that a “defect” (i.e. wrinkling or buckling) is due to the fact that the stress generated within the roll is greater than some “plasticity yield”, then it is crucial to predict the internal stress state.

Several process parameters must be carefully mastered (winding tension, velocity, etc.) as well as the material pertinent properties. One key issue is to optimize the surface topography of the flexible medium so that to improve the quality of the wound roll.

We propose here new parameters which describe the surface roughness of plastic films fairly well. The measurements were carried out by using a 3D roughness measurement device.

A mathematical model based on homogenization techniques is proposed, where the heights of the roughness peaks, their diameter and their spatial distribution are the governing parameters.

Sampling at different levels is carried out by expressing the percentage of peaks which exceed some given threshold value.

For each tested film, the threshold value will be the only adjustable parameter.

Introducing these parameters into the mathematical model which predicts the evolution of the squeezed air layer and comparing to the experimental data, the following results are obtained:

- It is possible to adjust one single parameter so that to obtain a very good agreement between the experimental data and the theoretical results.

- The smoother the film, the more important the highest peaks are in terms of air leakage.
A SIMPLE MODEL TO PREDICT WEB-TO-ROLLER TRACTION

B. S. Rice\textsuperscript{1} and R F. Gans\textsuperscript{2}

\textsuperscript{1}Eastman Kodak Company
\textsuperscript{2}University of Rochester
USA

ABSTRACT

We have studied the traction developed between a thin, flexible web and a rotating cylindrical roller. We present a new analytic model for high-wrap, circumferentially grooved rollers that couples air film pressure, web deflection, and asperity contact to predict traction. Our model predicts the “steady state” (far from the ends of the lubrication region) air pressure between the web and roller by judicious use of the foil-bearing concept. We verified our new model experimentally for non-grooved and high-wrap, circumferentially grooved roller surfaces. We have derived dimensionless groups that the roller designer can use to quantitatively assess the interactions of process variables (e.g., speed and tension) with design variables (e.g., groove depth, groove pitch, roughness, etc.). We also give a dimensionless group that quantifies the term high wrap.
PREVENTION OF WEB FLOATING AT WRAPPED TRANSPORT AND GUIDE ROLLERS

E.G. Welp, A. Kleinert and D. Schüler
Ruhr-University Bochum
GERMANY

ABSTRACT

Increasing productivity of web converting machines requires constructive improvements for the prevention of web floating at transport and guide rollers. Existing solutions which carry off the air like vacuum or grooved rollers as well as rough layers at the roller surfaces are on the one hand complicated and on the other hand limited in their effect.

On this background a novel principle, the so-called “gap throttle effect”, which was discovered at the institute of engineering design at the Ruhr-Universität-Bochum (LMK) is presented.

The following analysis contains initial practically orientated investigations of pressure development resp. air entrainment for the conventional system “wrapped roller” and subsequent investigations for the novel system “gap throttle”. The aim is to analyse the influence parameters with aid of a developed simulation program based on the finite differences method as well as to verify the results with experimental investigations at a test rig.

To show the influence and the potential of the “gap throttle effect”, LWC, SC, Tissue and Newsprint with different material properties especially, air permeability and surface roughness, are analysed by variation of relevant process, gap throttle and machine parameters.

The results prove that the effect can be used to achieve higher transferable friction forces and therefore higher web speed. Subsequent investigations show that the effect amount and its stability can be increased considerably by an additional small pressure on the web surface at the mounting area of the web. The innovation potential and the usefulness of this novel principle for web handling machines should be used for later research work, to increase the range of application, especially for winding and coating.
ABSTRACT

High-speed transportation of paper web sometimes leads the web handling system into unstable state because of increase in the air-entrainment into the gap between a rotating roll and moving web or the nip region of winding system.

In this paper, the property of the traction change with increase in the air-entrainment into the gap between a paper roll and web or the nip region of winding system was investigated experimentally and theoretically. The critical speed to avoid slippage between a roll and web was found to be estimable by applying and extending the concept of “effective” frictional coefficient with the consideration of air-entrainment, which is proposed by Good [1], Hashimoto [2] and so on, to the estimation of the traction force defined as the frictional force on a paper roll or at the nip region. Consequently, the web handling stability at high-speed was found to be predictable.
A TWO-DIMENSIONAL MODEL TO PREDICT WEB-TO-ROLLER TRACTION AT SMALL WRAP ANGLES

B. S. Rice\textsuperscript{1} and R. F. Gans\textsuperscript{2}

\textsuperscript{1}Eastman Kodak Company
\textsuperscript{2}University of Rochester

USA

ABSTRACT

We have studied the traction developed between n thin, flexible web and a rotating circumferentially grooved cylindrical roller. The traction model developed by Rice and Gans \cite{1} is inadequate for small wrap angles, because of the two-dimensional nature of the airflow in the entrance nip. We develop a new two-dimensional analytic model that couples air film pressure, web deflection, and asperity contact to predict traction for circumferentially grooved rollers with arbitrary wrap angles. The entrance effects are incorporated into our new traction model by adapting the squeeze film concept using the distance from the entrance as a surrogate for time. We introduce dimensionless groups that the roller designer can use to quantitatively assess the interactions of process variables (e.g., speed and tension) with design variables (e.g., groove depth, groove pitch, roughness, etc.) over the full range of practical wrap angles. Finally, we verify this model experimentally on a series of fourteen rollers and nineteen webs. The roller surfaces range from non-grooved to circumferentially grooved.
AERODYNAMIC FORCES OF A COANDA AIR JET

E. Y. Hong and Y. B. Chang
Oklahoma State University
USA

ABSTRACT

This paper discusses the aerodynamic pressure and frictional force on a plate (called web) placed against a plane wall jet of air. The air jet was ejected from a slot nozzle, turned 90 degrees following a curved surface, and then flew along a straight wall. The tendency of a jet flow to follow a contoured surface is commonly called the Coanda effect. The aerodynamic forces were determined for rigid and flexible webs, experimentally and computationally. A commercial computational fluid dynamics package, called Fluent, was used. For a flexible web, solutions which satisfied both the fluid dynamics and web deflection equations were obtained by manual iteration. Effects of the supply air pressure in the plenum of the air nozzle, flotation height (distance between the web and the nozzle surface), slot nozzle width (opening), radius of curvature of the curved surface, and applied web tension (for flexible web) on the aerodynamic forces on the web were examined. It was found that the aerodynamic pressure is very sensitive to the flotation height. For a stationary rigid web, the net lift force became nearly zero at a certain value of flotation height regardless of supply pressure. The magnitude of pressure on the web and friction were nearly proportional to the supply pressure in the entire range of measurements and computations. The effect of web speed on the aerodynamic friction was examined computationally. It was found that the frictional force dramatically reduces when the web runs in the direction of air jet. An analytical model to predict the aerodynamic traction on the web was developed. The analytical model, however, was only limited to a stationary rigid web.
ISSUES IN MODELING SLITTING OF MAGNETIC TAPES

R H. Andruet\textsuperscript{1}, R. F. Cook\textsuperscript{2} and W. R. Qualls\textsuperscript{1}

\textsuperscript{1}Imation Corporation
\textsuperscript{2}University of Minnesota
USA

ABSTRACT

In order to quantify and understand the driving force for film layer fracture, delamination, and the cutting phenomena in general, an idealized two-dimensional “slitting” model was developed. The model includes two lower (“female”) knives supporting the tape, through which a single upper (“male”) knife is passed. The knife surfaces are modeled as frictional rigid surfaces and the displacement of the male knife is imposed. The tape is modeled as an elastic-plastic material with a critical shear strain energy and hydrostatic pressure criteria for element-localized failure. The model follows a “quasi-static” dynamic explicit formulation scheme that handles highly nonlinear responses very efficiently. This technique has been widely used in the modeling of metal cutting and is able to capture many of the major features of the slit edge morphology but shows a strong sensitivity to mesh resolution.

Criteria for success of the model includes invariance of the edge morphology with mesh scale and agreement between predicted and observed slit edge morphology. Results showed a strong dependence on tape materials properties. The major focus of this work is the interrelationship of mesh scale and the failure criterion imposed.
CHARACTERIZATION OF A SLIT EDGE USING IMAGE ANALYSIS

H. Viswanathan and H. Lu
Oklahoma State University
USA

ABSTRACT

The paper deals with the characterization of edge quality of a slit web. The conventional way of determining the edge quality of a slit web is usually through visual inspection, sometimes under an optical microscope. In this paper, an algorithm was developed and implemented in a code to analyze digital image of a slit edge to characterize and quantify the edge quality of a slit web. The Root Mean Square (RMS) value of the edge profile after image analysis has been used to characterize the quality of the slit web. The image analysis involves grayscale thresholding to convert a digital image of 8 bits or higher into a binary image, component labeling to determine the connectivity of different domains generated through thresholding and the computation of the RMS. The proposed method is capable of quantifying the edge straightness and cleanness through the acquired micrograph image of a slit edge, and the approach works equally well for aluminum, paper, plastic and non-woven webs.
ABSTRACT

Due to the demand for an increasing quality of cutted or slitted products and the requirement of rising productivity in the slitting process, the optimization of mechanical slitting is gaining in importance for the converting industry.

In this paper the shear slitting process is analysed theoretically on the basis of a nonlinear orthotropic material law. In a basic investigation the states of stress and strain in the compression phase of the slitting process are discussed. The following application oriented calculations investigate the influence of individual parameters and lead to the suggestion of an optimal cutting tool geometry depending on the material to be cut.
ABSTRACT

A three-dimensional finite element (FE) procedure has been developed to simulate shear slitting using ABAQUS/Explicit, and the process of shear slitting has been investigated for aluminum webs obeying elastic-plastic constitutive behavior. Shear failure criterion is used in the FE model to allow the creation of new surfaces as the blades guide the web separation. Shear slitting of aluminum webs is analyzed for different slitting parameters to determine their effects on the burr creation at a slit edge. The numerical study focuses on the effects of clearance and blade sharpness on burr formation. Numerical analysis has determined burr shape and burr height at slit edges. Burr profiles from FE simulation agree very well with those from experiments. The relations between burr height and clearance are also found from FE analysis. The mechanism of burr formation during shear slitting has been studied from numerical analysis. The relations between slitting parameters and burr height for different materials, determined from FE analysis, can potentially be used to determine the optimum shear slitting parameters for a given material.
ABSTRACT

A web which has passed over a roll can exhibit coilset due to differential yielding of fibers through its thickness. Modeling can provide a radius of curvature, \( R \), the web would achieve if no external forces were applied. However, measuring this radius of curvature is often impractical and can be difficult when the radius of curvature becomes large. For tinplated steel products, a simple method of quantifying coilset is to hang a standard length of web on a wall, and measure the distance, \( C \), the web curls off the wall, In this paper, the non-linear differential equations to determine the coilset measurement, \( C \), from a given radius of curvature, \( R \), are developed and solved numerically.
ABSTRACT

Idler rollers are present in abundance on most web processing lines. Their simple design, a rotating cylinder driven by the web-to-roller traction, lead most to go unmonitored until degrading performance results in product defects. Idler roller performance is a balance of traction versus opposing forces of drag and inertia. Idler rollers appropriately designed for their specific application will prevent scratching, minimize web tension losses, and ensure good tracking. Past authors have presented simple measurements and models to evaluate bearing drag of an idler roller assembly, but have not presented the complete analysis needed to determine the risk associated with poor idler roller performance.

This paper presents a complete guide based on previously published models and measurement methods to evaluate idler roller performance. Step-by-step instructions show how to use the Spin Down measurements plus bearing drag, roller inertia, and traction models to determine any roller’s risk of slipping. A new term is introduced, the Traction Safety Factor, to assess and compare the risk of idler rollers slipping and to identify irregular performance. Beyond the recommended measurements and models, this paper will also review lessons learned in applying this protocol to a coating web line with over 300 idler rollers.
ABSTRACT

In typical winding processes, webs are rarely (if ever) ideal but instead thickness non-uniformity and distortions (two examples) are the norm. These deviations from ideal have significant ramifications to both predictive model development and to winding equipment design configurations. This paper will present methods for quantitative measurement of some of the important non-ideal web characteristics. Typical results will be presented for film and paper webs. Also presented will be examples of modeling enhancements needed to generate predictions of the winding behavior in systems comprised of non-ideal webs. Finally, examples will be given of hardware modifications that are driven, to a large extent, by the reality that webs are not perfect. The objective of this paper will be to enlighten the winding process development community regarding a very challenging and relevant area for future research.
WOUND ROLL GENERATED UNSTABLE VIBRATION

M. Jorkama\textsuperscript{1} and R. von Hertzen\textsuperscript{2}

\textsuperscript{1}Metso, Paper, Inc.

\textsuperscript{2}Helsinki University of Technology

FINLAND

ABSTRACT

Nip contact between the wound roll and the winding drum, rider roll or some other nip roller may cause that the wound roll is deformed into a convex polygon. This deformation process is accompanied with a very strong vibration. The conditions under which this phenomenon occurs depend much on the web properties. For example, in the paper industry some bulky grades with a high layer-to-layer COF are known to be prone to this unstable vibration.

In this paper a simple wind up model, capable of capturing quite comprehensively this phenomenon, is developed. The polygonal pattern formation is modeled as a viscoelastic surface deformation. This results in linear delay differential equations. In order to analyze the stability, the Laplace transformation is performed for the system equations. The inspection of the root locus shows several zones of instability during the winding cycle. In an example, it is shown how the model can be utilized to explain some well-known winder vibration phenomena.

The paper is concluded by stating general beneficial trends for the wind up design and by explaining how to determine the susceptibility of certain webs to unstable vibration by simple laboratory measurements.
THE EFFECT OF AIR-SIDE LEAKAGE IN ROLL WINDING

H. Lei and K. A. Cole
Eastman Kodak Company
USA

ABSTRACT

In web winding processes, a thin layer of air is entrained into rolls during winding. This air reduces the interlayer pressure in the wound roll because the air acts like a sponge between adjacent web layers. Winding models that include the effect of air entrainment have been developed in recent years to provide better prediction of wound-roll stresses and wound-roll quality. However, these models have limited predictive success in narrow-web winding, especially when a pressure roller is not used. During winding, and after a roll is wound, the air in the roll leaks out of the sidewalls through narrow gaps between the layers. The amount of air leaking through the sidewall, when the web is narrow and has a rough surface, is significant. When side leakage is not properly considered, the accuracy of the air entrainment model can be greatly affected. In this paper, a new winding model is developed that includes the effects of air entrained during winding and the subsequent air leakage through the sidewalls during and after winding. The formulation considers the effects of both pressure-roller and nonpressure-roller winding. Some results of this model are presented, together with comparisons to experimental results and predictions from other historical models (e.g., nonair entrainment and air entrainment without side leakage).
ABSTRACT

In this paper the elongation of a core in a roll bottom is studied experimentally and theoretically. The CD elongation effects are of interest especially because they are known to contribute prominently to a two-drum winder vibration or roll instability phenomenon called *bouncing* in the paper industry.

Analytical and numerical calculation models are used to study the effect of different geometrical, material, etc., parameters on the core and paper CD elongation. If the free lateral elongation and rotation is allowed and the friction between paper and the core is neglected, the radial and tangential stresses of the core are due to the radial pressure only. The lateral and shear stresses are equal to zero and the elongation depends on the pressure, Poisson’s ratios in the thickness-machine and thickness-cross directions, elastic modulus in the thickness and tangential directions and the geometry. If the lateral frictional forces between the paper and core are also taken into account, another, equally effective elongation mechanism is introduced.

The measurements of the paper and core elongation are in accordance with the calculated results. In practice, cores expand typically +/-1 mm/m depending on the tightness of the roll bottom and core properties. This study shows that the core elongation increases linearly with the radial pressure. Small diameter cores lengthen less than large cores. Cores with thicker wall thickness lengthen less than thinner cores, and cores with a bigger winding angle lengthen less than cores with a smaller winding angle (conventional cores).

The radial moduli of paper and the core wall also play an important role in the elongation of the core. Preliminary studies suggest that the softer the paper the more it tends to widen. According to paper stack modulus measurements, the radial modulus of paper layers in the roll bottom can be less than 100 MPa, even with high winding pressures. The radial elastic modulus of the core wall is usually 100 - 200 MPa or even greater depending on the core type. It is possible that the frictional force between the core and paper could force the core to elongate more than it would without paper.
OUT-OF-ROUND PAPER ROLLS

D. McDonald, J. Hamel and A. Ménard
Pulp and Paper Research Institute of Canada
CANADA

ABSTRACT

Paper is usually shipped in rolls covered by a thin wrapper to protect it from moisture and dirt. In effect, the roll becomes the shipping container for the paper. A single sheet of paper is weak and fragile, but in roll form it can withstand the substantial compressive forces required to lift it with clamps. However, even a small permanent deformation caused by clamping or impacts during transportation can cause a significant variation in web tension as the roll is unwound in a printing press. Tension variations can cause misregistration or flutter in a printing press. To compensate for out-of-roundness and the subsequent variations in tension, the operator will increase the average web tension, but that increases the chance of a web break. The ultimate solution is to make a paper roll that is resistant to the forces it will encounter between the winder and the printing press. As denser paper is made into longer and wider rolls, the force required to lift the roll increases, which may preclude handling by clamping. We have developed a mathematical model which shows that, for a given clamping pressure, the permanent deformation of the paper roll is related to the tension wound into the paper roll and the compressibility of the paper in the radial direction. The occurrence of out-of-round rolls can be reduced by tighter winding and using less compressible paper.
A METHOD FOR MEASURING WOUND-ON-TENSION

J. Paanasalo
Metso Paper, Inc.
FINLAND

ABSTRACT

The Wound On Tension (WOT) is the web machine direction stress as it has just passed the winding nip into the roll. It is the most important quantity that determines the wound roll structure and its internal radial stress distribution. All the other winding parameters can affect the WOT but they can change the internal roll stresses only through the WOT. The on-line measurement of the WOT has been possible only in laboratory winders. However, if the WOT would be known, the winding parameters could be more accurately adjusted to give optimized customer roll structure. The purpose of this work has been to find and evaluate WOT measurement method feasible in the production environment. Both the usual Small deformations model known as the Hakiel model and the more recent Large deformations model were evaluated. The WOT can be solved from the Hakiel model numerical approximation and the measured radial displacement. The numerical approximation is a large linear equation which can be reduced to a scalar equation linear for the WOT. The method is computationally effective allowing real time measurement of WOT during winding. The Density measurement is based on the roll length and diameter measurements giving the paper thickness and density when the basis weight is given. The web thickness under zero stress is needed to accurately measure the total radial displacement from this data. The results obtained with newsprint paper show that with paper grades having relatively low radial modulus the WOT can be measured at a reasonable accuracy if the free web paper thickness can be obtained from the preceding process machines.
The rolling of a cylindrical drum on a stack of separate paper sheets is studied using the finite element method. A two dimensional model under plane strain conditions is considered. The material of the sheets is modeled by a linearly elastic orthotropic constitutive law. The friction between the various contacting surfaces is modeled by the conventional Coulomb’s law. As a result of the FEM-calculations the time development of the displacements, stresses and strains of the paper layers is obtained. The slip behavior at the various contacting surfaces is presented. The results indicate the existence of an instant center in the stack demonstrated earlier experimentally. The micro-slip pattern of the contacting surfaces in the nip area and, particularly, at the trailing edge of the nip, seems to be the main reason for the tightening effect of the nip. The results are compared to the corresponding results for a solid elastic block under the rolling cylinder.
WOUND-ON-TENSION FOR TWO DRUM WINDERS

J. K. Good\textsuperscript{1}, B. R. Cowan\textsuperscript{2}, L. E. Doleza\textsuperscript{3}, and R. Markum\textsuperscript{1}

\textsuperscript{1}Oklahoma State University

\textsuperscript{2}Orbus Medical Technologies

\textsuperscript{3}IBM

USA

ABSTRACT

The two drum winder remains to be a high productivity winder for rewinding some paper and nonwoven webs at very high speeds. Winding models of varied capabilities exist for center winders, center winders with rider rollers, and surface winders. Winding models for two drum winders however are still in the introductory stages. Two drum winders are somewhat more complex than other winders due to the number of rollers, driven and undriven, which impinge the surface of the winding roll. The objectives of this paper are to show the influence of various winder operating parameters and thread path on the wound-on-tension in the outer layer (WOT).
PROCEEDINGS OF THE EIGHTH INTERNATIONAL CONFERENCE ON
WEB HANDLING

June 5-8, 2005

Web Handling Research Center
Oklahoma State University
Stillwater, Oklahoma

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MODELING AND SIMULATION TECHNOLOGY BEHIND EVERYDAY PRODUCTS

by

T. Lange
Procter & Gamble
USA

ABSTRACT

After a quick introduction to P&G and our products, we discuss the fact that 'soft goods' are 'hard' to know scientifically. We reveal the inverse relationship between the cost-per-use of consumer products and the complexity and technology of the production systems that make them. We show how modeling & simulation can greatly accelerate the pace of innovation…not just for airplanes and cars but for consumer package goods. Case studies are presented of how P&G is using advanced computing and simulation software to better understand how everyday products function and how the processes that make them affect their performance.
ABSTRACT

In the web handling technology, it is very important engineering problems to predict and protect web wrinkling from several view points of product quality, manufacturing cost and so on. In this paper, the prediction model for generating paper-web wrinkles due to misalignment of roller is presented with experimental verifications.
LATERAL MECHANICS OF BAGGY WEBS AT LOW TENSIONS

by

J. E. Olsen

SINTEF Materials and Chemistry
NORWAY

ABSTRACT

Existing mathematical models describing lateral movement of webs such as paper or plastic film, assume that the entire width of the web is carrying tension or that the web is capable of supporting compressive stresses. For many webs this is not true. Thus a mathematical theory describing lateral movement of baggy webs which do not support compressive stresses have been derived. It is shown that the mechanics of these webs are described by a nonlinear fourth order differential equation for which a numerical solution has been developed. Results show that the lateral deflection of baggy webs is significantly affected by tension at the lower levels of tension.
A NEW METHOD FOR ANALYZING THE DEFORMATION AND LATERAL TRANSLATION OF A MOVING WEB

by

J. L. Brown
Essex Systems
USA

ABSTRACT

A new method is presented for modeling the elastic behavior of webs conveyed over rollers. In addition to producing detailed descriptions of stress fields, it provides a new way of looking at problems that will help web process engineers form a better physical picture of web behavior.

The new method is based on two fundamental boundary conditions that define web behavior at the point of entry of the web onto a downstream roller. One is a generalization of an existing geometric concept called the normal entry rule. The other, presented here for the first time, is based on application of the principle of conservation of mass. For reasons that will become apparent, it is called the normal strain rule. This paper will show that these two rules, together with a nonlinear version of the equations for two-dimensional plane stress enable the solution of a large class of unsolved web handling problems. Numerical solutions are calculated with a finite-element partial differential equation solver.

The basic principles are developed and shown to produce results that are in agreement with published test results for two problems that have been solved by other means.

1. Lateral displacement at a misaligned roller: Results are compared to Shelton's 1968 thesis [2].
2. Lateral displacement at a tapered roller: Results are compared to the 2001 IWEB paper by Markum and Good [4].

In both cases, the referenced studies used beam theory to predict lateral displacement. The experimental results are compared with predictions from the new method (P. D. E. model) and shown to be in excellent agreement.
Following a brief summary of the background of the problem, the new boundary condition is derived and other relevant equations summarized. Results are then computed and compared with results for the two cases mentioned above.
ABSTRACT

A new method of analysis is applied to the problems that have resisted detailed solution. These are:

1. Concave roller
2. Curved-axis roller
3. Cambered web (Curvature of the relaxed web along its longitudinal axis)

In the first two of these, the primary interest is the stress/strain field near the downstream roller. In the third, the primary interest is the lateral translation. In all cases it is useful to have information on the stress field throughout the span to evaluate the potential for damage and wrinkling.

For each case, the normal strain and normal entry rules are used to develop downstream boundary conditions that can be used with a nonlinear version of the theory of elasticity for two-dimensional plane stress. A finite-element partial differential equation solver is used to develop steady-state solutions that include stress/strain fields and displacements throughout the spans.

Along with specific numerical examples, there is a discussion of implications for such things as wrinkling, spreading, lateral translation and overstressing.

A major advantage of the new method is that it provides a new way of looking at problems that will facilitate other approaches to modeling. This is illustrated by developing a beam theory model for cambered webs.
ANALYSIS OF TROUGH FORMATION AND LATERAL STEERING OF A WEB DUE TO A TAPERED DOWNSTREAM ROLLER

by

J.A. Beisel and J.K. Good
Oklahoma State University
USA

ABSTRACT

Cylindrical rollers are never perfectly cylindrical. A common defect of a cylindrical roller is radial taper. A roller with a radial taper will induce a lateral shear force into the web. This shear force will cause a steering effect as well as a cross machine direction compressive stress which can lead to the formation of troughs and wrinkles in a web. This publication addresses these topics and presents a model to help determine the specification for taper in “cylindrical” rollers. An analytical model is presented, experiments were performed, and the data was compared to predictions from the proposed model.
INTERACTION BETWEEN TWO WEB SPANS
BECAUSE OF A MISALIGNED DOWNSTREAM ROLLER

by

J. J. Shelton
Oklahoma State University
USA

ABSTRACT

Fourth order differential equations for two web spans are solved, with the required eight boundary conditions reflecting conditions at the upstream end of the first span, the downstream end of the second span (at the misaligned roller), and at the roller between the two spans, where slippage occurs. Required relationships between the moment and lateral force at the slipping roller are derived from analysis of distributed frictional vectors across the web, along with the auxiliary variable $K_s$ which is determined by the curvature and slope of the web at the intermediate roller. The solution of three equations with three unknowns is accomplished by iteration, then the three parameters are substituted into the solutions of the differential equations.

The patch of contact between the web and the intermediate roller is assumed to be rigid, as supported by many observations and photographs. The distributed loading on the intermediate roller is assumed to be uniform, but the effects of a nonuniform loading as imposed by a web wrapping the roller are examined and found to be little different from the effects of a uniform loading.

Besides identifying the conditions which lead to failure of a guide, interaction of spans is established as a potentially major source of erratic lateral behavior of a web, including a newly identified 'jump' phenomenon. Another result includes identification of conditions which would cause a slack edge.

Because of the potentially severe problems of lateral behavior when interaction occurs, simple methods for prevention of interaction are recommended for installation of steering guides. Also, tolerances for parallelism of stationary rollers for avoidance of interaction are recommended.

The results of the analysis compared favorably with existing experimental data for the case of the web wrapping the slipping roller, even when the steering was great enough to cause a slack edge.
WRINKLING OF WEBS ON ROLLERS AND DRUMS

by

D. P. Jones¹ and M. J. McCann²

¹Emral, Ltd.
UK
²McCann Science
USA

ABSTRACT

Wrinkles are frequently observed in thin webs wrapping rollers, winding cores, and drums in vacuum coaters. They are the buckling response of the web to compressive deformation in the transverse direction (TD), which may arise from inward steering of the web edges (e.g. on a roller bending under its own weight), or thermal expansion (under the heat load of coating deposition). Analysis of conditions which cause wrinkling starts from the idealised case of a free thin cylindrical shell under end load. This buckles to form a regular pattern of rings, which run round the circumference and are sinusoidal in the TD. However, the analysis fails to account for the rigid roller or drum preventing deformation towards the axis, and friction between the web and roller surface.

A new, approximate, Rayleigh-Ritz variational analysis has been used to find the conditions for wrinkling into a continuous sinewave on a roller or drum. The wavelength is smaller, and the critical strain higher, than the case of the free thin cylindrical shell. Furthermore, wrinkling can be suppressed by imposing a tension in the machine direction. At a particular tension, wrinkles only form above a certain level of TD strain. They require a trigger, such as the presence of a dirt particle, to form. Practically, this continuous solution is expected when the coefficient of friction is extremely high, or the edges of the web are physically restrained.

In other cases with more typical coefficients of friction, the web can adopt a lower energy configuration by forming isolated wrinkles (approximated by a single cycle of a sinewave) and flat areas in between. The TD strain in the web after buckling varies in a sawtooth manner, with minima at the web edges and the wrinkle locations, and maxima midway between them. Once again, wrinkles require an initiating event to form, and the critical TD strain for wrinkling increases with tension. The spacing between wrinkles falls with increasing tension. Wrinkles are approximately equally spaced, typically 100 mm apart, and absent from the web edges, in accordance with observations.
WRINKLE-FREE CONVEYANCE IN NIPS

by

B. S. Rice
Eastman Kodak Company
USA

ABSTRACT

Wrinkling in nips with ultra-thin webs is empirically studied. In web converting, nips are used for tension isolation drives, gravure coaters, prevention of air entrainment on rollers and winding rolls, calendaring, laminating, etc. A common concern is wrinkles/creases that can form in the nip. The effects of roller design (straight, concave, bow, expanding surface, and compliant spiral groove) immediately upstream of the nip, web tension, web speed, and nip load on wrinkles are tested. Over the range of process parameters tested, the bowed roller was the most robust at preventing wrinkles in the nip. It was also learned that under certain conditions, the nip, itself, helps to prevent wrinkles.
ABSTRACT

The stability of web lateral motion is of importance in many engineering applications where the deviation of the web from the processing direction is highly undesirable and can cause various defects. This is especially true for sheet metal rolling, where sudden lateral deviations of the web from the rolling direction, known as strip track-off, is a serious operational problem that can lead to catastrophic consequences, such as mill crashes and damaged rolls.

The early studies of strip track-off in metal rolling showed that neither the magnitude of lateral deviations nor the catastrophic track-off observed in practice can be explained by the model of strip deformation in the span based on beam theory, common in the web handling literature. It has been suggested that strip buckling may play an important role in strip track-off phenomenon. In addition, it has also been observed in web handling literature [1,2] that the model predictions based on conventional beam bending analysis do not agree with observed web lateral motion in the situations when buckling of the web is present.

This paper presents a discussion of the recent studies of the effect of strip buckling on strip lateral dynamics in metal rolling. The analysis is based on the model of strip plastic deformation in the mill and a simplified physically based strip buckling model suggested by Benson [1]. Introduction of buckling changes the nature of the strip lateral motion, which becomes unstable once a critical level of asymmetry in rolling conditions is exceeded.

In metal rolling, the longitudinal residual stresses in the strip are usually present due to non-uniform plastic reduction. In this paper, an extension of the Benson's buckling model to include the effect of residual stress is proposed. The numerical analysis of the extended model suggests that the web with the tensile residual stress at the edges and compressive stress in the middle is less susceptible to instability compared to the web with compressive residual stresses at the edges and the case without residual stress.
Abstract

The Flexible Panel Display (FPD) business is rapidly growing in Asia. Many industrial companies not only from traditional coating industries but from others such as electronics, printing, and film manufacturing industries, are coming into this business in Japan, Korea, Taiwan and quite possibly in near future, China because of such a high growth opportunity. The total capital investment announced by several key companies, is several billion dollars for next one to two years. Due to the fact of the application to optical (quality) and consumer (cost) products, we have challenges in web handling technology besides coating and drying technologies. For example, the thin film precision coating, which is crucial for display products, requires the precision web handling, which means, for example, the technologies such as the uniform cross web tension of thin film and the scratch free web handling of wide film are essential.

The FPD business will be overviewed and the technological challenges in web handling in combination with coating process will be discussed briefly based on the current and future needs.
CONTROL AND ONLINE TENSION REFERENCE OPTIMIZATION IN
WINDING SYSTEMS: APPLICATION TO AN IDENTIFIED THREE-
MOTORS SIMULATOR

by

D. Knittel¹, P. Bourgin², and M. Boutaous²

¹Louis Pasteur University
²Laboratoire de Recherche Pluridisciplinaire en Plasturgie
FRANCE

ABSTRACT

It is well known that the tension reference value, which a priori guarantees a good quality roll, is based on the stress generated within the roll. However, due to the imperfections of the winding systems and to the limited performances of the disturbances rejection controllers, a control with fixed reference never generates perfect follow-up of the tension. A solution would consist in adjusting the tension reference online, according to real measurements.

In a previous paper, the criterion for tension adjustment was the tangential stress. A method for online control based on prediction-correction using the simplex algorithm was presented. This method was tested numerically. In the present paper, we propose to generalize the criterion of tension reference optimization by considering both the tangential and the radial stress within the roll during winding. The same optimization algorithm is used, taking into account the dynamic tension model. Moreover, a dynamic gauge is now introduced, so that it can vary during the winding process. It generally represents the limits of elastic deformations of the web.

The new optimization algorithm for the on-line reference tension calculation has been validated on a dynamic non-linear winding model. This complete model used for simulations was validated on a three-motor setup using brushless motors. The setup is with PI controllers, where the web velocity is imposed by master traction motor and the tension is controlled by unwinding and winding motors. In this approach, a new tension-prediction algorithm using a linear parameter varying (LPV) model is used. The influence of the tension prediction algorithm is also analyzed.

Several illustrative examples will be presented and the improvement as compared to an offline control will be commented.
EFFECT OF COMPLIANCE AND BACKLASH ON THE OUTPUT SPEED OF A TRANSMISSION SYSTEM

by

R. V. Ramamurthy and P. Pagilla
Oklahoma State University
USA

ABSTRACT

Backlash is one of the most commonly encountered nonlinearities in drive systems employing gears or ball-screws and indicates the play between adjacent movable parts. Presence of backlash causes delays and oscillations and consequently gives rise to inaccuracies in the position and velocity of the machine. Coupled with this, if the drive system consists of compliant members, torsional oscillations may also occur. Though the presence of backlash may not be of utmost significance in the case of a general speed controlled drive system, web handling systems stand as a unique exception to this observation; any small change in the web speed causes large changes in the controlled tension and hence tight control of speed is an essential requirement in web handling systems. Also, it is of interest to know an estimate of the accuracy of speed achievable in a given closed-loop control system. This paper addresses the effects of compliance and backlash on the output speed of the transmission system.

A model to include the effects of compliance and backlash is proposed under the assumption that the collisions due to backlash are sufficiently plastic to avoid bouncing. The proposed model considers the compliance (which may be either due to the elasticity of the shafts or belt in a belt-pulley transmission system) and backlash appearing in series in a drive system. In contrast to the classical backlash model which considers both input and output to the backlash as displacements, the proposed model considers (torque) force as input to the backlash and (angular velocity) velocity of the driven member as the output of the backlash. Thus, the proposed model does not assume that the load is stationary when contact is lost due to backlash width, i.e., momentum of the load is taken into account in the proposed model.

From the proposed model, a bound on the speed error due to the presence of backlash is derived. To derive the bound on speed error due to backlash, two situations are considered: (i) closed-loop speed control system with a given backlash, and (ii) the same closed-loop system with no backlash. The difference between the outputs of these two systems indicates the error caused by the backlash and represents the achievable accuracy of the closed-loop system. Closed-loop experiments were conducted on a rectilinear system to obtain the error caused by different backlash widths. The bound obtained from the experimental results agrees with the theoretically computed bound.
TENSION CONTROL IN THIN FILM PRODUCTION LINES.

by

G. Oedl
Bruckner Maschinenbau Siegsdorf
GERMANY

ABSTRACT
A comparison of speed and tension control in pull roll stand at film production lies is given. One typical error (periodic error) of standard gear box drives is analyzed and discussed. The design of a active tension control based on observer is explained. The simulation environment is shown. Results from production lines at various film thickness (4 to 25 µm) are shown.
ABSTRACT

Stable web transport through processing machinery is critical in the web processing industry. Demands for improved performance under a wide variety of dynamic conditions and web materials are placing additional emphasis on developing new advanced control techniques. Further, technological advances in areas such as drive hardware, microprocessors, and sensors, are opening up new possibilities for implementing advanced control methods that are robust to a number of process and material variations and result in superior performance over existing industrial control methods.

Mathematical models of fundamentals elements in a web process line are presented. A systematic procedure for computing the equilibrium inputs as well as reference velocities of all rollers based on the master speed reference is given. Recently developed robust control methods for web longitudinal control are described. Implementation of the controllers on two experimental platforms is given, and a sample of the experimental results is presented. Finally, some potential new directions and future research topics are discussed.
MODELING THE BEHAVIOR OF THE PAPER WEB
IN PRINTING PRESSES

by

S. Vuorinen and M. Parola
VTT Information Technology Media
FINLAND

ABSTRACT

The production efficiency of printing presses is limited by runnability problems such as web breaks, register errors, wrinkling and lateral instability of the paper web. To explore these phenomena, one must study the interaction mechanisms between the paper web and the printing press. In offset printing damping water is applied to the web affecting the rheology of the running paper web. In numerous printing applications many webs are printed simultaneously, split and run together in the folder. Different webs should ideally be combined in certain tension steps. In practice this goal is difficult to achieve as paper properties may change from reel to reel and the press conditions may change temporally.

Finite element modeling (FEM) was applied to study the interactions between the paper web and printing press. The tension changes along the press line, the nip load and the dimensional changes of the paper were modeled by FEM. The paper was modeled as in a plane stress state using membrane elements. Measurements were carried out in laboratory, pilot and production scale. Measurements included nip load distribution, tension profile and web dimension measurements. Material parameters for modeling were measured and obtained from earlier work.

Nip load and its distribution affect the web's dimensional changes like dry widening and presumably the rate of moisture absorption to the paper web. The effect of printing nips on the pressure and nip length were modeled and the results were verified with the measurements. Results showed that the structure of the printing blanket has a considerable effect on nip pressure and nip length. Nip conditions may affect the magnitude of the web widening (fan-out) through the delayed time of the paper in a nip and through the magnitude of the nip pressure.

The formation of the paper web's tension profile in a newspaper offset press was studied. The effect of damping water to the tension was modeled and the results obtained by FEM correlated well with the measurements.

It was found that FEM can be successfully applied in order to model and simulate the interactions between the printing press and the paper web. The effects of printing nips
were modeled as well as the changes in the web tension profile in the press. The modeling results correlated well with the measurements. The benefits of modeling are obvious as the productivity of printing presses is highly dependent on the tension behavior of the web and the actions taken in the press. This means that better productivity can be achieved by increasing the knowledge of the interaction mechanisms.

In this paper we will also discuss the requirements of FEM in the printing process. Future work should include more precise material models as various parameters, such as the creep / relaxation phenomena of the paper web, were not included in this work.

Steady state analysis was performed for a moving paper web. The modeling results gave a better understanding of web transportation and FEM appears to be a promising tool for analyzing paper web behavior in different web handling systems.
A COMPLETE MATERIAL LAW OF PAPER FOR MODELLING AND SIMULATION OF FINISHING PROCESSES

by

E. G. Welp, E. Wolf, and V. Niebuhr
Ruhr-University Bochum
GERMANY

ABSTRACT

A complete three-dimensional material law is necessary for the mathematical description of the material behaviour and for the simulation and calculation of finishing or converting processes. In order to achieve this goal, all necessary material properties have been experimentally determined for different paper and cardboard grades. New testing equipments and analysis methods have been developed to record the complete force-displacement-relations in all main directions (MD, CD, ZD) and for every possible axial and shear loading condition.

Based on experiments a complete three dimensional nonlinear material law is developed, which is able to describe mathematically the complete mechanical behaviour of paper from the macroscopic point of view. This new material law contains an excellent plastification model and stiffening effects.

The described material law is implemented into the FEM-System Marc&Mentat, which now allows the simulation and calculation of paper stress-strain-behaviour in finishing and converting processes. The implementation of the new material law achieves a very good correlation between simulations and experiments.
SHEAR SLITTING OF ALUMINUM WEBS

by

J. Ma¹, H. Lu¹, and M. Li²
¹Oklahoma State University
²Alcoa, Inc.
USA

ABSTRACT

Shear slitting of aluminum webs using both disk knives and block knives were investigated using a laboratory slitter. The effects of the clearance, overlap, blade overdrive, and cant angle on burr height were studied on four different aluminum webs. It was observed that the burr height is small when the clearance was less than a critical value, and the burr height increased drastically when the clearance was larger than the critical value. The effect of overdrive was negligible for the experiments performed. The burr formation was revealed through a series of micrographs at different stages of slitting.
WEB HANDLING FOR FLEXIBLE DISPLAY MANUFACTURE

by

R. L. Walton
Eastman Kodak Company
USA

ABSTRACT

Flexible displays manufactured in a continuous roll-to-roll fashion are the "Holy Grail" of the display industry. This paper offers an assessment of the development efforts related to web handling, which are required to achieve this goal.
THEORETICAL MODELING OF TRACTION CHARACTERISTICS BETWEEN
PAPER-WEB AND STEEL-ROLLER BASED ON THE CONTACT MECHANICS

by

H. Hashimoto
Tokai University
JAPAN

ABSTRACT

This report describes the theoretical modeling of friction coefficient between uncoated paper web (newsprint; for example) and steel roller. In the modeling, the paper base is approximated by the linear spring and surface asperities are treated as rigid body. Introducing the contact mechanics and assuming the Gaussian distribution of surface asperities, the mixed friction coefficient is formulated theoretically for a wide range of roller surface velocity, in which the air film thickness between the web and roller is estimated based on the foil bearing model. In the experiments, the newsprint is used as uncoated paper-web. Euler's belt formula is applied to calculate the friction coefficient from the measured data on tension increase. The measurements are carried out by changing five design parameters such as web width, wrap angle, tension, roller diameter, and roller surface velocity. The measured results are compared with the predicted results by the friction model. Good agreements can be seen between the predicted results and measured results.
ABSTRACT

The mechanics of the interactions between a flexible web and an externally pressurized air cushion is modeled. The web is wrapped around the porous cylindrical turn-bar at an oblique angle (helically). The turn-bar supplies pressurized air into the web/turn-bar clearance. The shell model used to represent the mechanics of the web is an extension of a previous model, and it allows the web to be wrapped around the cylinder in a helical fashion. The geometric relations are based on Rongen's work [1] and steady state equilibrium equations are developed based on the work of Müftü and Cole [2]. The fluid mechanics of the air in the web/turn-bar clearance is a two dimensional form of the incompressible Navier-Stokes equations averaged in the clearance direction and augmented by non-linear source terms. Contact between the web and the reverser, which is undesirable in a turn-bar application, is included in the model in order to enable the analysis of the limiting cases. This paper describes the theory. Case studies and design recommendations are presented.
ADAPTIVE, SELF-UNDERPRESSURIZING SUCTION ROLL
FOR FAST WEB HANDLING CONCEPTS

by

M. Kurki\textsuperscript{1} and P. Martihainen\textsuperscript{2}
\textsuperscript{1}Metso Paper, Inc.
\textsuperscript{2}VTT Processes
FINLAND

ABSTRACT

In web handling one of the most demanding area is nip or pocket area for incoming or outgoing web. Depending on speed of web and rotating roll surfaces, boundary layers transport air causing negative or positive relative pressure difference between top and bottom sides of the web. Numerous publications and studies show that this effect causes web deflections, which can lead to web instabilities and deteriorations in web handing.

Pocket areas are also difficult from the viewpoint of fluid flow analysis since tangential points of the pocket geometry will lead to singularities in normal situation. This means that pressures are "infinite" and cannot be handled without "leakage effects" coming from surface roughness, or in this case, roll grooving.

Typically one possibility to avoid web handling problems in pocket areas is to increase substantially such "surface roughness" which can receive or convey air transported by viscous boundary layers. One form of this extra "surface roughness space" is roll grooving which is simply a helping duct or escape for air, especially in pocket areas.

In this paper we present a roll and a method not only to overcome pocket effects, but also a technique where boundary layers together with optimized roll groove structure can create a suction roll mechanism. This forms an underpressure between the roll and the web surface stabilizing the web.

Roll functioning is based on carefully designed but simple groove geometry where closing and opening pockets correspondingly create sealing and underpressurizing areas. Adequate and deep groove design ensures good air conveying utilizing air-surface friction forces. The roll arc covered by fabric is underpressurized as a whole.

Both CFD and experimental results show that underpressure develops adaptively according "Bernoulli's law", i.e. second power with roll surface speed. Roll is especially designed to work with supporting permeable fabrics. Since underpressurizing power is coming from rotational speed and boundary layers, no external vacuum or suction
devices are needed. Since whole wrap area is underpressurized from closing nip to opening nip, roll performance is ideal for such web handling situations where excessive web tensioning and web straining should be avoided.

In paper making industry with continuously increasing web speeds, more cost effective web handling systems are needed. There, the web supporting is in essential position. With permeable, supporting paper making fabrics, web handling possibilities can be improved significantly when roll pocket effects can be controlled efficiently.
INVESTIGATION OF FLUID MECHANICS OF SLOTTED AIR-JETS
FOR AIR REVERSER APPLICATIONS

by

E. Lopez and S. Müftü
Northeastern University
USA

ABSTRACT

The fluid mechanics of the air flow, caused by a series of impinging air-jets, in a constant-height, rigid channel is investigated using computational fluid dynamics (CFD). The primary goal of this work is to investigate the effects of the interactions between different air-jets. The model is representative of a cross section of the clearance between a web and an air-reverser. A cross flow is generated by the air trapped in the clearance. Using the CFD package Fluent, the effects of channel-height, spacing between the air-jets, supply pressure for the air-jets and number of jets, on the flow characteristics is investigated. In particular a flow "loss" coefficient, defined as the ratio of the velocity obtained using average velocity of each jet from the CFD analysis to the velocity obtained from the Bernoulli's equation, was shown to vary from air-jet to air-jet. It was found that a lower channel-clearance increases jet interaction, as it forces jets to flow into each other. Larger spacing of the air-jets also increases jet interaction, as cross flow fully develops into lateral flow. Supply pressure was seen to have a small effect. The flow "loss" coefficient behavior was characterized as functions of these variables.
ABSTRACT

The Bi-Wind and the Rho-Meter hardness tester are two well-known achievements of the Beloit Corporation's Downingtown Research Lab and there were many more in the period 1964 to 1971. A small group of researchers, building on their own discoveries, saw a major shift in thinking in that seven-year period, lead by Kenneth G. Flye, appointed Manager of Research in 1964.

We acted as a harmonious group, seeking out new solutions to existing problems based on what we had previously uncovered, and what we could learn through the assimilation of technologies that could reveal new answers. We found ourselves working in fields that were unusual for a lab based on paper technology -- aerodynamics, acoustics, electronics, optics, printed circuits, lasers, microscopy, polymers, and metallurgy, to name a few. At the same time, we relied on the fundamentals of materials science, mechanics and kinematics, and machine design.

As new facts and solutions to problems were discovered, they were presented in industry seminars and publications in technical journals. Contrary to the current practices of the day, we published as it happened, not waiting until years after the fact. That in itself was unusual, as competition was secretive about what they were working on. Sometimes the knowledge spawned new products and new patents. In other cases the products came later as the understanding branched into different fields. The sequence of development will be of interest to other researchers, but of particular interest is the number of findings that were never officially published, and the number of investigations which were left incomplete when the Downingtown Laboratory abruptly closed in 1971. Some of these topics are still worthy of study by graduate students and other researchers.
ABSTRACT

To optimize is to find the "best" solution given certain conditions and constraints. What is meant by best and how to find it has received scant attention. To the engineer, "best" may be fastest, strongest, most reliable and so on. The engineer will have models to determine whether one solution is better than another based on objectives such as these. "Best" in business is quite different. It means to maximize profit or minimize loss. The economist or accountant also has models. Note the obvious disconnect between the objectives of engineering and business models. This disconnect has hindered us from finding a practical best to improve profit on the plant floor. Simple questions like "what is the best tension to run" have no useful answers from a strictly engineering or business viewpoint.

This paper begins by defining best for several familiar examples. However, it quickly concludes that the only "best" that makes sense in an industrial environment is that which will minimize total costs. To find this best we must integrate engineering and business models. This technique developed here is very powerful, flexible and adaptable approach. The technique can be applied explicitly using calculus or similar numerical techniques when cost functions are well known. Even more flexible is an implicit approach which can be used when very little is known about costs. Five web handling examples are used to illustrate this problem solving technique. These examples include a variety of objectives such as optimum rejection levels, core waste, web tension, and layon roller nip and water flow rate. These examples show how it is easy to combine apples and oranges, such as waste and delay, when one converts to a common denominator of cost.
THE ABILITIES & INABILITIES OF WOUND ROLL MODELS TO PREDICT WINDING DEFECTS

by

J. K. Good
Oklahoma State University
USA

ABSTRACT

Wound roll models began appearing in the literature 40 years ago. These models predict internal stresses within wound rolls due to winder operating conditions and web material properties. The models have progressed much in their ability to model the complex properties of webs and winder type on the internal stresses. Defect models have also advanced but not at the rate of the wound roll models. The first objective of this paper is to establish the current state of wound roll and winding defect models that can be used to enhance productivity in web process machinery. The second objective is to establish what winding defects cannot be attacked with current models and why.
ROLL DESIGN EFFECT ON NIP PRESSURE

by

G. Simbierowicz and R. Vanninen
Metso Paper, Inc.
FINLAND

ABSTRACT

The quality of reeling process is a key factor in achieving production efficiency, especially when machine speed and paper width continue to increase. For calendered and coated grades of paper the main problem are the formation of air entrapment, web instability and wrinkles. Nip pressure may be used as a tool for controlling the air entrapment as well as for limiting large wound on tension that would lead to yielding or wrinkling defects within the wound roll.

In this paper nip pressure is studied as a function of geometrical and material parameters of the rolls in order to identify and quantify their individual and cumulative influence. For this purpose measurements with Tekscan's pressure-sensing technology and Fuji's colour-forming and developing films were performed together with finite element calculations.

The results offer a better understanding of the connection of geometrical and material parameters to the quality of reeling process and can be used as practical guidelines for designing reeling rolls.
ABSTRACT

Literature on wound roll structure of non-homogeneous webs is scarce. Experimental and analytical research on wound roll structure of homogeneous materials such as plastic films and paper has been reported extensively, although at some scale the homogeneity of paper can be questioned. This paper will focus on a non-woven polyethylene. Results from the literature for film and paper webs show proportionality between wound-in-tension and nip load at lower nip loads and at higher nip loads the wound-in-tension becomes independent of nip load in both surface winding and center winding with an undriven rider roller. The proportionality between wound-in-tension and nip load at lower nip loads has been shown to approach the kinetic coefficient of friction between web layers for those materials. In the non-woven polyethylene web studied, the proportionality was much less than the kinetic coefficient of friction. Tests conditions, including slip velocity, are known to affect measured friction coefficients. Wound-in-tension is the result of micro-slippage and elongation of the web in the contact zone beneath the rolling nip which involves the field of contact mechanics. Theorists in this field have presented arguments that friction coefficients used in contact analyses must be appropriate for the conditions of micro-slip which occur in the contact zone. Results of winding tests and finite element contact analysis will be presented which focus on this problem.
WOUND ROLL GENERATED UNSTABLE VIBRATION 
ON A TWO-DRUM WINDER

by

M. Jorkama¹ and R. von Hertzen²
¹Metso Paper, Inc.
²Lappeenranta University of Technology
FINLAND

ABSTRACT

Nip contact between the paper roll, winding drum and rider roll or some other nip roller may cause that the wound roll is deformed into a convex polygon. This deformation process is accompanied with a strong vibration. The conditions under which this phenomenon occurs depend very much on the web properties. For example, in the paper industry some bulky grades with a high layer-to-layer coefficient of friction are known to be prone to this unstable vibration.

In this paper a simple wind-up model of a two-drum winder, capable of capturing quite comprehensively this phenomenon is developed. The pattern formation is modelled via viscoelastic surface deformation. This results in a system of linear delay differential equations. Performing Laplace transformation to the system equations enables to study the stability of the system as a function of the web properties, nip drum stiffness, windup geometry and damping. The model parameters related to the viscoelastic surface deformation are measured experimentally for several paper grades.

The paper is concluded by studying the system stability in a certain resonance condition. It is demonstrated that the system can be stabilised by changing the structural parameters of the winder.
ABSTRACT

Much consideration has been given to the relationship between web line tension and the stresses they induce in three dimensional wound rolls. Three dimensional wound rolls are distinctive because their radial and circumferential stresses are not uniform across their width. The non-uniformity results from numerous factors including Cross Machine Direction variations in the core stiffness, web thickness, or web line tension. Whatever the source, ultimately they produce variations in the radius across the width. In order to maintain material continuity, the incoming layer must therefore conform to a winding roll that is non-uniform in radius across its width. This is accomplished when the applied web line tension allocates across the width in proportion to the roll's local radius, as it converts into the outside layer's circumferential stress. The tension concentrates in high regions and disperses in the low regions. The model presented herein combines axisymmetric finite element analysis with a radius based tension allocation algorithm in order to simulate the actual stresses in a three dimensional roll. The circumferential stresses across the width are iteratively made to sum to the web line tension boundary condition. Comparison with experimental data from three dimensional rolls shows the model captures the essence of the roll behavior. It thus confirms the existence of the radius dependent tension allocation.
WIDTHWISE VARIATIONS IN WEB PROPERTIES
AND WOUND ROLL STRUCTURE

by

J. E. Olsen
SINTEF Materials and Chemistry
NORWAY

ABSTRACT

Widthwise variations in web properties affect wound roll structure. Cole & Hakiel published a two-dimensional model in 1992 which took widthwise variations in web thickness into account. Based on this publication a model accounting for widthwise variations in thickness, MD- and ZD-stiffness and frozen-in strains have been derived. The model enables calculations of wound roll stresses and outer roll radius. The model is presented and results of different effects discussed.
WINDING OF INTERLEAVED MATERIALS

by

H. Lei and K. A. Cole
Eastman Kodak Company
USA

ABSTRACT

The manufacturing of flexible display products has very tight specifications on the dimensional changes between the coating stations or between different passes of a multi-pass coating process. Web stretching and stress relaxation during conveyance and roll storage all contribute to the dimension stability of this product, and therefore are potential concerns. The quality of a flexible display is very sensitive to defects in the films that are used as part of the assembly. Many film components used in the display are very delicate and can be damaged during web handling. To protect the film from damage during the winding process, it can be interleaved with another film, typically one that is softer and significantly cheaper. This paper reports data from a stress relaxation test on a specific polyethylene terephthalate (PET) web, and on the modeling of the stress development, stress relaxation, and dimensional changes of the PET from roll winding and wound roll storage. We also present modeling results and empirical data on the winding of interleaved films.
ON THE DURABILITY OF CORES AND REST ROLL DYNAMICS

by

M. Ilomäki
Sunoco-Alcore
FINLAND

ABSTRACT

The printing industry is facing the same challenges as many other industries, in that demand is increasing for its processes to run faster and more reliably. Roll weight, width and web speed are steadily increasing which put increasing demands on unwinding stability and durability of cores.

Durability and especially the unwinding stability of cores is one of the most important topics when designing new wider printing machine unwinders. The majority of paper and printing industry processes run with recyclable paperboard cores. A change in core geometry could lead to significant retrofitting costs for both the paper mill and printer.

Winder and printing press reel stand design, especially with regards to chucks, can have a considerable effect on the maximum tolerated roll weight and unwinding web speed. It is important to use the right combinations of cores and chucks to maximize performance and cost savings.

The risk of rest reel explosions increases rapidly in the vicinity of the resonance frequency of a rest reel. It is important to know the safe web speed ranges in different situations. The range of safe web speed can be estimated according to the presented theory. The maximum tolerated mid span vibration is typically +/- 5 mm.

Cores must also withstand the alternating, cyclic roll supporting stresses during winding and unwinding. The risk of core failure can be minimized by using cores which have sufficiently high dynamic delamination strength (roll weight capacity).

The durability of cores can be estimated by dynamic chuck load capacity tests and by testing cores in simulated winding-unwinding conditions. The simulation test results are reduced to correspond to certain confidence levels by reducing the simulation curve by a certain number of standard deviations.

With a sufficient number of chuck load capacity tests, statistically reduced winding-unwinding simulation results and test data concerning behavior of cores in the vicinity of Resonance, core recommendations can be built for core users as shown here.
IN-ROLL STRESS ANALYSIS CONSIDERING AIR-ENTRAINMENT AT THE ROLL-INLET WITH THE EFFECT OF GROOVES ON NIP ROLL SURFACE

by

M. Sasaki¹, K. Kohno¹, K. Tanimoto¹, S. Takahashi¹, S. Suzuki¹, and H. Hashimoto²
¹Mitsubishi Heavy Industries, Ltd.
²Tokai University
JAPAN

ABSTRACT

High-speed winding of paper web sometimes leads the winding system into unstable states, interlayer slippage of wound roll, paper breakage and so on, due to the excessive air-entainment at the roll-inlet of nip contact region. These phenomena are more frequently observed on coated paper or plastic film comparing with newspaper, because the former allows little permeation of air and their surface roughness is small. Therefore, it is of vital importance to clarify the in-roll stress of wound roll considering the effect of air-entainment.

Generally, it is known that the amount of air-entainment is affected by grooving shape of nip roll surface. In this paper, we focused on the grooving shape and investigated the relationship with the air-entainment into two rolls being pressed each other and the grooving shape in order to achieve stable winding at high speed. We conducted experiments using small sized test machine. Entrained air-film thickness was evaluated applying the solution of the elasto-hydrodynamic lubrication for foil bearing with the consideration of nip profile at the grooved area. Air film thickness was measured to ensure the applicability of the above theory.

Consequently, we found that the air film thickness can be estimated considering the effect of grooves on the nip roll surface, and that the validity of the above estimations was ensured from experimental investigations. Furthermore, it became to be able to propose the optimal shape of grooves on nip roll surface to maintain the stable winding at high speed and at large-diameter in reel.
INFLUENCE OF THE GAP THROTTLE EFFECT ON THE WINDING PROCESS AND ROLL QUALITY

by

E. G. Welp, A. Kleinert, and V. Smukala
Ruhr-University Bochum
GERMANY

ABSTRACT

In the paper industry the winding technology has a significant influence on the quality of finished rolls. The rising productivity and quality efforts require a constant optimization of the winding process concerning the winding speed, the damage-free structure of the wound rolls and the appropriate transport stability. The air between the layers of the roll negatively affects the achievable quality. Up to now, grooved or nip rollers were used to avoid air entrainment. These principles were proved to be insufficient at high winding speeds in their operation limits.

The innovative application of a gap throttle foil reduces the air entrainment to such an extent, that a higher contact pressure between the incoming layer and the roll is reached. In this work the performance of the gap throttle effect during winding was theoretically investigated. A simulation tool, which calculates the inner state of stress in a wound roll under different process parameters by the use of a gap throttle foil, was developed. Especially the influence of web tension, web speed, roll radius, gap throttle foil thickness and immersion depth are considered as parameters. Furthermore additional elements like contact rollers to support the gap throttle effect are investigated.

The results prove, that the effect can be used to achieve higher radial tension in the roll. Subsequent investigations show, that the effect amount and its stability can be increased considerably by an additional small pressure on the web surface at the mounting area of the web. This novel principle for winding machines should be investigated furthermore, because without nip rollers, a paper friendly winding process and a winding quality comparable to the quality of center-surface winder could be realized.
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RAISING INNOVATION TO THE POWER OF
SCIENCE AND TECHNOLOGY

by

Peter Dulcamara
Kimberly Clark Corporation
USA

ABSTRACT

Mr. Dulcamara will discuss how/why innovation is the key business imperative for the 21st century and how/why strategic investment in science & technology is critical in creating long-term shareholder value. We have reached a point in human history when virtually all knowledge is available to everyone (think Wikipedia). The only true differentiator is creativity, imagination, innovation, and the ability to execute. Before the Internet, Bacon was right, “knowledge is power;” but in the post-Internet world, Einstein is right, “Imagination is more important than knowledge.” While Quality was the mantra of the ‘80s (think Deming, Juran, Crosby, Kaizen, TQM, etc) and productivity was the focus of the ‘90s (think Hammer, SAP, ERP, Six Sigma, etc), the business imperative today is innovation. Strategic investment in science & technology is required to develop distinctive capabilities to provide differentiated offerings & business models to the marketplace. It is through these differentiated offerings that brand equity is built and ultimately long-term shareholder value is delivered by corporations.
MECHATRONIC DAMPING FOR CONTACT ROLLS IN FILM WINDERS

by

Bernd Sieber
Brückner Maschinenbau GmbH & Co. KG
GERMANY

ABSTRACT

The winding of a web is one of the most extensive and error-prone processes in web handling. All known solutions are limited in the range of properties and production parameters. To broaden the mentioned limits, a new mechatronic system for the feeding drive of the contact roll has been developed. A comprehensive simulation with several models has shown the behavior of the new system. The model considers in the final state the elasticity and mass of all relevant elements. The main functions of the feeding drive operating the contact roll for positioning, pressing against the winding roll and for the active damping have been modeled. The simulation has revealed the avoidance of backlash in the feeding drive as the most important factor for the winding result. The second important factor is the damping of the contact roll.

The principle of the new system involves the application of an electric linear motor for the feeding. This drive is free of backlash. The linear drive as a part of the control loop is featured by a simple remote control according to the most relevant parameters in the winding process – the nip pressure and the damping of the vibrations excited by the rotating winding. A test stand consisting of the components of a real feeding drive assembly was built to verify the simulation results. The test results confirmed the simulation results. The results in industrial applications have shown the congruence with the results of both the simulation and the test bed.

The new drive has been introduced in film stretching lines. The results in industrial applications have shown the congruence with the results of both the simulation and the test bed. Especially the remote control of the contact force and the damping are the most important features. The quality of the wound roll has been improved significantly.
MODELING WOUND ROLLS USING EXPLICIT FE METHODS

by

B. K. Kandadai and J. K. Good
Oklahoma State University
USA

ABSTRACT

A new method of wound roll analysis using an explicit finite element formulation is presented in this paper. The stresses developed in center wound rolls with and without an undriven nip roller are discussed and compared with analyses found in literature. For center wound rolls with an undriven nip roller, the results show that the Nip-Induced-Tension (NIT) is proportional to the coefficient of friction between web layers and the nip load. The NIT is also found to be independent of the web tension. The conditions of slip that exist between the layers in the wound roll, the effect of start-up web to core discontinuities, advantages and limitations of this modeling technique have also been discussed.
GAUGE OPTIMIZATION OF THE REFERENCE TENSION IN WINDING SYSTEMS USING WOUND INTERNAL STRESSES CALCULATION

by

M. Boutaous,¹ D. Knittel² & P. Bourgin³
¹Centre de Thermique de Lyon
²Louis Pasteur Université
³Ecole Centrale de Lyon
FRANCE

ABSTRACT

In winding process, the quality of the roll is directly connected to its stress state. The winding tension is the most significant parameter which plays an important role in the stresses generated within a roll, during winding. If the stresses exceed a critical value, defects can appear in the roll and make the web non usable.

This work concerns the estimation and optimization of the maximal dispersion of the reference tension, so that the tangential and radial stresses values remain in a gauge. It aims to find automatically the maximum and minimum limits for the reference tension, so that all curves ranging between these two limits or thresholds, generate radial and tangential stresses, theirs selves included in a gauge fixed in advance. The results lead to a practical gauge optimization of the reference tension for industrial applications.
AUTO TAPER TENSION PROFILE MAKER
IN A CONVERTING MACHINE

by

C.W. Lee,1 J.W. Lee,1 K.H. Shin,1 and S.O. Kwon2
1KonKuk University
2Sung-An Machinery
KOREA

ABSTRACT

Winding is an integral operation in almost every web handling processes. Center-winding are suitable and a general scheme in winding systems. However, the internal stresses within center-wound rolls can cause damage such as buckling, spoking, cinching, etc. Wound roll quality and performance are known to be related to distribution of in-roll stresses. It is therefore necessary to analyze the relationship between taper tension in winding section and internal stress distribution within center-wound roll to prevent the potential winding failure (starring, buckling, telescoping, etc.).

In this study, a new taper tension control method for producing high quality wound roll was developed. The new method was induced from analyzing the winding mechanism by using the stress model in center-wound rolls, nip induced tension model, taper tension profile-telescoping relationship, and taper tension type-internal stresses relationship, etc. Auto taper tension profile making method for avoiding the damage (telescoping, buckling, cinching, etc.) is presented. The experimental results show that the proposed method is very useful.
A NEW METHOD FOR MEASUREMENT OF WOUND-IN-TENSION IN WEBS
WOUND INTO ROLLS

by

J. K. Good, B. K. Kandadai, and R. Markum
Oklahoma State University
USA

ABSTRACT

The Wound-In-Tension (WIT) is the tension in the outermost layer of a winding roll. The Wound-In-Tension is an important parameter that controls the stresses inside the wound roll which in turn determines the quality of the wound roll. Existing on-line methods of measuring or inferring WIT can be interfering measurements or suffer from inaccuracy. This paper documents a method of on-line WIT measurement that is based on the change in deformation of the web from a first location upstream of the winder, where the web tension is known, to a second location where the web has become the outer layer of the winding roll. It will be shown that these measurements can be made by non-contacting means such as Laser Doppler Velocimetry or by contacting means where encoders are employed. Results of the WIT measurement by the new method are compared to traditional WIT measurements on wound rolls of various materials.
A PSEUDO 3D VISCOELASTIC WINDING MODEL

by

Haowen Yu, Edmond Poh, J. Keith Good and Hongbing Lu
Oklahoma State University
USA

ABSTRACT

A pseudo 3D winding model that has considered orthotropic viscoelastic effects during winding and storage has been developed and implemented in a code revised from the 2D viscoelastic winding code developed by Qualls and Good [1]. The model discretizes the web into smaller segments of equal width, each having a constant web thickness within a segment. Tension is assigned to each segment using Hakiel's approach [2]; the tension is updated after the winding of each lap based on the deformed radius of the segment relative to the relaxed radius profile of that lap. In each segment, a 2D winding model is applied. The pseudo 3D model is capable of dealing with (1) a varying thickness profile in both CMD (cross machine direction) and MD (machine direction); (2) winding tension variation with the winding laps; and (3) varying core stiffness in the CMD. Moreover, with the consideration of viscoelastic behavior in the web, the effects of winding conditions, such as winding speed and tension, on the wound roll stress can be determined. The model is especially suitable for viscoelastic materials with relatively short characteristic relaxation times, such as plastic webs with glass transition temperature close to room temperature. Numerical methods were used to determine the stress distributions in the wound roll. The pseudo 3D viscoelastic winding model was validated by comparing results on the dimensional changes of a web in three situations. They include (1) the formation of cambered web (in-plane imperfection) due to linearly varying thickness; and (2) the formation of localized baggy lanes due to an edge burr following slitting; and (3) the formation of baggy web (out-of-plane imperfection) due to increased web thickness in the middle of the web. Simulation results compare favorably with experimental data.
ABSTRACT

Aspects of lateral behavior discussed in this paper include (1) the concept of a web span as a tensioned beam, analyzed for large ratios of L/W, small ratios, and general ratios, and (2) static interaction of two spans and the bistable “jump” phenomenon.

Aspects of transport of a web which are discussed are (1) the importance of $J/R^2$ for a roller, not the mass moment of inertia J by itself, (2) dimensionless energy parameters which determine the effectiveness of dancers and other elements of transport as attenuators of disturbances to tension, and (3) principles of design of rollers, such as the need for uniform wall thickness and the need for large, thin-walled rollers.
ADVANCED CONTROLS FOR WEB HANDLING: READY FOR PRODUCTION?

by

Dan Carlson
3M Company
USA

ABSTRACT

The science of web handling has numerous control challenges. Longitudinal control is especially challenging because the machine is a distributed, high order, tightly coupled flexible system. Advanced controls were developed in the last few decades, and have been widely applied in several fields, most notably aeronautics, robotics, navigation, and extremely large-scale high-value industrial processes, such as petroleum refining. There have been numerous advanced web handling control strategies papers previously presented at this conference. However, there are few implementations of advanced controls in commercially available web handling equipment.

The Proportional-Integral-Derivative (PID) controller was originally developed in the 1920’s. The PID controller dominates web handling controls to this day; virtually all web handling is controlled by variations of the PID algorithm. While an optimized PID controller can perform well, there are superior control algorithms that have higher performance and more flexibility, but they have yet to displace even a small number of PID systems.

While this paper is fundamentally on control topics, this presentation is targeted towards a general web handling audience; a general broad overview will be presented. This paper will provide a brief history of control, emphasizing the role of PID in industry. It will illustrate some of the circumstances that have limited the adoption of advanced web handling control strategies, and propose potential solutions to increase the rate of adoption of advanced web handling controls. In addition, several high value web handling problems that may greatly benefit from these strategies will be discussed.
PEELING PROCESS DEVELOPMENT FOR THIN FLEXIBLE WEBS

by

Herong Lei¹ and Kevin A. Cole²
¹Eastman Kodak Company
²Grid Computing Solutions, LLC
USA

ABSTRACT

Many consumer products are manufactured from continuous media. When the media is thin and flexible, it is referred to as a web. Webs are typically manufactured by extrusion or casting; however, for some applications, a coating process onto a sacrificial carrier web, followed by a peeling process, provides a more robust means to achieve the functional requirements of thin webs. One example of this is with the protective cover sheet for LCD polarizers. Conventional casting is impractical because of the thickness and tear-sensitivity of the preferred support material. The coating and peeling processes, however, are not without their own problems. This paper describes work aimed at developing a robust coating and peeling process for the manufacture of protective cover sheets for LCD polarizers. First, we describe the general process method. Next, we focus our discussion on the development of the web peeling process and review in detail the peeling imperfections, such as ripping and tearing defects, that negatively impacted our ability to successfully peel the thin webs from the carrier webs. Web handling findings from this work will also be shared.
ABSTRACT

For purposes of design and optimization of industrial processing, many of the physical properties of paper have to be taken into account. The knowledge of the mechanical properties as part of the physical ones must be extended by considering hygroscopic, thermal, optic and electric material aspects. The knowledge on these properties will support the paper processing and converting industry in optimization of their processes and quality of paper.

In previous projects at the Institute of Engineering Design (LMK, Ruhr-University Bochum, Germany) a complete material law was developed and implemented into a finite element system [37]. This model contains also yielding and hardening which are major mechanical properties of paper.

Our ongoing research on the physical properties of paper determines thermal and hygroscopic material behavior. The determination of these physical parameters can be divided into a constructive, an experimental and an analytical part which was performed iteratively.

At first a usual test chamber with temperature control for general material testing was used for determining mechanical properties of paper in the three main directions under all process relevant temperature conditions. In this setup the climate conditions reach the limit for paper testing very soon. Therefore, an individual test chamber was conceived and developed to perform the relevant test environment for the analysis of paper under process relevant thermal and humid climate conditions. Secondly, mechanical experiments were performed in order to find the physical paper behavior, beginning with the mechanical properties of heated and moistened paper. Finally a mathematical formulation of hygro-mechanical behavior of paper was determined.

From our data we found correlations between moisture content and runnability properties. The humidity influence on the elastic modulus and on the strain properties of paper were determined with tensile tests in machine direction (MD) and compression tests in thickness direction (ZD).

Improving this knowledge of general physical material parameters can lead to a realistic mathematical formulation of the physical force-deformation-behavior in paper.
and paperboard grades in future. Principles, designs and settings of finishing and converting machines can be optimized by using material laws in process analyses, based on this advanced material knowledge. Furthermore, details of the expected runnability properties of established paper and paperboard grades can be determined.
ABSTRACT

C Shear slitting of two aluminum webs, namely 1050 H18 of 0.28 mm thick and 5182 H19 of 0.20 mm thick, using block knives are investigated through experiments using a laboratory slitter. This investigation focused on two aspects of shear slitting using block knives, appropriate for relatively thick webs. They are: (1) tangential shear slitting at zero rake angle, i.e., traditional shear slitting with a pair of block knives. In this aspect, the effects of major slitting parameters on the burr height at the slit edge were investigated. These include the clearance, overlap, overdrive and cant angle. The critical clearances for both webs have been determined; and (2) slitting at a rake angle, a new method for edge trimming when the two blades are not necessarily in contact. The top blade geometry was modified for slitting with a rake angle of -15° to allow slitting of an aluminum web, up to 1 mm thick in this investigation. This new method of edge trimming using block knives was found to be very effective and robust over a (relatively) very wide range of slitting parameters. Very good slit edge was produced, and the burr height was found to be independent of slitting parameters over a relatively large range of slitting parameters. Because two blades do not have to be in contact in slitting so that the blade wear is much less than in the case of traditional shear slitting, this new method is expected to extend significantly the block knife service life while producing consistently high quality slit edges.
DESIGN OF FIXED STRUCTURE CONTROLLERS FOR WEB TENSION CONTROL

by

P.R. Pagilla¹, M. Cimino¹, and D. Knittel²
¹Oklahoma State University
USA
²Louis Pasteur University and INSA, Strasbourg
FRANCE

ABSTRACT

It is a common practice in industry to design a Proportional-Integral (PI) velocity feedback controller cascaded with a PI outer tension loop to regulate web velocity and tension to their desired values. The controller gain tuning is often heuristic and does not explicitly account for process variations, and often fails to provide adequate performance in the presence of uncertainties. To address these issues, one can pose two key questions: (1) How does one systematically obtain controller gains for a given controller structure and a set of operating conditions? (2) Is it possible to systematically choose controller gains to satisfy some pre-defined performance specifications for the closed-loop system when the operating conditions and web material properties have variations?

The goal of this paper is to investigate methods to address the above two questions. Methods from robust control theory are used to investigate and develop techniques to systematically design fixed structure controllers that satisfy pre-specified performance criterion. Although the design procedure allows for choosing controller structures with different number of gain parameters, emphasis will be given to controller structures that contain two or three gain parameters (The PI controller structure has two gain parameters). The objective is to use parametric methods whose end result is a region of controller gains which will satisfy the specified performance criteria. Although emphasis is given to tension control, the proposed techniques can be used for other control loops such as velocity or dancer or lateral position control systems. Since the methods used are an outgrowth of classical time and frequency response methods, it is expected that a control engineer with an understanding of classical techniques will be able to comprehend the design procedures discussed in the paper.
VIBRATION OF TWO AXIALLY TRANSLATING MEDIA INTERCONNECTED BY WINKLER ELASTIC FOUNDATION

by

M. Gaith¹ and S. Müftü²
¹Al-Isra Private University
 JORDAN
 ²Northeastern University
 USA

ABSTRACT

Transverse vibrations of two translating strings interconnected by a Winkler elastic foundation, and subjected to axial loading are investigated. The natural frequencies are composed of two infinite sets, representing in-phase and out-of-phase vibrations of the two strings. The effects of the axial tension ratios of the two continuous media, as well as the effects of the elastic foundation stiffness are investigated. In general, it is found that the natural frequencies increase with increasing foundation stiffness. Different mass and tension ratios between the strings alter the critical translation speed, in contrast to presence of the elastic foundation.
ABSTRACT

This paper discusses the aerodynamic dancer that is effective in a wide range of frequency and do not cause excessive lateral web deflection, touching, or flutter. An aerodynamic model of air-turn bar has been developed. The model can handle air-turn bars that have varying density of air-emitting holes. The model predicts the average flotation height of the web, cushion pressure profile under the web, and the rate of air consumption for given operating conditions. Experimental verification of the aerodynamic model has been done with a stationary-web test setup. The air gap profile, the cushion pressure profile, and the air consumption were measured, and the results were compared with the prediction. Also examined was the possibility of using an air reverser for determination of web tension. Web tension was varied up to 175 N/m (1.5 lbf/in). The measurement error of web tension based on cushion pressure was less than 5 percent in the entire range of test conditions. An air dancer model has been developed based on the aerodynamic model of air-turn bars and compared with experimental results. It was shown that the air dancer system has a much wider useful frequency range compared to the conventional dancer system.
MODELING OF LAMINATED WEBS

by

P. R. Pagilla, K. N. Reid, and J. Newton
Oklahoma State University
USA

ABSTRACT

A dynamic model of the longitudinal behavior of a laminated web is developed. A single web model that takes into account both thermal and hygral strains is developed first from first principles; the model assumes heat transfer in the region of wrap and free web span and moisture diffusion in the free web span. A classical one-dimensional heat equation is considered in the transverse direction to determine the heat transfer in the region of wrap. In the free web section, a lumped capacitance model is used to investigate heat transfer from the web surface. Moisture diffusion from the web surface is assumed to follow Fickian diffusion, which is used to determine hygral strain in the web. Mechanical and physical properties of a laminated web consisting of two isotropic webs of different material are stated using the rule-of-mixtures. The developed single web model and the laminate properties are used to derive a dynamic model for a laminated web span immediately downstream of the laminator rolls.
FREE VIBRATION ANALYSIS OF THIN, TENSIONED, HELICALLY WRAPPED WEBS USING MINDLIN-REISSNER FINITE ELEMENT METHOD

by

Ernesto Lopez¹, James Masters² and Sinan Müftü¹
¹Northeastern University
²CD-adapco
USA

ABSTRACT

Free vibration analysis of a thin tensioned web, wrapped around a reverser was studied. The effect of helix angle was considered. The eigen-problem was formed using finite elements and solved numerically. Design parameters such as tension, radius of cylinder, wrap angle, width of the web, lengths of non-wrapped web and helical wrap angle were studied. It was seen that the free edges cause a frequency clustering of the lateral-modes about the dominant longitudinal-mode. It was also seen that the effectiveness of the plate-shell junction to act as a stiff support depends on problem parameters. Eigenmodes with same mode-shape numbers are observed in symmetric and anti-symmetric fashion about the center of the plate, for configurations with equally long unwrapped sections. The results also showed that the first natural frequency is reduced at large helical angles for the parameters studied.
ABSTRACT

Parylene-C, an inert and relatively mechanically strong polymer, which can be deposited in a conformal manner, is a promising substrate candidate for flexible electronics (Flextronics) devices. Parylene-CNT sandwich-films were fabricated by utilizing single-walled carbon nanotube (SWNT) layers sandwiched between two, 10 μm thick parylene layers. The device was fabricated using shadow mask technology and SWNT drop casting on top of the Parylene substrate. The electrical conductivity and mechanical properties of the samples were tested under tensile loading. The load-unload tests showed small change in electrical resistance (~1%) when applying a strain in the range 0 - 2%, with negligible hysteresis. The tensile test also showed ~32% increase in the elastic modulus ($E$) of the sandwich film, relative to pure parylene. Potential applications are in interconnects for flexible electronics devices, and strain sensors for biological systems.
ABSTRACT

This paper proposes a metric for the permeation of the science of web handling into industry. The variable of interest is misunderstandings, myths if you will, that are common in plants. The origin of the myths is unimportant and often undeterminable. What is important is whether the old plant conventional wisdom has been replaced by the new science of web handling. Perhaps the most common myth is that spiral taping or grooving of rollers spreads the web. However, there are many other misconceptions in the areas of tracking, tension control and winding that are least as limiting. This paper lists these myths, their possible arena of application, the dangers of assuming validity in applications where they are not correct and references for our current best understanding.

Science is but an image of the truth. - Francis Bacon

It ain’t so much the things we don’t know that get us into trouble. It’s the things we know that just ain’t so. - Artemus Ward
ABSTRACT

A concave roller is an effective and inexpensive wrinkle-preventing roller design. By definition, a concave roller (a.k.a. a reverse-crowned roller) is a roller with a larger diameter at the edges than at its center. But a definition is not an engineering specification. What is the right amount of diameter variation? What is the best way to shift from large to small diameter? This paper will present a simple, logical approach to specifying a concave roller’s profile tailored to roller and web properties.

Beyond a concave roller’s anti-wrinkle effects, they also have a lesser known web-to-roller traction benefit. Most air lubrication and traction models only consider cylindrical rollers. Concave rollers induce crossweb tension variations, creating crossweb differences in air lubrication and web-roller coefficient of traction. By combining concave roller tensioning with air lubrication and traction models, this paper will show how a concave roller will maintain good traction and better control under higher lubricating layers than a cylindrical roller of the same surface roughness or texture.
WEB SAG AND THE EFFECT OF CAMBER ON STEERING

by

Dilwyn P. Jones
Consultant, Emral Ltd.
UK

ABSTRACT

A web in a horizontal span will deflect downwards due to gravity. This sag is more pronounced for heavy materials in long spans under low tension. It is possible for a web whose unstretched length is greater than the span to be under positive tension.

A cambered web will sag more on the baggy side, especially under low web tension. This side therefore has a longer path length between rollers in good alignment, which provides a mechanism for lateral steering. The boundary conditions of normal entry and velocity matching on the downstream roller (which successfully predict the steering of straight webs by misaligned and tapered rollers) can still be applied without modification.

A horizontal span of cambered web under tension has been simulated using Finite Element Analysis, showing that the web steers to the tight side. The amount of movement varies with span length, tension, density, amount of camber and width. For low tensions, the displacement can be quite large, but it falls rapidly as tension is increased.
ABSTRACT

In an earlier IWEB paper, “A New Method for Analyzing the Deformation and Lateral Translation of a Moving Web” [5], a nonlinear PDE model, suitable for use with low-cost FEA software, was developed. That work considered only in-plane deformation of a flat web. For a twisted web, something more is needed. Attempts to run a straightforward three-dimensional model on a 3D version of the FEA software were unsuccessful. It seems that adding an extremely thin third dimension causes serious convergence difficulties for the solver. Furthermore, the number of nodes increases dramatically, causing run times to increase from minutes to hours. More sophisticated or special-purpose FEA codes might be able to cope with the problems. However, one of the goals of this work is to develop methods that will run fast on low-cost software. So, attention is focused on creating a two-dimensional solution based on concepts similar to those used in large-deflection plate theory.

This paper describes such a model. It incorporates the following features.

1. It allows analysis of the effects of rollers that have both in-plane and out-of-plane misalignment, including large rotations.
2. Since the equations of equilibrium for the in-plane stresses are the same as those used in the [5], this model is a natural extension of that work.
3. It incorporates the normal entry and normal strain boundary conditions for the downstream roller and can, therefore, include the effects of nonuniform webs and rollers.
4. Nonlinear definitions of stress and strain incorporate the effects of large rotations.
ABSTRACT

All known web spreading hardware work based upon one of three principles. Sometimes it is unclear which principle(s) apply to a given spreading device. The flexible spreader roller is such a device. In this paper we will employ engineering mechanics to determine by what principle these devices spread a web. If the analysis is successful we will be able to design a flexible spreader roll to remove the lateral slackness from a given web.
Session 1 – Winding

 Finite Element Analysis of Winding Nip Mechanics
  B. K. Kandadai and J. K. Good, Oklahoma State University, USA

 Measurement of Nip Induced Tension and Contact Stresses
  B. K. Kandadai and J. K. Good, Oklahoma State University, USA

 Prevention of Wound Roll Defects on Coated Webs
  T. Kanda¹, S. Akemine¹, and H. Hashimoto², ¹LINTEC Corporation, ²Tokai University, Japan

 Large Deformation Winding Models
  C. Mollamahmutoglu and J. K. Good, Oklahoma State University, USA

 Optimization of Wind-Up Tension of Webs Preventing Wrinkles and Slippage with Experimental Verification
  H. Hashimoto, Tokai University, Japan

 Axisymmetric Wound Roll Models
  C. Mollamahmutoglu and J. K. Good, Oklahoma State University, USA

 Gentle Wavy Defects in Knurled Wound Rolls
  K. Cole, Optimation Technology, Inc., USA

 Keynote Presentation I

 The Ups and Downs and Thrills of the Space Program
  J. Herrington, (Commander USN, ret., former NASA astronaut)

 Session 1 – Winding (continued)

 Intelligent Roll Platform for Better Runnability
  T. Pitkänen¹, B. Bettendorf², and M. Tuomisto³, ¹Metso Paper, Finland, ²Metso Paper, USA, and ³Martti Tuomisto Consultant, USA

 Modeling Grooved Rolls with Moving 2D Porous Media
  S. Nurmi¹, F. Berström¹, E. Immonen¹, A. Lehtinen¹, K. Juppi², and L. Martinsson³, ¹Process Flow Ltd Oy, Finland, ²Metso Paper Oy, Finland, and ³Albany International AB, Sweden
Session 2 – Web Dynamics & Tension Control

Modeling and Control of Web Velocity and Tension: An Industry/University Perspective on Issues of Importance
D. Carlson¹, P. Pagilla², and M. Weaver³, ¹3M Corporation, ²Oklahoma State University, ³Rockwell Automation, USA

Web Tension in an Accumulator and Industry Needs for the Future
N. J. Michal, Kimberly-Clark, USA

Improvement of Control of a Web Accumulator
J. J. Shelton, Oklahoma State University, USA

Modeling and Identification of the Source of Oscillations in Web Tension
C. Branca, P. R. Pagilla, and K. N. Reid, Oklahoma State University, USA

A Mechanistic Survey of Accumulating, Resonant, and Self-Exciting Systems in Web Handling
D. Roisum, Finishing Technologies, Inc., USA

Web Line Resonant Frequencies
Y. Diao and P. R. Pagilla, Oklahoma State University, USA

A Process Direction Dynamic Model for High Precision Web-Belt Transport Systems
M. Yang, Xerox Corporation, USA

Computation of Span Length Variations Due to Out-of-Round Material Rolls
C. Branca, P. R. Pagilla, and K. N. Reid, Oklahoma State University, USA

Session 3 – Air Entrainment, Traction, Surface & Slitting Mechanics

Industrial Use for the "Nip-Inducted Effect" to Separate Sheets
M. Desch¹, T. Kaulitz, and E. Dörsam, ¹Technische Universität Darmstadt, Germany

Improvement of Slippage and Wrinkling of Transporting Webs Using Micro-Grooved Rollers
H. Hashimoto¹ and S. Hikita², ¹Tokai University, ²Fujifilm Corporation, Japan

Laminate Theory Based 2D Curl Model
S. Kidane, 3M Corporation, USA

A 2D FSI Model for Paper Webs and Fabrics Moving Close to Each Other in Complex Geometries
E. Immonen¹, F. Bergström¹, S. Nurmi¹, A. Lehtinen¹, K. Juppi², and L. Martinsson³, ¹Process Flow Ltd Oy, ²Metso Paper Oy, Finland, ³Albany International AB, Sweden

Measurement of Web Surface Profiles Using Fringe Projection
H. Lu, V. Bhumannavar, J. Liang, and Y. Ren, Oklahoma State University, USA

Phenomens of Rolling Contact in Paper Calendaring
V. Niebuhr¹, M. Desch², and E. G. Welp¹, ¹Ruhr-University Bochum and ²Technische Universität Darmstadt, Germany

Static and Dynamic Properties of CFRP Rollers
U. von Hülsen, Inometa Technologie GmbH & Co. KG, Germany
Transient 2D Paper Web Drying Model Based on CFD
A. Lehtinen¹, F. Bergström¹, E. Immonen¹, S. Nurmi¹, L. Martinsson², D. Ingvarsson², and K. Juppi³,
¹Process Flow Ltd Oy, Finland, ²Albany International AB, Sweden, and ³Metso Paper Oy, Finland

Keynote Presentation II

Predicting Web Wrinkles on Rollers
J. Beisel, H. Yurtcu and K. Good, Oklahoma State University, USA

Session 4 – Web Mechanics

Lateral Dynamics of Non-Uniform Webs
R. Swanson, 3M Corporation, USA

An Updated Model for Lateral Displacement of Nonuniform Webs
J. E. Olsen, SINTEF Materials & Chemistry, Norway

Two-Dimensional Behavior of a Thin Web on a Roller
J. Brown, Essex Systems, USA

The Taxonomy of Wrinkles
T. J. Walker, T. J. Walker & Associates, Inc., USA

Ultrasonic Based Multiple Web Sensing for Lateral Control Application
J. Haque, D. Winter, and W. Ploetz, Fife Corporation, USA
FINITE ELEMENT ANALYSIS OF WINDING NIP MECHANICS

By

B. K. Kandadai and J. K. Good
Oklahoma State University
USA

ABSTRACT

Wound-on-Tension (WOT) is the tension in the outermost layer of a winding roll that is created due to the incoming web tension and the tension induced by the nip roller called Nip-Induced-Tension (NIT). This paper presents the analysis of the contact mechanics between the nip roller, incoming web layer and the winding roll and explains the development of wound-on-tension in a winding process. In order to understand the contact mechanics an explicit finite element formulation is employed. The results show that the surface tractions that exist in the top and the bottom surfaces of the incoming layer underneath the nip roller give rise to a net traction. The sum of the incoming web tension and the total traction which is calculated as the integrated value of the net traction over the contact width produces the wound-on-tension. The numerical results show that the NIT is equivalent in both center and surface winding.

1 B. K. Kandadai works as a Mechanical Engineer at Kimberly-Clark Corporation.
MEASUREMENT OF NIP INDUCED TENSION AND CONTACT STRESSES

By

B. K. Kandadai and J. K. Good
Oklahoma State University
USA

ABSTRACT

Wound-on-Tension (WOT) is the tension in the outermost layer of a winding roll that is created due to the incoming web tension and the tension induced by the nip roller called Nip-Induced-Tension (NIT). Kandadai and Good [1] presented the analysis of the contact mechanics between the nip roller, incoming web layer and the winding roll and the development of wound-on-tension in a winding process using an explicit finite element formulation. This paper verifies the results presented in Kandadai and Good. Strain in the nip contact zone measured using contact strain gages compare well to the results from finite element analysis presented in Kandadai and Good. WOT measured using load cells compare well to the WOT values from the finite element analysis. Details including measurement devices, instrumentation and techniques are discussed herein.

1 B. K. Kandadai works as a Mechanical Engineer at Kimberly-Clark Corporation.
PREVENTION OF WOUND ROLL DEFECT OF COATED WEB

By

T. Kanda¹, S. Akemine¹ and H. Hashimoto²
¹LINTEC Corporation
²Tokai University
JAPAN

ABSTRACT

The web which is coated with a coating agent on the surface to add a function is called coated web. This coated web is often made into wound roll to ease handling and storage after coating, and then it is passed to next the manufacturing process to convert to a final product. However, if winding and unwinding tensions are inappropriate, wound roll defect which leads to the function degradation could occur. It is a method to generally adjust the tensions to prevent the wound roll defect. The adjustment has often been through a trial and error process that might lead to loss of time and cost. In order to cut them down, our work is to establish the technology to determine adequate winding and unwinding tensions efficiently through prediction of radial stress and slippage condition within wound roll. In this study, a release paper which is coated on a base paper with a release agent, has an easy peel-off property for pressure-sensitive adhesive (PSA) label is used as an example of coated web. We show one of the efficient methods determining the tensions to prevent the wound roll defect which causes the function degradation that leads trouble during a set of labeling process of PSA label. Additionally, the applicability of the method is showed by experimental verification.
LARGE DEFORMATION WINDING MODELS

By

C. Mollamahmutoglu and J. K. Good
Oklahoma State University
USA

ABSTRACT

Almost all winding models incorporate the assumption of small linear deformations and strain in development. As such these models treat the addition of a layer of web to a winding roll with linear analysis using linear strain theory. Some webs such as tissues and nonwovens are highly extensible in-plane and highly compressible through their thickness. Do the models which assume small deformations apply to these web materials?

In this paper a winding model developed using large deformation theory will be presented. The output of this model will be compared with the results of winding tests done in the laboratory and with the outputs of models which employ small deformation theory to answer the question posed.
ABSTRACT

This paper describes the optimization method of wind-up tension to prevent wound roll defects, mainly star defect (wrinkling) and telescope (slippage), based on the optimum design technique. Hakiel’s nonlinear model with air entrainment effects is applied to analyze in-roll stress distributions in the radial and tangential directions. It is well known experimentally that a decrease in the wind-up tension prevents star defects due to negative tangential stress under winding. Thus, in the present optimization method, wind-up tension is gradually decreased in the radial direction to minimize the tangential stresses under the constraint of nonnegative tangential stresses. At the same time, we consider the friction conditions to prevent the slippage between web layers due to a decrease of radial stresses and friction force. Successive quadratic programming, which is the typical mathematical programming method, is used as the optimization technique. Wind-up tension is expressed by the third-order spline curve of a radial coordinate. The linear function with respect to the radial coordinate is used as the original wind-up tension. The optimized wind-up tensions are obtained for various winding condition, and we confirmed theoretically and experimentally that the in-roll stress distributions were very much improved for preventing wrinkle and slippage by optimization method proposed.
ABSTRACT

Axisymmetric wound roll models provide the greatest definition of wound roll internal stresses to date. Simple one dimensional models can provide the user with radial profiles of pressure and circumferential stress as a function of radius. These models later evolved into pseudo two dimensional models where for the first time the impact of web nonuniformities such as thickness and web length could be studied across the web width. These models are described as pseudo two dimensional models because they were a series of the earlier one dimensional models. As such the outputs were limited to the pressure and circumferential stress outputs of one dimensional models but could also be used to predict the shape of the wound roll. Axisymmetric models provide outputs of pressure, circumferential stress, axial stress, and shear stress as a function of radius and cross machine direction location throughout a wound roll. As such these models are capable of describing more types of roll defects than all previous winding models. This paper will focus on the development of a new two dimensional axisymmetric wound roll model based upon a pre-stress formulation. The roll defects that axisymmetric models can be used to analyze will also be discussed.
GENTLE WAVY DEFECTS IN KNURLED WOUND ROLLS

By

Kevin Cole
Optimation Technology, Inc.
USA

ABSTRACT

The manufacture of many products involves the winding of continuous thin, flexible webs into wound rolls. In many applications involving the use of plastic webs, it is beneficial to mechanically emboss the edges of the web prior to winding so as to provide a thickening of the web in these areas. During and after winding, radial pressures developed in the wound roll then are concentrated in the localized embossed areas. This reduces the sensitivity to the formation of web distortions due to stress concentrations that would otherwise develop due to lengthwise persistent widthwise thickness nonuniformities. One of the drawbacks of this process is that the wound roll is now more sensitive to buckling-type defects owing to reduced interlayer pressures in the bulk of the roll away from the embossed edges. In this paper, we present results for a particular type of web defect known as a Gentle Wavy Defect (GWD) that forms in the wound roll due to presence of axial corrugations that develop in the wound roll. We begin by presenting product and process information characterizing this situation along with potential theories as to the cause of the corrugations and GWDs. Next, we provide results from numerous experiments that provide guidance on the likely mechanism responsible for the formation of the roll and web defects. Through these experiments and the application of winding models, we then demonstrate the cause of the defects and provide guidelines on how to avoid them in future applications.
THE UPS AND DOWNS AND THRILLS OF THE SPACE PROGRAM

By

John Bennett Herrington
Commander, USN, Ret. and Former NASA astronaut
USA

ABSTRACT

John B. Herrington graduated from Plano Senior High School, Plano, Texas, in 1976. He received a bachelor of science degree in applied mathematics from the University of Colorado at Colorado Springs, in 1983, and a master of science degree in aeronautical engineering from the U.S. Naval Postgraduate School in 1995.

John Herrington was a Distinguished Naval Graduate from Aviation Officer Candidate School, Pensacola, Florida, in 1984, and was designated a Naval Aviator in March 1985. From 1985 to 1995 he served in many command and test pilot roles within the U. S. Navy, and logged over 3,800 flight hours in over 30 different types of aircraft.

Selected by NASA for astronaut training in April 1996, Herrington reported to the Johnson Space Center in August 1996. Two years later, he qualified for flight assignment as a mission specialist. Herrington was assigned to the Flight Support Branch of the Astronaut Office where he served as a member of the Astronaut Support Personnel team responsible for Shuttle launch preparations and post-landing operations. He flew on STS-113 Endavour (Nov 23-Dec 7, 2002), the sixteenth Shuttle mission to visit the International Space Station. During the mission Herrington performed three EVAs totaling 19 hours and 55 minutes. STS-113 brought home the Expedition-Five crew from their 6-month stay aboard the Station.

Herrington left NASA in 2005 to join the commercial space company Rocketplane Global, Inc. as vice president and director of flight operations. He was slated to pilot the company’s passenger-carrying suborbital XP spaceplane. He resigned from Rocketplane in December 2007.

John Herrington continues to serve as an advisor to NASA and as a consultant in the commercial space industry because he believes “commercial space is the next great adventure in aerospace.” He is widely recognized as a motivational speaker to both industry and educational institutions, and as an advisor to the National Institute for Space, Science and Security Centers at the University of Colorado. In addition, he also works with the Chickasaw Nation, of which he is a member. He is active in the national
program FIRST Robotics, and helped bring a FIRST Robotics Regional Competition to Oklahoma in 2008.

Herrington said that working at both NASA and Rocketplane was a dream come true. There’s an aura associated with being an astronaut, but the reality is that it’s a lot of hard work,” he said. “When the thrill wears off, you stick your head in the books and you spend a lot of time learning what you need to know and then performing in a hostile environment. But it was a dream I had as a kid, and when you fulfill a dream like that it’s a phenomenal feeling.”
INTELLIGENT ROLL PLATFORM FOR BETTER
RUNNABILITY

By

Tatu Pitkänen¹, Bob Bettendorf², and Martti Tuomisto³
¹Metso Paper, FINLAND
²Metso Paper, USA
³Martti Tuomisto, Consultant, USA

ABSTRACT

An intelligent roll is a mechatronic system consisting of a roll in a web handling machine that is also used as a transducer for sensing cross machine tension or linear load. The intelligent roll has electret film force sensors mounted on it in a helical arrangement. The force sensor measures the force applied by the product that is being produced, such as a paper web and thus provides information about the behavior and quality of the product. In addition to the force sensors, the intelligent roll system has an electronic signal processing module on the roll end along with a digital radio link to transmit the data from the rotating roll. The receiver is connected to an automation network.

Using an intelligent roll as a reel or winder drum enables online measurement of linear load profiles in reeling and winding. The linear load profile correlates with roll hardness and diameter profiles. An intelligent reel drum combined with actuators such as calender zone controls or coat weight profilers in a closed loop control system enables response to profile-related quality variations.

Another application is to use an intelligent roll as a measuring roll that monitors the tension profile online without separate scanning devices. With online measurement, the tension profile can be optimized with closed loop control.

Intelligent roll technology also enables temporary process and runnability analysis measurements by using tape-mounted sensors. Problems such as loose web edges, off-machine coater web shifting, winding problems, and reeling defects have been solved with these measurements.

Besides paper making, intelligent rolls may be used in web handling applications such as: printing, converting, plastic film production, fabric production, etc.

Three cases of using intelligent roll technology are presented in this paper:
1. Online control of web tension profiles
2. Online control of roll hardness / diameter profiles and replacing inaccurate thickness measurement
3. Finding and removing the reason for lateral web shifting in an off-machine coater.
MODELING GROOVED ROLLS WITH MOVING 2D POROUS MEDIA

By

Simo Nurmi\textsuperscript{1}, Fredrik Berström\textsuperscript{1}, Eero Immonen\textsuperscript{1}, Antti Lehtinen\textsuperscript{1}, Kari Juppi\textsuperscript{2}, and Lars Martinsson\textsuperscript{3}
\textsuperscript{1}Process Flow Ltd Oy
\textsuperscript{2}Metso Paper Oy
\textsuperscript{3}Albany International AB
FINLAND
SWEDEN

ABSTRACT

Rolls are widely used in paper machines to heat, press and support paper webs and fabrics in order to facilitate rapid drying and transport of the paper web through the machine. In modern high speed paper machines, however, the interaction of boundary layer flows on the rolls, fabrics and the paper web often results in an undesirable pressure development at nip regions, ultimately causing an uncontrolled motion of the paper web. This runnability issue can be mitigated by using a so-called suction roll construction, which forces the required pressure profile over the paper web. Its operational costs are high, however. One result of the study is that the topology and the material of the roll surfaces, in particular the introduction of grooves on the smooth roll surfaces, can have a tremendous impact on the overall runnability potential of the paper web.

The complexity of solving the governing Navier-Stokes equations and the sheer variability of paper machine constructions makes a comprehensive analytical study of the roll-grooving effect difficult. To the authors' knowledge, analytical solutions for nip pressures only exist for two-dimensional geometries and for smooth roll’s. Moreover, numerical 3D simulations of grooved rolls in large paper machine sections are not feasible with today's computational or modeling resources.

In this article, we propose a computational 2D model for a grooved roll. The model reproduces three-dimensional wall friction effects and minor losses in 2D by treating a grooved roll surface as a moving porous medium. The nip pressures are calculated and compared for:

a grooved roll interacting with a rigid impermeable horizontal wall at a tangent point (symmetric 3D)
a grooved roll interacting with a rigid impermeable horizontal wall at a tangent point where the groove geometry is described in 2D with moving porous media.

The roll models describe the roll as infinitely wide, thus capturing friction effects between the roll and the surrounding air. The simulations are conducted with the RANS-method of computational fluid dynamics (CFD) on a commercial solver.
The results show that the proposed computational 2D model for a grooved roll yields similar pressure profiles at nip regions as the more computationally expensive full-scale 3D models. The significance of this observation is that the 2D model now facilitates the study of grooved rolls in large sections of paper machines.
MODELING AND CONTROL OF WEB VELOCITY AND TENSION: AN INDUSTRY/UNIVERSITY PERSPECTIVE ON ISSUES OF IMPORTANCE

By

Dan H. Carlson¹, P.R. Pagilla², and Mark D. Weaver³

¹3M Corporation
²Oklahoma State University
³Rockwell Automation

USA

ABSTRACT

The goal of this paper is to provide an overview of current industrial practice in control of web velocity and tension and discuss some critical issues that require future research from the community which is pertinent to problems faced in the industry. It is well known that there is a considerable gap (and time lag) between what is currently practiced in various industries and what is being researched in academia and research laboratories. This gap appears to be much more significant in the web handling industry when compared to some other established industries such as aerospace, automobile, semiconductor manufacturing, and robotics, to name a few. There are a few plausible reasons for this. First, the number of products made from materials manufactured in rolled form is very large. Second, since a wide spectrum of materials is manufactured and processed in rolled form, machines that handle different materials are diverse and so is their operation. Yet, there is a substantial amount of commonality between various web process lines that handle different materials. Two key process variables that need to be monitored and controlled in almost all web process lines are web tension and velocity. The discussions in the paper will highlight and focus on issues related to modeling and control of these two key process variables.

The paper will first give discussions on the “typical” webline, potential performance enhancements and commissioning improvements that modern control methods can provide, and advances in drive and microprocessor technology that allow implementation of modern controllers. A brief description of the models for web tension and velocity is given. Many modern control algorithms have been suggested for controlling tension and velocity in the recent years. But very few, if any, have been transferred to current industrial practice. One of the reasons is that the development and presentation of these new control strategies is often too abstract for controls engineers who are trained in implementing and tuning PID-type algorithms. The paper will examine some of these new control strategies whose implementation is relatively simple and present a
reasonable level of complexity while providing superior performance to currently used PID techniques.
WEB TENSION IN AN ACCUMULATOR AND INDUSTRY NEEDS FOR THE FUTURE

By

Neal Michal
Kimberly-Clark Corporation
USA

ABSTRACT

A web is defined as a continuous strip of flexible material. Continuous web processes provide cost savings to manufacturers and converters. Converting processes use unwinds to provide a continuous supply of web material. Accumulators are often used for unwinds to allow a splice without stopping the web process. Accumulators are also used for winders to allow a roll transfer while the process continues to run. Webs are stored in wound rolls under stress and spend most of the time in storage before being converted into a final product. The combination of stress and time cause the web to have floppy edges, baggy lanes, and web camber. Accumulators must be capable of processing these non-ideal webs.

Web tension is the most important parameter for any web process. Individual span tensions vary significantly within the accumulator during steady state operation. Individual spans undergo extreme tension differentials during the accumulator fill and feed process. Poor tension control within an accumulator can lead to waste and delay. Symptoms of poor tension control within the accumulator include web instability, web weave, wrinkling, and neck down. Failure modes include total web collapse and ultimately web breaks.

Web tension collected from an accumulator will be presented. An emphasis will be given to the dynamic fill and feed operation of the accumulator. It will call attention to the challenges of proper accumulator design and control.

A survey of industry needs for improved equipment and process capability will be offered. Fundamental research for web handling has been primarily limited to a single roller in an open span. There are several dozens of published papers that describe traction, air lubrication, and wrinkling. There have been a handful of papers that describe accumulators with little to no validation. Equipment builders have not improved their designs based on published papers. As a result, most accumulators are operated using a trial and error approach.
ABSTRACT

Previous analysis of the dynamics of a conventional accumulator (no driven rollers within the accumulator, with all rollers identical) was published by Shelton [1]. This 1999 analysis showed that such accumulators commonly suffer from an excessive difference of tension between the entry and exit, often leading to excessive local changes in tension as well as slackness and/or slippage between the web and specific rollers. The analysis also showed that the inertia of the carriage, because of its usually large mechanical advantage, often is negligible in comparison to the total inertia of the rollers. Additional conclusions were that (1) \( J/R^2 \), not the inertia \( J \) by itself, is a governing parameter, (2) as the operating velocity is increased, the required height (distance of travel) of the accumulator may become excessive, and (3) the force required for counterbalancing the carriage can be calculated for specific goals of optimization of operating conditions. Specific schemes of control were not addressed in the 1999 IWEB paper.

This paper does not repeat derivations or results of the 1999 paper; instead, it examines schemes for control of tension within an accumulator, with emphasis on control of velocities instead of the less desirable control of forces and torques. Equations for velocities during steady-state running, stoppage, constant acceleration or deceleration of the web, and filling or emptying of the accumulator are derived.

Lateral errors, sometimes great enough to cause a failure, are commonly caused by the long multiple spans of an accumulator in combination with excessive flexibility of the locating elements of the carriage and the imperfection of the web; hence, schemes are presented for automatic leveling of the carriage, or tilting of the carriage for incremental correction of errors caused by camber or other imperfections.

Driving all the rollers in an accumulator with precise control of their velocities along with synchronized control of the velocity of the carriage, should almost eliminate the tension variations inherent in current practice, and should almost eliminate the carriage travel now required for the acceleration and deceleration modes of the rollers.
ABSTRACT

Although there has been much work in dynamic modeling of different web handling elements and web longitudinal behavior, efforts to systematically validate models by experimentation on a web platform are non-existent. Existing literature has extensively used dynamic models for numerical analysis and/or design of control systems without adequate experimental validation of the models. One of the well known modeling techniques for creating a model for the entire web line is based on the concept of primitive elements. In this approach every primitive element of the web line is modeled separately using first principles approach, and then the entire web line model is obtained by appropriately combining the primitive element models. The goal of this paper is to present results from recent investigations on validation of key primitive element models. Model refinement and modifications are also considered when sufficient level of agreement between model and experimental data was not obtained.

Since the dynamic model for web tension in a span is nonlinear, designing experiments for web line model validation is a formidable task. There are a few known model validation techniques for nonlinear systems but these do not provide any clear procedures that can be applied to the web line. Therefore, the approach taken in this study was to consider test cases of experimentation that mimic typical web line operations in the industry such as acceleration/deceleration of the line and running the line at a constant speed. A number of test cases for model simulations and experimentation were considered. A representative sample of the results is shown and discussed. Data from the simulations of existing models did not contain the oscillations found in measured tension signals. This study also considered refinement and modifications of dynamic models that would lead to better agreement between the model and experimental data. It was found that span length variations introduced by out-of-round and/or eccentric rollers are the direct cause of oscillations in the tension signal. A refined model for web tension that includes span length variations is given. Comparison of the data from
simulations of the refined model and experimental data shows a high level of agreement. These results are shown and discussed.
A MECHANISTIC SURVEY OF ACCUMULATING, RESONANT, AND SELF-EXCITING SYSTEMS IN WEB HANDLING

By

David R. Roisum
Finishing Technologies, Inc.
USA

KEYWORDS

Air-entrainment, calender_barring, gage_bands, locked_core_winding, (spreading) interweaving, critical speed, resonance, vibration

ABSTRACT

Certain problems in web handling can be challenging because they tend to get worse with time. Consider mechanical resonance. The longer you run at resonant vibration conditions, the worse the problem will initially get. Yet the effects of resonance are usually limited because of damping and in many cases are not even perceivable. There are conditions that are much more challenging because they are accumulating or self-exciting. These problems not only get worse with time, they may get much worse with time. The response or response rates are ever-increasing and unbounded except by breakdown or shutdown. This paper is a mechanistic survey of some of the toughest problems in web handling including:

Accumulating
   Air Bubbles Behind Nips
   Gage Bands in Wound Rolls
   Loose Lanes in Locked Core Winding

Resonant
   Guide Control
   Tension Control
   Roller Critical Speed
   Wound Roll Vibration

Self-Exciting
   Calender Barring
   Interweaving on Simplex Winders
Knots in Wound Rolls
Telescoping on Core Supported Winding
Wound Rolls that Uncoil After Cutover
WEB LINE RESONANT FREQUENCIES

By

P.R. Pagilla and Y. Diao
Oklahoma State University
USA

ABSTRACT

The goal of this paper is to investigate the resonant frequencies of a system of idle rollers and web spans. Of particular interest is the determination of the minimum resonant frequency as a function of the number of idle rollers, web span lengths between idle rollers, web properties such as the modulus of elasticity and area of cross-section, and inertia and radius of the idle rollers. Any conclusions from the analysis that can provide insights into maximizing the minimum resonant frequency by choosing particular web paths or span lengths are of benefit to the web machine designer as well as the control system engineer. Knowledge of the minimum resonant frequency and the factors that influence it can assist the machine designer in reconfiguring web paths and/or number of idle rollers between two driven rollers such that the machine induced vibrations do not excite resonances. Further, the knowledge of the minimum resonant frequency will assist the control engineer to better select the bandwidth of the closed-loop system as well as the crossover frequency of the controller.

A simple linear model that describes the dynamics of tension in a web span is considered. It is shown with experimentation on a web platform that the simple model is able to predict resonant frequencies in an idler roller system. Therefore, the simple model is used to investigate the behavior of the minimum resonant frequency as a function of the number of idle rollers and span lengths. Analytical solutions for computing the minimum resonant frequency for one idler (one idle roller and two spans) and two idler (two idle rollers and three spans) systems are given. Numerical analysis and discussions on how to maximize the minimum resonant frequency for two, three, and four idler systems are also given. An analytical approximation of the minimum resonant frequency for equal span lengths and any number of idle rollers is derived. This approximation tends to converge to the actual minimum resonant frequency with increase in the number of idle rollers. This is useful in getting a quick and reliable estimate of the minimum
resonant frequency in festoons/accumulators that contain many idle rollers and equal span lengths.
A PROCESS DIRECTION DYNAMIC MODEL FOR HIGH PRECISION WEB/BELT TRANSPORT SYSTEMS

By

Ming Yang¹
Xerox Research Center Webster
USA

ABSTRACT

This article proposes a process direction dynamic model for closed loop belts and open loop webs used in high precision transport systems such as those found in printers where micron level registration is required. It gives the detailed derivation of the lumped parameter-based, elastically-stretchable dynamic model and shows that the angular velocities of the rolls, instead of the surface velocities of the belts/webs, should be the variables directly used in the governing equations. It discusses the effects of traction as well as disturbance sources such as roll eccentricities and the drag from stationary rolls (backer-bars). The focus of this article is on the enhanced inertia compensated tension rolls (dancers) which may be used in either open loop webs or closed loop belts (US patents pending). The design formula of the enhanced inertia compensated tension rolls takes into consideration the belt/web elasticity, belt/web tension and wrap angle. Validation of the model by other numerical methods and experiments is also discussed at the end of this article.

¹ The author would like to thank Barry Mandel, William Nowak, Bin Zhang, Elias Panides and his other Xerox colleagues for their many valuable suggestions and discussions and he would like to particularly thank William Nowak, Roger Leighton and Thomas Wyble for their work in the validation experiments.
COMPUTATION OF SPAN LENGTH VARIATIONS DUE TO
OUT-OF-ROUND MATERIAL ROLLS

By

C. Branca, P.R. Pagilla, and K. N. Reid
Oklahoma State University
USA

ABSTRACT

It is well known that non-ideal elements such as out-of-round/eccentric material rolls affect web tension. However, the mechanism through which these non-ideal components induce tension oscillations was not clear previously. In a companion paper (Modeling and Identification of the Source of Oscillations in Web Tension) it is shown that an out-of-round/eccentric material roll produces length variations in the web span adjacent to the roll. These length variations are the main reason for oscillations in the tension signal; this was experimentally verified in the companion paper. In order to reproduce these tension oscillations in model simulations, it was necessary to include span length variations in the tension dynamics models. Given a generic profile for the out-of-round unwind roll, determination of the length of the adjacent span as a function of time as material is released from the roll is a formidable task. The focus of this paper is on finding a relationship between the shape of the out-of-round material roll and length of the span adjacent to it.

The simplest case to analyze is the length variations due to an eccentric roller. Considering the geometry of the problem, it is possible to find an expression in closed form that gives the length of the web span as function of the angular displacement of the roller. The expression for the rate of change of span length as a function of angular velocity is obtained by direct differentiation of the closed form expression. Finding closed form expressions for length of the span adjacent to an out-of-round material roll even for simple cases, such as an elliptical roll, is not trivial.

As a starting point, an elliptical material roll is taken into consideration. To find the length of the web span between the material roll and the idle roller it is necessary to find the line tangent to both of them. An analytical approach to the problem did not provide any insights into finding a closed form expression for span length as a function of angular displacement of the material roll. To overcome this problem a convex optimization problem is formulated and an efficient numerical approach is developed to obtain the
common tangent to the material roll and the first idle roller. Once the common tangent is obtained, span length and rate of change of span length can be found numerically as well. The algorithm and related pertinent discussions are given. Incorporation of this algorithm into web line model simulation software will enable better correlation of model and experimental tension data.
ABSTRACT

This paper introduces an analytical method for the explanation of the nip inducted effect. This effect is known for a long term as a disturbance effect in the web handling industry. Here it is used for breaking bindings between the surface of sheets. The nip inducted effect causes a displacement of layers due to rolling a cylinder over a stack of sheets, known in the winding process of paper coils.

The developed model is based on the assumption that the kinematic processes of the nip inducted effect are explainable with a gear of hollow cylinders. It is shown how the geometry of a hollow cylinder is attuned. The geometry and the translation of the gear will be influenced by the material parameters of the promoted paper.

The analytical model will be discussed with the results of Pfeiffer and sorted in the existing knowledge about the nip inducted effect.

The model is explained on the example of a developed machine for breaking bindings between the surfaces of paper sheets.

Another focus is set on the measurement of the reversible extension of paper. These measurements are important for the industrial use of the nip inducted effect.
ABSTRACT

We describe an entirely new method of improving the slippage between web and roller. First, the concept of a micro-grooved roller is introduced, and then a theoretical model for estimating the slip onset velocity under the transport of web by the micro-grooved roller is formulated. The predicted results are compared with the experimental data to verify the applicability of the prediction model of slippage. Moreover, the web-wrinkling condition, which is in a trade-off relationship with the slippage condition, is also considered in the model. From the theoretical and experimental results, it is confirmed that the optimized micro-grooved roller is very effective in improving the slippage and wrinkling of thin web under the high-speed transport with low tension at the actual production line.
ABSTRACT

The laminate theory provides a method of analyzing the mechanics of multilayer composite laminates. With the appropriate definition of the load vector, the laminate theory can be extended to model curl resulting from different stages of web handling. The most direct application would be for predicting curl resulting from change in temperature or moisture content of a multilayer web. Other curl sources such as web lamination and curing/drying shrinkage can also be modeled if the load vectors are appropriately defined. This paper shows some applications of a laminate theory based 2D curl model for predicting web curl in both Machine Direction and Cross Direction. The results obtained from this model are validated by both Finite Element Analysis and Experimentation.
A 2D FSI MODEL FOR PAPER WEBS AND FABRICS MOVING CLOSE TO EACH OTHER IN COMPLEX GEOMETRIES

By

Eero Immonen¹, Fredrik Bergström¹, Simo Nurmi¹, Antti Lehtinen¹,
Kari Juppi², Lars Martinsson³
¹Process Flow Ltd Oy
²Metso Paper Oy
³Albany International AB
FINLAND
SWEDEN

ABSTRACT

In the present article we develop a two-dimensional computational fluid-structure interaction (FSI) model for small transverse deflections of a moving paper web, supported on one side by a fabric, both moving in an arbitrary geometry containing boundaries and nips (e.g. as in the drying section of a paper machine). In our FSI model, the transverse deflections of the paper web and those of the fabric are individually assumed to satisfy an equation of motion for axially moving membranes, such as:

\[ m \frac{d^2 w}{dx^2} + 2mv \frac{d^3 w}{dx^3} + (T - mw) \frac{d^2 w}{dx^2} = f\left(\Delta P, g, a, c\right) \]  

Displacements \( w(x, t) \) in Equation \{1\} are induced by the pressure difference profile \( \Delta P \), across the membrane, gravity \( g \), adhesion \( a \), and centrifugal forces \( c \), as well as any contacts with boundaries. The equations for the fabric and the web utilize different tension and mass parameters \( T_{\text{fabric}}, T_{\text{paper}}, m_{\text{fabric}}, m_{\text{paper}} \), but the axial velocities coincide, i.e. \( v_{\text{fabric}} = v_{\text{paper}} \). The pressure differences across the web (\( \Delta P_{\text{paper}} \)) and fabric (\( \Delta P_{\text{fabric}} \)) are obtained by numerically solving the Navier-Stokes equations for air flow motion around the paper web and the fabric. This air flow motion results from the motion of solids in the flow field, and it also generates subsequent motion of solids through the coupling in Equation \{1\}. A remarkable feature of this FSI model is that it is to a large degree geometry-independent, and hence applicable in a wide array of paper machine regions. In particular, the model is suitable for such modern paper machine drying sections which are arranged in the modern single-run configuration, whereby the wet paper web is only supported by a dryer fabric on one of its sides. We show by qualitative examples that the proposed FSI model yields useful results in realistic single-run geometries. The inclusion of fabric dynamics in the model provides an important and non-trivial extension of a recent FSI model covering paper web dynamics only in the same context.
MEASUREMENT OF WEB SURFACE PROFILES USING FRINGE PROJECTION

By

Hongbing Lu, Vinay Bhumannavar, Junfeng Liang, and Yao Ren
Oklahoma State University
USA

ABSTRACT

In this paper a full-field measurement technique, namely fringe projection technique was implemented to determine the three-dimensional surface profile for situations where webs are opaque or translucent. In this method, a grating is projected to the surface of a web. The projected grating will be distorted due to the non-flat surface. The image of the distorted gratings will be shifted on a reference grating on a computer to form Moiré fringes. The phase of the fringes is determined and converted to the surface profile of the web. Calibration was conducted, and validation was made on surfaces with known geometry. Surface profiles of Polyvinyl Fluoride (PVF), nonwoven and polyethylene webs, as well as non-flat side walls of a wound roll determined as examples illustrating the technique. The accuracy of the method is discussed. The method has potential for industrial scale applications due to its ease in setup and speed in three-dimensional reconstruction.
PHENOMENS OF ROLLING CONTACT IN PAPER CALENDERING

By

V. Niebuhr¹, Desch², E.G. Welp†³
Ruhr-University Bochum
GERMANY

ABSTRACT

In soft calenders synthetic roll covers are “state of the art”, without knowing their detailed rolling contact behavior and their phenomenological effects to gloss and smoothness of paper. Complex interactions of process and material parameters lead to time consuming adjustments of the machine settings. Regarding the interacting material parameters the mechanical paper properties are as important as the elastomer cover properties of the rollers. This challenged coupling of the threesome paper, cover and process typifies a limit for new innovations in calendering. That is why present development objectives in calendering for example to higher calendering temperatures and higher process velocities have to be tested in practice as black box solutions concerning their effects.

Present research activities are focusing on the thermo mechanics in the interaction of process and material parameters of the rolling contact of the calendering nip. With advanced knowledge on the paper properties [2, 4], with the theory of rolling contact and with the knowledge of the influence on runnability and printability parameters, it is possible to discuss phenomenological rolling contact effects on a macroscopic level. The results point out that the physical attributes of roll cover material and of paper material have to be analyzed along with the process parameters in order to achieve improvements in calendering.

¹ Dipl.-Ing. Volkhard Niebuhr, scientific coworker of the Institute of Engineering Design of the Ruhr-University Bochum, Germany. The publication is published in the context of the dissertation of Mr. Niebuhr
² Dipl.-Ing. Michael Desch, scientific coworker of the Chair of Printing Science and Technology. Mr. Desch held the presentation at the 10th IWEB in proxy.
³ Professor Dr.-Ing E. G. Welp (*28.11.1944 - †01.02.2009) leader of the Institute of Engineering Design (LMK) of the Ruhr University Bochum, Germany.
The investigated interactions motivate a new evaluation of the calendering process under consideration of mechanic, thermal, hygrosopic, visco-elastic and rolling contact effects. This point of view is close to reality and permits the detection of physical interactions in the calender nip. From these detected dependencies we can formulate conclusions to gloss and smoothness behavior as well as to the other printability and runnability parameters.

To reduce time consuming process optimization in production, precise details on optimal machine settings in the process can be delivered. Although details to paper and roll cover properties for calendering can be given by identifying the physical interactions in the rollers’ nip. Knowledge of these interactions will reveal the basic calender processes.
STATIC AND DYNAMIC PROPERTIES OF CFRP ROLLERS

By

Ulrich von Hülsen
Inometa Technologie GmbH & Co KG
GERMANY

ABSTRACT

Carbon fiber rollers combine high axial stiffness with low weight. This leads to higher bending frequencies and increased critical speed and makes them suitable for high speed machines as web guide rollers or as other functional rollers. Due to the orthotropic properties of fiber composites static deformation as well as dynamic vibration modes of CFRP rollers differ significantly from those of metallic rollers. Improved performance of CFRP rollers compared to metal rollers is not only a result of the increased critical speed but is also coming from improved damping characteristics.

If CRFP tubes are optimized for axial stiffness and high bending frequencies, static and dynamic deformation that is negligible in metal rollers become significant due to their much lower shear modulus and circumferencial elastic modulus. These deformations have to be taken into account when designing a roller for high speed machines. FRP is a design material which allows to distinctively modify materials properties differently in different direction of the material. With the filament winding process the properties of fiber composites can be modified in a very efficient and versatile way. Additional design options can be used to decrease deformation.

Energy absorption in the resin matrix as well as in the fiber material contribute to the improved damping characteristics and can increase the damping factor of the dominant modal shapes by an order of magnitude.

Composite tubes having unique combination of static and dynamic properties have been produced by filament winding. Static and dynamic properties of these CFRP tubes have been investigated by Finite Element Methods and experimental Modal Analysis.

With the results of these analysis methods complete systems of multiple rollers interacting by nip contacts or through a web can be modeled and investigated. The goal is to derive design rules for rollers that help improving dynamic aspects of web handling.

Using optimized CFRP tubes considering all aspects of their static and dynamic properties rollers can be designed that show better performance in highly productive machines.
TRANIENT 2D PAPER WEB DRYING MODEL
BASED ON CFD

By

Antti Lehtinen¹, Fredrik Bergström¹, Eero Immonen¹,
Simo Nurmi¹, Lars Martinsson², David Ingvarsson³, and
Kari Juppi³
¹Process Flow Ltd Oy
FINLAND
²Albany International AB
SWEDEN
³Metso Paper Oy
FINLAND

ABSTRACT

In the present article, a model combining the benefits of the small scale and large
scale approaches towards modeling paper drying in a paper machine dryer section
environment is described. The model is transient and two-dimensional, taking into
account the MD and the thickness directions but neglecting the phenomena in the CD
direction.

The combined model consists of two parts:
1. A large scale CFD model of the surroundings of the paper web solving the
RANS equations
2. A specific-purpose small scale model for heat and moisture transport
phenomena inside the paper web.

The model is aimed at predicting the drying process in a paper production
environment. The present model can be combined with a separate paper web deflection
model in order to simulate the drying process and the paper web runnability
simultaneously.
ABSTRACT

There are two levels of web instability in web lines. The first level of web instability is called web troughs. Web troughs are due to the instability of webs that occur in free web spans. Web troughs have been shown to be predictable using traditional buckling theory. Closed form expressions have been developed and verified in the lab that predict when web troughs will result from roller misalignment and roller taper. Web troughs can be a nuisance in web processes where the web must be planar. The troughs themselves may not damage the web but can be responsible for reductions in web quality after processing that can result in lost profit.

The next level of instability is called web wrinkles. Web wrinkles are due to the instability of webs that are transiting rollers. When webs transit rollers they assume the shape of a sector of a cylindrical shell. A cylindrical shell of web is much more stable than the web in free spans. Compressive stresses which are two to three orders of magnitude larger than those required to induce web troughs are necessary to buckle the cylindrical shell. This paper will demonstrate that web wrinkles are a post buckling phenomena that result from web troughs. The source of the high compressive stresses needed to buckle the web into wrinkles on rollers will be shown. We will show how web wrinkles can be predicted and we will show experimental verification for the cases where a misaligned or tapered rollers were the source of the troughs and wrinkles. Web wrinkles can damage the web as a result of inelastic deformation, fold-overs, and in the worst case may cause full separation or failure of the web. When web wrinkles can be predicted, they can also be prevented.
LATERAL DYNAMICS OF NON-UNIFORM WEBS

By

Ronald P. Swanson
3M Company
USA

ABSTRACT

A new method of generating and testing cambered web has been developed. Experimental lateral static data is presented for twenty six different conditions and dynamic data is presented for five of these conditions. Numerous models have been proposed to describe the static and dynamic lateral behavior of non-uniform webs. Despite the plethora of theoretical hypotheses, debate continues about the direction, not to mention the magnitude, of lateral displacement of a cambered web. Previously presented models and data are discussed in light of these new experimental findings.
AN UPDATED MODEL FOR LATERAL DISPLACEMENT OF NONUNIFORM WEBS

By

Jan Erik Olsen
SINTEF Materials & Chemistry
NORWAY

ABSTRACT

1. The theory for lateral mechanics of nonuniform webs in the open literature is believed to be flawed and an updated theory is presented. The theory is based on beam theory and a set of boundary conditions. The so-called fourth boundary condition is discussed and a condition is chosen based on the argumentation. A new term in the governing differential equations is derived. The updated theory predicts that the web moves to the slack side if there is sticking friction between web and roller.
ABSTRACT

A web on a roller is usually modeled as a one-dimensional belt in a state of pure circumferential stress. However, most of the important problems in lateral web behavior involve shear stress and cross web stress. Furthermore, these stresses, as well as machine direction stress, are often nonuniform. Some work has been done for particular cases using continuum mechanics software. But there are no two-dimensional models that capture the relevant physical principles in a way that can provide a general basis for calculation and insight. Some of the issues that might be addressed with such a model are:

Localized loss of traction due to nonuniform stress
The amount of spreading that can be supported on a concave or curved roller
Strain transport into the next span
Interaction of spans due to loss of traction on part of the roller

In this paper, the two-dimensional equations of equilibrium for a thin web on a roller are developed from first principles, taking into account cylindrical roller geometry and the effects of friction between the web and roller. The questions listed above are explored by experiment and FEA analysis. A method is developed for determining the conditions that must be met at the entry to a roller to insure that entry span stresses - machine direction, cross web or shear - do not cause slipping. Conditions for both nonuniform webs and nonuniform rollers are treated.
THE TAXONOMY OF WRINKLERS

By

Timothy J. Walker
T. J. Walker and Associates, Inc.
USA

ABSTRACT

Taxonomy is the practice and science of classification. Without taxonomy, everything is lumped into one pot and confusion prevails. All wrinkled or buckled webs should not be filed under one category. Just as birds are observed and divided by what they look like and where they appear wrinkled webs have characteristic visual clues and common causes. Much of taxonomy in other fields is justified by the ability to separate the good from the bad, such as managing invasive species. For wrinkles, all forms are considered invasive and undesirable, but taxonomy will help to understand the causes of specific wrinkles and help point the direction of either eliminating the cause or finding an appropriate remedy based on the cause.

This paper outlines one approach to categorize wrinkling causes based on over twenty year’s observations and the contributions of other experts of wrinkle prevention and elimination. This taxonomy divides buckled webs by three locations: in spans, on rollers, and within rolls. Buckled webs on rollers, the narrow definition of wrinkling, are divided into four mechanisms. Shear wrinkles, as defined by the work of Gehlbach, Good, and Kedl. Tracking wrinkles (or principle stress wrinkles) where the left and right sides of a web track toward the web’s centerline (or other lane) with enough crossweb compressive stress to induce buckling. Constrained expansion wrinkles, such as develops in on-roller conduction or radiant heating or hygroscopic expansion in the outer wraps of a paper roll. Accumulation wrinkles, the only wrinkle species forming dominantly crossweb creases, where the compressive stresses build up in the machine direction. This paper includes over 50 examples of where these wrinkle mechanisms occurs despite our best efforts.
ULTRASONIC BASED MULTIPLE WEB SENSING FOR LATERAL CONTROL APPLICATION

By

Jami Haque, Darcy Winter and William Ploetz
Fife Corporation
USA

ABSTRACT

As sensing requirements in guiding applications increase in complexity, innovation must increase to meet these needs. In applications with multiple webs, space restrictions often limit the placement of sensors. In this case, a single sensor that can sense multiple edges would be desired. Sensing multiple edges within the same sensor opens other new possibilities in guiding applications as well.

To address these needs, staggered arrays of ultrasonic transducers in a through-beam configuration can be employed using a combination of FPGA and microprocessor based technology. The transmit side consists of an array of ultrasonic transducers which are driven individually with a precisely timed signal. The receiver side consists of an identically arranged array of transducers diametrically opposed to the transmitter. To handle the concept of multiple edges, a methodology can be adopted to partition the sensor field of view into many individual “virtual sensors”. Virtual sensors can further be selective about the type of edge polarity they sense. Because virtual sensors exist only mathematically, they can overlap each other in any conceivable manner and can be moved around to reposition their respective webs. This scheme has another advantage that is useful particularly in sensing and guiding applications. The entire sensor field of view is active at all times which open the possibility to provide multiple edge tracking within the complete sensor field of view.

Ultrasonic sensing technology is often preferred for its ability to sense wide varieties of materials such as opaque, clear and photosensitive type web materials. However it is often limited to smaller bandwidth because of transducer size. Those sensors that offer wider sensor field of view are typically limited to single edge detection. Multiple edge detection with edge polarity awareness is achieved by keeping all of the transducers active at all times. A sensor with these capabilities can operate like a conventional sensor with a single edge, or provide more advanced capability using multiple edge detection. Multi-edge applications include center or edge guiding one or more webs,
multiple web width measurement, web position, and lane measurement (distance between webs).
Keynote Presentation I

**Advanced Process Models and Control Strategies for Rotary Printing Presses**
G. Brandenburg, Technische Universität, Germany

Session 1 – Tension Control, Tension Effects, and Electrostatics

**Web Tension Behavior in the Presence of Eccentric Rollers: Modeling and Validation**
C. Branca, P. Pagilla and K. Reid, Oklahoma State University, USA

**Web Tension Variations Caused by Temperature Changes and Slip on Rollers**
D. Jones¹, M. McCann², and S. Abbott³, ¹Emral Ltd, United Kingdom, ²McCann Science, USA, ³Steven Abbott TCNF Ltd, United Kingdom

**Modeling and Frequency Response of Web Tension with a Pendulum Dancer, and Comparison of Load-Cell and Dancer Based Tension Control Systems**
P. Raul and P. Pagilla, Oklahoma State University, USA

**The Ke Models: Theoretical Dynamic Subsystems of Longitudinal Web Strain**
Gary P. Strike, Webtech Omega, LLC, USA

**Modeling and Analysis of Rotogravure Printing Presses**
A. Seshadri¹, P. Pagilla¹, and J. Lynch², ¹Oklahoma State University, ²Armstrong World Industries, USA

**Multi-stage Tensile Straining during Drying of SC Paper**
J. Kouko¹ and P. Kekko², ¹VTT Technical Research Centre, ²Metso, Finland

**Bagginess and Baggy Streaks: A Novel Measurement Technique to Quantify Tension Profile of a Web in Cross-Direction at High Resolution**
F. Parent and J. Hamel, FP Innovations, Canada

**Controlling Static on an Unwinding Roll**
K. Robinson, Electrostatic Answers LLC., USA

Keynote Presentation II

**Winder Vibration: Causes, Defects, and Remedies**
Session 2 – Winding, Lateral Mechanics, and Wrinkling

Movement of Layers and Induced Tension in the Nip Area between Drum and Paper Layers
Peter Hoffmann¹, Michael Desch², and Edgar Dörsam², ¹Stora Enso Research Centre, Mönchengladbach, ²Institute of Printing Science and Technology, Technische Universität Darmstadt, Germany

The Use of Conservation of Mass in Modeling Lateral Behavior in Moving Webs
J. Brown, Essex Systems, USA

Explicit Analysis of the Lateral Mechanics of Web Spans
B. Fu, R. Markum, A. Reddy, S. Vaijapurkar, and J. K. Good, Oklahoma State University, USA

Two-Dimensional Behavior of a Thin Web on a Roller
J. Brown, Essex Systems, USA

Explicit Analysis of the Lateral Mechanics of Webs Transiting Concave Rollers
S. Vaijapurkar and J. K. Good, Oklahoma State University, USA

Wrinkling of Foils
T. Walker¹, K. Cole², S. Zagar³, and Jeffrey Quass³, ¹TJWalker+Associates, Inc., ²Optimation Technology Inc., ³Megtec Systems, Inc., USA

Analysis of Web Wrinkling in Accumulators
N. Michal, B. Kandadai, and A. Patil, Kimberly-Clark Corporation, USA

Wrinkling of Wide Webs
T. Walker¹ and K. Cole², ¹TJWalker+Associates, Inc., ²Optimation Technology Inc., USA

Session 3 – Web Handling

A Century of Web Handling Literature
D. Roisum, Finishing Technologies, Inc., USA

Measurement of Web Feed Rates in Rubber Covered Nip Roller Applications and the Impact on Wrinkle Formation
K. Cole¹ and T. J. Walker², ¹Optimation Technology Inc., ²TJWalker+Associates, Inc., USA

Determining the Amount of Sheets in a Stack of Paper by Using a Pressure Stamp
M. Desch and E. Dörsam, Technische Universität Darmstadt, Germany

The Advantages of Inertial Roll Alignment Device in Eliminating Web Handling Issues
C. Woo, PRÜFTECHNIK Service, Inc., USA
Digitally position controlled and synchronized AC motors which have replaced the former mechanical line shaft allow for advanced control strategies of rotary printing presses. New controls require new process models. The state of the art of tensile force, stress and strain in the web is revisited in Part 1 of the contribution and extended to the dynamic behavior of so-called partial cutting register errors (PCRE) which add up to the total cutting register error (TCRE) at the cutting cylinder. These equations allow for the reconstruction and measurement of rapid changes of the modulus of elasticity (Young’s modulus) and the cross section of the web which occur in the case of reel changes on the run. The reconstructed signal can be used for feed-forward control of closed loop controls. Furthermore, the mathematical description of the so-called doubling errors between two printing units is presented. Their correlation with color register errors yields new insights into the printing process. Part II of the contribution is devoted to the web dynamics in systems of rollers with macro slip and so-called partial slip which are responsible for the generation of sustained cutting register errors. They are explained for a three roller system. The transition from micro to macro slip entirely switches the dynamic structure of the system. For a roller combination, where the web is pressed onto a steel roller by narrow rolls with very small axial areas of contact, partial slip between web and the steel roller is assumed. A “q-model” is developed as a first approach to explain the upstream travelling of disturbances. Herewith a new component is available which can serve to model the entire printing press in the future. The introduction of partial register errors has led to the design of a two-variable control of both the partial cutting register error and the tensile force in the same web span, which is dealt with in Part III. This control which does not require any additional mechanical effort, considerably reduces the paper waste and increases the economic efficiency of the printing press. Experiments with a modern commercial web offset press confirm the above theoretical results.
WEB TENSION BEHAVIOR IN THE PRESENCE OF ECCENTRIC ROLLERS: MODELING AND VALIDATION

By

C. Branca, P. R. Pagilla, and K. N. Reid
Oklahoma State University
USA

ABSTRACT

Since rotating machinery is used to transport the web on rollers, it is common to observe periodic oscillations in measured signals such as web tension and web transport speed. These periodic oscillations are more prevalent in the presence of non-ideal machine elements such as eccentric rollers and out-of-round material rolls. One of the main objectives in transport of webs is to maintain tension at a prescribed value. Tension regulation affects almost all key aspects of web transport including printing, registration, wrinkle formation, winding, etc. Therefore, models of web tension and web transport velocity in the presence of non-ideal rollers which can accurately predict measured behavior will be beneficial to the analysis of web transport under various dynamic conditions and in the design of suitable control systems.

The focus of this paper is on modeling the effect of eccentric rollers on web tension. The governing equations for web velocity on an eccentric roller and web tension in spans adjacent to the eccentric roller are presented and discussed. To solve these governing equations, one requires the knowledge of the entry and exit point of the web on the eccentric roller as it rotates and the length of web spans adjacent to the eccentric roller; a method in obtaining this information is described. To corroborate the models and the developed approach, data from experiments on a web platform are compared with model simulations and results are presented and discussed.
WEB TENSION VARIATIONS CAUSED BY TEMPERATURE CHANGES AND SLIP ON ROLLERS

By

D. P. Jones,¹ M. J. McCann,² and S. J. Abbott³
¹Consultant, Emral Ltd, UK
²MJMcCann Consulting, USA
³Steven Abbott TCNF Ltd, UK

ABSTRACT

Webs are frequently heated or cooled on rollers, where thermal expansion or contraction attempts to reduce or increase tension respectively. In the case of vacuum coating, the web first cools on the chilled drum, then is heated by coating deposition and radiation, and finally cools before exit. Friction between the web and drum surface may be unable to sustain the tension gradient that the temperature profile would produce in the web moving at constant speed. In that case, zones of microslip exist over at least part of the wrap, possibly including the entry region.

A method of calculating the tension profile around the roller or drum for an elastic web in steady state will be presented, using simple friction laws. The speed difference between web and drum surface is determined by iteration, working backwards from the exit tension until the correct entry tension is attained. However, forward integration is necessary if the web is not elastic, or the heat transfer is affected by the tension or the amount of slip.

The calculation shows that the web may be slipping over a large proportion of the contact area. In some cases, the speed matching is only momentary. Practically, this may lead to difficulties in controlling tension or speed. The model also allows the cross-web direction stress to be estimated. In a region of heating, this often becomes compressive, and can be compared with a critical value for buckling. Exceeding this level would lead to wrinkle formation in the hot, soft web, usually a serious quality problem. The model can therefore be used to explore process design and conditions to reduce the likelihood of wrinkling and improve the ability to control tension and speed.
ABSTRACT

In web processing lines, web tension is typically regulated using an outer loop that provides a trim to the velocity reference of the inner velocity loop. The feedback signal for the outer tension loop is either a position signal from a dancer or tension signal from load cells mounted on a roller. Both these strategies are used extensively in the web processing industry, but a systematic analysis, based on mathematical models and experimental observations, on the benefits and limitations of the strategies is lacking. The paper will report two investigations. First, a model that describes the action of a pendulum dancer on web tension will be developed, and frequency response of web tension in the presence of the pendulum dancer will be discussed. Second, a comparison of tension control strategies based on force feedback from load cells and position feedback from dancer motion will be given.
ABSTRACT

Efficient design and optimization of many production processes often require models which predict transient and steady state web strains. To date, much attention has been given to modeling web strains much less than unity. Considerably less attention however, has been given to modeling strains of relatively lower modulus materials. A particular related challenge often involves selection of dancers vs. load cells as feedback devices in tension control systems.

This paper explores derivations of theoretical “𝐾𝑒” models as primitive functions of roller motions. At a fundamental level, simple linear and nonlinear differential equations exist for each strain component or “subsystem” independent of others. Combinations can determine total strains in web spans including those at inputs and outputs of dancer rollers and within festoons. Validity is retained at any value of strain including zero and negative values (compression). The author demonstrates that mathematical equations of high web strains instead of becoming unwieldy, can be applied with accuracy and with a large degree of natural elegance. Applied classical control theory allows users a natural intuition when interpreting results which are primarily outputs of computer simulations.

The “free web span” has been extensively studied within the web handling community and is again examined here as a 1st section of web under any dynamic strain feeding into a 2nd section of web between two driven rollers. A free web span 𝐾𝑒 based model is compared to a first order approximate model of the same physical system while applying step changes to roller velocities. Both models are compared as final values of strain approach extremely high values toward infinity. Using 𝐾𝑒 models, all strain-time trajectories in the free web span as a result of step changes to roller velocities are shown to be sections of an S-shaped curve designated “The Universal Strain Time Curve”. The output of the first order approximate model, when plotted on the Universal Strain Time Curve (USTC), reveals that the first order approximate model may often be applied with acceptable results for strains from 0 through 25%. Finally, an example model of a tension control system with load cell feedback demonstrates how consecutively higher order subsystems may be included as elements of a 𝐾𝑒 Subsystem Library.
A practical and intuitive method of modeling web strains of any value has been developed here and may be applied by scientists and engineers having a basic knowledge of classical control system theory. With relatively accurate input data, effects on strain resulting from various roller inertias, web span lengths, dancers vs. load cells, and many other design decisions can be simulated. For both high and low modulus materials, $Ke$ models provide a high degree of accuracy when simulating web strains during process design and optimization. This research is applicable to a broad spectrum of webs from thin plastics to paper, textiles, flat metals, wires, films, belts, foils, strips, threads, fabrics, and composites which are manufactured in rolling processes. The academic derivation process which has been applied also reinforces a useful framework to solve similar scientific problems.
ABSTRACT

Print registration is the method of overlapping successive printed patterns to form a complex multicolor pattern. Registration error is the misalignment in the overlapped patterns. This paper deals with modeling machine direction registration error in a rotogravure printing press with multiple print units coupled by mechanical shafts. The model is developed by considering various dynamic elements in a print unit such as the print cylinder, doctor blade assembly, print unit compensator roller, cooling rollers, print unit motor, the effect of friction in various locations, etc. Experimental data from typical production runs on a print line is used to corroborate the model developed. Based on the developed model, mechanical design and control design recommendations to reduce registration error in print units are provided.
ABSTRACT

During multi-cylinder drying on a paper machine, the paper web is under stress in the machine direction, whereas the cross direction is more or less free. The web shrinks due to drying and contracts due to web draws. The machine speed, dryness and tension level determine the speed difference between drive groups, which in turn determines the level of MD straining. Straining and stresses during drying have a significant influence on the elastic properties of paper. The objective of this study was to investigate the effects of multi-stage straining during drying on the tensile properties of dried paper.

Oriented SC paper samples were prepared on a pilot paper machine with varying levels of draw between the press and the press cylinders. Never-dried SC paper samples were then dried in a C-Impact laboratory tensile tester. The tensile force, strain, surface temperature and dryness of the samples were measured during drying.

The design of the trials was full factorial (multivariate), which enabled the use of statistical methods in the data analysis. Two of the five straining tests were performed on a pilot paper machine during sample preparation, and three of the five during drying on a laboratory tester. The draws were combined in order to form two separate 3^4 full factorial designs. It was concluded that the use of a fractional factorial design instead of a full factorial design would lead to equally statistically good results, but would also be biased towards the most powerful factor term.

The measured tension of the paper samples during drying was affected by the straining, dryness and tension relaxation of the paper. The straining and drying history of the paper also influenced the tensile properties. Increased straining generally led, almost linearly, to decreased strain at break of the dried paper. The tensile stiffness of the dried paper and the drying tension at the end of drying (final drying tension) were increased considerably by straining. Although a certain level of strain is needed to ensure wet web runnability, straining has a detrimental effect on a number of dry paper web properties. Straining strategy improvements can be made by controlling the dryness of straining. The C-Impact tensile tester was found to realistically simulate the paper drying process at paper machine conditions.
ABSTRACT

A tension beam was designed to quantify cross-directional tension profile of a moving web at high resolution and high accuracy. The beam, composed of 50 individual Teflon pads resting on load cells, allows the measurement of the tension profile of a 1270 mm wide web. The tension beam was installed on a roll tester machine that has the capabilities of unwinding large roll. A method to evaluate the tension profile of a full width machine from individual rolls was also developed. Over the past years, the beam was used to test different types of material, from lightweight paper to polymer films, airlaid material and paperboard. Tension analysis showed that cross-directional tension profiles may vary a lot for different web conditions. Examples of non-uniform tension profiles on paper machines related to cross-directional properties variations are illustrated. Models that predict the cross-directional tension profile of as full machine width from basic web properties can also be established using the tension beam.
ABSTRACT

Excessive static charges on insulating webs are the root cause for a number of problems in roll-to-roll manufacturing operations. Static charges attract contaminants and cause discharges that can ignite flammable vapors, shock operators, damage machine control systems, and change the surface chemistry of carefully formulated products. Webs are commonly unwound and wound several times in a manufacturing operation. For example, webs formed by an extrusion process are wound. The roll may be unwound in a coating, slitting, or converting process and wound a second time in a customer roll. Finally, the roll may be unwound a third time in a customer application such as printing or in a label application process.

Static charges on the web are stored in each wound roll. Each time a roll is unwound is a unique opportunity to neutralize static. Proposed here is a new method for neutralizing static on unwinding rolls. The static control method has three key elements. First, a high performance static bar must be located to neutralize the outside surface of the unwinding roll. Second, a static bar must be located downstream of the first conveyance roller to neutralize the inside surface of the web. Third, the first conveyance roller after the unwinding roll must contact the inside surface of the web.

The method to neutralize static on an unwinding roll is analyzed to show that static charge separated at the unwinding nip by tribocharging may be substantially reduced. The same method also reduces static charges wound into the roll from previous operations.

Finally, the effect of the first conveyance roller on static control is discussed. The web exiting the unwinding roll is likely to have a high level of static that will cause a static discharge known as pre-nip ionization that occurs in the gap between the charged web and the surface of the first roller prior to contact. Pre-nip ionization requires that the first conveyance roller contact the inside surface of the web. Otherwise, the charge neutralization performance of this method is compromised and the web will remain highly charged through the production operation resulting in high static in the winding roll.
ABSTRACT

Web process machines employ various winder types depending on the web being wound. These winders have various rolling contacts between machine elements and the winding roll which give rise to complex vibration phenomena. Consequences of the vibration vary from wear of the machine elements and web material defects to wound rolls being thrown catastrophically from the winder. The type of the vibration excited is very much dependent on the web material properties. Hence, the remedies for vibration problems can differ depending on the web. Despite recent advances in reducing the vibration, roll vibration continues to be the major obstacle to increasing winding equipment speeds.

The web properties which contribute to vibration sensitivity are discussed as well as various mechanisms which can cause wound rolls to become out-of-round and compound vibration problems. When the basic dynamic features of the winding process are studied with elementary or more detailed mathematical models the influence of the damping enhancement of the winder components can be simulated. Some typical vibration types are described together with commercially available solutions.
ABSTRACT

During paper manufacture and processing production losses occur during winding of machine-wide paper rolls and finished rolls due to winding faults. During the winding process at least one drum (steel or rubber-covered) is in contact with the winding roll and creates a nip area where tension and shifting of layers are induced. This process in the nip area with several layers of paper is not known in detail but the knowledge would be helpful to improve winding processes.
ABSTRACT

Though conservation of mass has played a prominent role in modeling longitudinal tension, it has seen limited use in modeling problems where lateral behavior is important. This may be due to the fact that most lateral modeling has been done with methods borrowed from structural analysis. These have advantages. They are well-tested and provide closed-form solutions. However, they tend to be specific to particular structural problems and do not provide a conceptual framework in which conservation of mass can be incorporated. For example, when using beam theory to analyze deflection due to a misaligned roller, it isn’t obvious that conservation of mass has anything to do with the problem. But, in fact, when viewed from the standpoint of two-dimensional elasticity theory, it can be shown that it is responsible for a key boundary condition of the beam theory model – the famous (to web handling specialists) zero moment condition.

Elasticity theory is the obvious candidate for two-dimensional and three-dimensional modeling. Unfortunately, it is viewed by many as a last choice because it requires the use of partial differential equations that can only be solved numerically. This is not the problem it once was. FEA software is now so fast and versatile that it can be used interactively. With turn-around times of only minutes, it can even be used as a tool for learning elasticity theory.

A method for using elasticity theory is described in a 2005 IWEB paper, “A New Method for Analyzing the Deformation and Lateral Translation of a Moving Web” [1]. It shows how to set up and solve a wide range of lateral behavior problems. A key boundary condition for the method, called the normal strain rule, relies on conservation of mass. A mathematical statement of this rule is,

\[
\frac{V_2}{V_1} = \frac{1 + \varepsilon_2}{1 + \varepsilon_1},
\]

{1}
where the subscripts 1 and 2 refer to the upstream and downstream rollers, respectively, and $V$ and $\varepsilon$ refer to the velocities and strains at the point of entry to the rollers. This relationship is applied as a boundary condition to each increment of web width and can, therefore, model lateral non-uniformities in both the web and roller.

This paper will show that the normal strain rule is a special case of a more comprehensive concept that provides a framework for solving a broader scope of problems than contemplated in 2005, especially those in which the relaxed web is not flat. It will also introduce a computationally efficient method for implementing this concept by treating all webs, flat or otherwise, as membranes in a two-dimensional frame of reference.

To be of practical use to investigators, the concepts discussed here and in the 2005 paper [1] require the use of numerical analysis software to solve the partial differential equations. Adaptation of the mathematics to the requirements of a solver is not a trivial task. Therefore, in the hope of facilitating work by others in this area, I will make available the solver script for a misaligned roller to anyone who requests it.
EXPLICIT ANALYSIS OF THE LATERAL MECHANICS OF WEB SPANS

By

B. Fu, R. Markum, A. Reddy, S. Vaijapurkar, and J. K. Good
Oklahoma State University
USA

ABSTRACT

All previous analyses of webs being steered through process equipment have required enforcement of assumed boundary conditions. An example is the normal entry boundary condition which has been employed in many web/roller analyses.

Explicit finite element analyses show much promise for studying all types of web handling problems. The primary benefit of this type of analysis is that only very basic assumptions are required, average web velocity and tension for example. Beyond this the interaction of webs with rollers are governed entirely by forces of contact and friction that develop between the web and rollers. Conditions of stick and slip are possible. Additional benefits include the ability to study web deformations and stresses which may result in the development of boundary conditions that can be employed in models that are computationally less expensive.

This paper will focus on a study of the lateral behavior of a web transiting a set of rollers in a process machine, one of which will be misaligned. The misalignment will be increased until there is interaction with an upstream span, a phenomena that has been previously called moment interaction. Any steering of a web laterally in a process machine produces reactions that must be resolved as frictional forces between the web and rollers. Thus the slightest misalignment of a roller will induce some slippage between the web and an upstream roller. That slippage will become gross as the degree of misalignment increases until it migrates around the upstream roller and induces lateral deformation in the upstream span. These phenomena will be studied and results will be compared to experiments. Finally an assessment of potential boundary conditions will be made.
ABSTRACT

This paper presents a continuation of work described at the 2009 IWEB conference in a paper titled, “Two-dimensional Behavior of a Thin Web on a Roller” [1]. In that paper (which will be referred to as Part I), linear two-dimensional equations of equilibrium for a thin web on a roller were developed, taking into account cylindrical roller geometry and the effects of friction between the web and roller.

The 2009 paper focused primarily on behavior as the web enters onto a roller. A steady state condition necessary for existence of a stick zone at the entrance was defined. This is particularly useful for predicting slipping on concave and curved-axis spreader rollers.

In Part 2, the following issues are considered.

1. Why is the steady state stick zone always at the roller entry regardless of the direction of microslip? This is one of those innocent questions that stretches the mind. A latex web, operating at large strain, is used to demonstrate that, in the absence of acceleration, the microslip predicted by the capstan equation is a process that propagates upstream from the exit.

2. The lateral entry slip criterion developed in the 2009 paper [1] takes no account of the wrap angle and yet there are clearly situations where wrap matters – even when there is no MD tension difference across the roller. How does this happen?

3. Is there a capstan equation for shear?

The 2D + w model, described in a companion paper [2], presented at this conference, will be used to put the cylindrical model on a more rigorous mathematical foundation, using curvilinear coordinates and the nonlinear elasticity equations.
ABSTRACT

All previous analyses of webs encountering spreading devices have required enforcement of assumed boundary conditions. An example is the normal entry boundary condition which has been employed in many web/roller analyses. Explicit finite element analyses show much promise for studying all types of web handling problems. The primary benefit of this type of analysis is that only very basic assumptions are required, average web velocity and tension for example. Beyond this the interaction of webs with rollers are governed entirely by forces of contact and friction that develop between the web and rollers. Conditions of stick and slip are possible. Additional benefits include the ability to study web deformations and stresses which may reveal the boundary conditions that can be employed in models that are computationally less expensive.

This paper will focus on a study of the behavior of a web transiting a concave roller. It will be shown that a concave roller can be an effective spreader locally in the entry span as a web approaches a roller but can cause web instability in the form of troughs in an exit span. Results for several roller concavities, friction coefficients and web materials will be presented. Finally an assessment of when kinematic boundary conditions such as the normal entry condition are valid will be made.
ABSTRACT

Aluminum and copper metal webs less than 150 microns (6-mils) are considered foils. Demand for aluminum and copper foils are growing, driven by growing markets for flexible electronics, flat panel displays, lithium batteries, and solar products. In many of these products, thinner foils have cost or weight advantages, but as with nearly any web, thinner means an increased sensitivity to wrinkling in web handling processes.

Nearly all of published web handling research and development work have been based on polymer films and paper webs. Since the web wrinkling theories are based on first principles, they should apply to the foil webs. However, applying models confirmed with paper or foil on narrow widths (less than 0.3m or 12-in wide) to the uncharted territories of foils with 20x elastic modulus and 4x width increases will likely lead to interesting discoveries.

This paper will present a comparison of empirical wrinkling results from trials of handling thin and wide aluminum and copper foils (less 25 micron thick by greater than 0.6m wide (less than 0.001-in thick by 24-in. wide). The experimental results will be compared to wrinkling theory, with conclusion about how wrinkling in foils differs from film and paper webs.
ABSTRACT

Accumulators provide a large amount of web storage in a small space. They are used to allow start/stop events like an unwind splice or a transfer to a new roll on a winder. It is common to see a loss of productivity due to wrinkles and lateral movement of the web as it travels through an accumulator.

An explicit finite element model has been developed to study wrinkle formation and web steering inside of an accumulator. Four cases will be presented: perfect web / perfect accumulator; imperfect web / perfect accumulator; perfect web / misaligned accumulator; imperfect web / misaligned accumulator. Model results indicate that the misalignment required to cause wrinkles within the accumulator decreases with increase in number of misaligned rollers. Model results also indicate that the critical misalignment to cause wrinkles decreases if the web has imperfections in the form of thickness variations.

A seven roller accumulator set up was designed and built to study the wrinkling dynamics of a low modulus nonwoven web and to compare the model results. Measurements indicate that the model predictions compare reasonably well to experiments. The study highlights the criticality of acceptable limits for tolerance on misalignments within the accumulator for process robustness.

ANALYSIS OF WEB WRINKLING IN ACCUMULATORS

By

B. K. Kandadai, N. J. Michal and A. Patil
Kimberly-Clark Corporation
ABSTRACT

Wrinkling remains one of the top causes of converting process waste. Though wrinkles created by roller misalignment and web bending (shear wrinkles) are well-understood, nearly all the published research and modeling has been based on narrow web experiments (less than 15-in wide). Other causes of wrinkling, such as wrinkling due to roller deflection or uneven nipping, have had little or no published results. Similar to wrinkling, most published research on spreading and anti-wrinkle rollers has been based on narrow web experiments.

This paper will review the results from wide web wrinkling due to roller misalignment for various materials and compare the experimental wrinkling results to isolated-span shear wrinkle models. Also, we will share results from over ten different roller designs (including various concave roller profiles) demonstrating their relative effectiveness in preventing shear wrinkles and their ability to spread a web slit down its center. Lastly, during our shear wrinkles trials we unintentionally created tracking or gathering type wrinkles from a deflecting rollers at the top of a long, vertical span. This led to an experiment investigation to eliminate these wrinkles and an upgraded model to predict these wrinkles caused by roller deflection in the negative bow direction.
ABSTRACT

This paper is a review of some 3,500 published works in the areas of web handling, winding, converting and related subjects. These individual works include articles, books, columns, conference papers, instruction manuals, theses, course notes and other material spanning the better part of a century. There are hundreds of authors that have contributed to this vast body of industrial art and science. These authors represent scores of companies, independent consultants, universities, trade organizations and trade publishers. The individual works were found by a combination of professional and public database searches as well as direct inspection of collections at libraries, attendance at conferences, magazine subscriptions, websites and other sources. These original works were then inspected for the bibliographies contained therein and added when new and relevant items were found. All web related works were entered into a flat database of a dozen fields that extended beyond the obvious (author, title, publication) to include such information as author’s employer, copyright holder, rating and other fields. The search and database construction took place over the course of a quarter century.

Analysis of this database within this paper includes a study of publication counts by author, subject, type and source. While the great majority of authors have only a single or a few web handling publications, some of those are uniquely valuable as they may be the only treatment of a particular topic. A handful of authors have more than one-quarter century of steady publication. Even so, the most prolific author still only accounts for less than 10% of the total. The organizations that account for the majority of the web related publications include TAPPI, Paper Film Foil Converter Magazine, the Converting Magazine, AIMCAL and, of course, the Web Handling Research Center. The publication count ranking nearly matches the age of the major organizations, possibly suggesting a steady publication rate. Unfortunately, the overall publication rate seems to show the common life-cycle pattern of development, introduction, growth, maturity and decline. If TAPPI publications are not considered, because the paper industry has been in a decade plus long decline, the remaining publication rate seems to be holding since its peak in the mid 1990’s. A prospective of near future publication is also given.
ABSTRACT

Nip rollers are used extensively in web handling processes; however, rubber-covered rollers have the unwanted and often unpredictable characteristic of unknown surface speed owing to coupling between circumferential and radial strains within the nip. When nip rollers are used to transport continuous webs, this behavior can lead to speed or feed rate variation between the nip roller and the web line in the process direction. Further, variations in feed rate across the width of the web due to roller deflection or other widthwise variations can lead to corrugations and wrinkles. In this paper, a measurement method is described and demonstrated for accurately measuring nip roller feed rates. Data is presented for asymmetrical nip systems consisting of a rubber-covered nip roller loaded against a metal roller. Results are shown for a conventional nip roller covering and a second nip roller covering engineered with the ability to control nip roller feed rate while retaining desirable nip pressure characteristics. Results from a troughing and wrinkling study using two pairs of end-loaded symmetric nip rollers of each design are also presented. These results are used to compare and contrast the performance of nip rollers systems where differences in nip roller feed rate significantly alters system behavior.
ABSTRACT

The paper will investigate the quality of an easy measuring procedure for determining the amount of sheets in a stack of paper.

One of the central questions is the comparability of the height of a loaded stack consisting of a single sheet, a small stack or a high stack of sheets. Here two approaches were examined to constitute the different deformation behavior of a single sheet and a stack of paper.

Experiments showed that deformation of the lowest and the highest surface of paper is not relevant and can be neglected if the stack of paper has more than 20 single sheets. Also experiments with different pressure stamps showed the spreading of a punctual charged load in the form of a cone to a bigger area while going down in the stack of paper. This has a high influence to the deformation allocation inside a stack of paper.

The interesting reference factor - thickness of a loaded sheet - for the measuring procedure will even in high stacks not converge to a constant value. Analysis of the measurement data certifies this effect. Measuring the height of a stack of paper is not possible in required accuracy with the procedure due to the low quality of the measured reference factor.

While comparing the calculated amount of sheets with the correct amount of sheets, a linear correlation between these values is conspicuous. Upgrading the easy measuring procedure with this linear correlation guides to a satisfactory measurement result. The use of the respective regression parameters is needed. The deviation to the exact amount of sheets can be lowered compared to the easy measuring procedure for example at 400 sheets, by factor 10 to 0.2 percent.

The procedure can be used for measuring the amount of sheets in a stack of paper with a high accuracy.

DETERMINING THE AMOUNT OF SHEETS IN A STACK OF PAPER BY USING A PRESSURE STAMP

By

M. Desch and E. Dörsam
Institute of Printing Science and Technology
Technische Universität Darmstadt
GERMANY
ABSTRACT

Roll alignment plays a crucial part in eliminating web handling issues in manufacturing processes. Web handling issues due to roll misalignment includes tracking, tension control, uneven material gauge, and in some cases, misalignment alters the molecular properties of the material being produced.

While the pace of the manufacturing industry has evolved, with machines today running faster than ever, commonly used roll alignment methods such as such as theodolites and transits has not change much. Such systems inherently contain errors as well as geometrical limitations in measuring rolls in machinery of various configurations. A few of these issues were addressed by the newer laser alignment devices but these systems still need to be set up roll by roll with a line of sight, therefore consuming valuable time.

These issues are addressed with the invention of the inertial roll alignment method. The inertial roll alignment device eliminates geometrical limitations due to its highly engineered and compact design. The device does not require a line of sight because it has three ring laser gyroscopes that measure the x-y-z positions (or roll, pitch and yaw) of a roll in space. The inertial roll alignment method eliminates errors that are present in the other methods. The advantages of inertial roll alignment device are in terms of higher accuracy, precision, speed of data collection, compactness, and no line of sight needed. If rolls in machinery are aligned with the inertial roll alignment device, manufacturing processes would expect less web handling issues.
Keynote Presentation I

Precision Die Coating Technology and Related Web Handling Challenges
E. Pederson, Avery Dennison, USA

Session 1 – Lateral Mechanics, Dynamics and Instability

Lateral Dynamics Simulation of Webs Having Cross-Machine Variation
S. Lange, M. Looney and J. Carrle, Procter & Gamble Company, USA

Wrinkle Initiation and Development in Heated Webs on Drums
D. P. Jones¹, M. McCann², C. A. Bishop³ and S. Abbott⁴, ¹Emral Ltd., United Kingdom, ²MJMcCann Consulting, USA, ³C. A. Bishop Consulting Ltd., United Kingdom, ⁴Steven Abbott TCNF Ltd., United Kingdom

The Behavior of Webs Transiting Crowned Rollers
S. Vaijapurkar, J. A. Beisel and J. K. Good, Oklahoma State University, USA

A General Model of Lateral Web Dynamics Between Two Reels
H. Yang and S. Müftü, Northeastern University, USA

Using Roll Hardness to Screen for Excessive Web Bagginess
A. Thuer, Avery Dennison, USA

Evaluating the Impact of Non-Uniform Paper Properties on Web Lateral Instability on Printing Presses
F. Parent and J. Hamel, FPInnovations, Canada

Web Wrinkling Resulting from Moment Transfer
B. Fu and J. K. Good, Oklahoma State University, USA

The Behavior of a Flexible Web in Contact with a Roller
D. P. Jones, Emral Ltd., United Kingdom
Session 2 – Winding & Tension Control

The Effect of Winder Type and Web Material Properties on Wound-on-Tension
Y. Ren, B. Kandadai and J. K. Good, Oklahoma State University, USA

Longitudinal Slip in Rolling Contact
U. Fügmann and W. Beier, Chemnitz University of Technology, Germany

Winding of Plastic Barrier Films
F. Hoffman¹, T. Kirchhoff² and F. A. Heinzler², ¹Windmöller & Holscher, ²University of Duisburg-Essen, Germany

Surface Compression of Wound Rolls
C. Mollamahmutoglu, S. Ganapathi, and J. K. Good, Oklahoma State University, USA

Gauge Optimization of the Reference Tension and Nip-Load in Winding Systems Using Wound Internal Stresses Calculation
D. Knittel¹, I. Bencheikh¹, M. Boutaous² and P. Bourgin², ¹University of Strasbourg, ²Centre de Thermique, France

Wireless Monitoring of Internal Wound Roll Pressures
T. J. Walker¹ and R. C. Updike², ¹TJWalker + Associates Inc., ²Optimation Technology, Inc., USA

Web Tension Regulators – Classical Control Heuristics
C. Klassen, KlassENgineering, Inc., Canada

Session 3 – Web Handling

Myth Busters: Web Handling and the Power of Modeling
R. Lynch, RJLynch & Associates, LLC, USA

Machine and Transverse Direction Errors in Webs: Diagnosis and Remedies
T. J. Walker, TJWalker + Associates Inc., USA

Method for Calculating Catenary Web Spans
J. Dobbs and D. Carlson, 3M Company, USA

Influence of Heating on Tensile and Relaxation Behavior of Wet Paper
J. Kouko¹, E. Retulainen¹ and P. Kekko², ¹VTT Technical Research Centre, of Finland, ²Metso Paper, Finland

Modeling of Nip Pressures and Web Feed Rates in Rubber Covered Nip Rollers
K. Cole, Optimisation Technology, USA

Modeling Web Behaviour in Printing Press and in Printed Electronics
M. Parola and J. Sorvari, VTT Technical Research Centre of Finland, Finland
Guidelines for Allowable In-Plane Roller Misalignment Using Wrinkling and Web Break Models
D. R. Roisum, Finishing Technologies, Inc., USA

Keynote Presentation II

Fully R2R Gravure Printed Near Field Communication (NFC) Smart Tags
G. Cho, Sunchon National University, Korea

Session 4 – Longitudinal Dynamics & Tension Control; Challenges in Roll-to-Roll Manufacturing

Comparison of Control Strategies for Roll-to-Roll Printing Presses
A. Seshadri and P. R. Pagilla, Oklahoma State University, USA

Application of Dimensional Analysis to Roll-to-Roll Manufacturing Systems
P. R. Raul and P. R. Pagilla, Oklahoma State University, USA

Effects of Parameter Uncertainties on Longitudinal Web Dynamics
J. Frechard, D. Knittel and Y. Martz, University of Strasbourg, France

Adaptive Feedforward Based Control Strategy for Attenuation of Periodic Tension Oscillations in Roll-to-Roll Manufacturing
C. Branca, P. R. Pagilla and K. N. Reid, Oklahoma State University, USA

Control Design for Longitudinal Web Dynamics: Benefits and Drawbacks of Robust Control Approaches
D. Knittel, J. Frechard, and Y. Martz, University of Strasbourg, France

Modeling of the Transport Behavior of Low Modulus Webs
P. R. Raul and P. R. Pagilla, Oklahoma State University, USA

On the Governing Equation for Web Tension with Out-of-Round Rolls
C. Branca, P. R. Pagilla and K. N. Reid, Oklahoma State University, USA
ABSTRACT

Avery Dennison is the global leader in manufacturing of pressure-sensitive (PS) materials and adhesives for the label and packaging industry. In addition to the proprietary chemistry of our adhesives, the quality and consistency of our adhesive coatings is critical to the performance of our materials in the label converting and application processes by our business partners. In the 80’s and early 90’s, as coating widths and speeds were increasing, AD was faced with new product quality challenges and manufacturing efficiency issues related to our existing roll coating and off-the-shelf die coating equipment. AD responded by committing the corporate R&D engineering organization to develop core competencies in modern precision die coating technologies to replace older, less efficient methods. This vision required building fundamental understanding of how our materials behave throughout the coating process using state of the art modern engineering principles and tools. The resulting proprietary, high speed, precision die coating equipment and processes delivered highly efficient manufacturing processes that provided superior quality and consistency as well as enabling new first to market multi-layer constructions. In this presentation we will discuss our journey as we developed and implemented our precision slot die and curtain coating technologies throughout our plants worldwide as well as an overview of the tools and methodologies used to design our coating equipment. As speeds increased to a thousand meters per minute and material thicknesses continue to be reduced to just tens of microns, proper web handling and winding is of vital importance in our manufacturing processes and we will share with this audience some of the challenges that we face today.
ABSTRACT

Webs often include sectional variation in caliper or modulus of elasticity as a result of undesirable manufacturing variation or by intentional design. These variations influence wrinkle formation and tracking control in multi-span web handling systems. This paper shares the results of finite element simulations of the lateral dynamics of webs having variation in thickness and modulus in cross-machine direction. Span length and machine-direction bulk strain were varied and the effects on lateral steering and wrinkle formation were simulated for a variety of inhomogeneous webs.

Key variables affecting the lateral steering include the CMD location of the thick section and its width, the stiffness of the thick section, the z-direction bias of the thick section relative to the roller surface, the average strain in the composite web and the span length/width ratio. The web shifted in most cases toward the half of the web having the thick section, though not all. The combination of a web with a thick, stiff section having a width 1/10-1/6 that of the base web, coincident with the web edge, in long spans with low strain generated the largest lateral shift. Wrinkles were generated for some conditions where the thick section was located on or near web centerline.
WRINKLE INITIATION AND DEVELOPMENT IN HEATED WEBS ON DRUMS

By

Dilwyn P. Jones,1 Michael J. McCann,2 Charles A. Bishop,3 and Steven Abbott4
1Emral Ltd., UK
2MJMcCann Consulting, USA
3C. A. Bishop Consulting Ltd., UK
4Steven Abbott TCNF Ltd., UK

ABSTRACT

Wrinkles often occur in webs heated on drums and rollers. Anecdotal evidence from vacuum metalizers suggests that wrinkles are initiated by small grit particles or surface imperfections that lift the web off the drum. An elliptical patch of web centered on the dirt particle is lifted off the drum against the tension pressure acting to restore contact. A numerical “tent model”, based on plate theory, has been formulated to predict the critical transverse direction (TD) stress at which the web spontaneously lifts off the grit, forming the wrinkle. The model iterates to find the tent shape for a given TD stress, and then uses an interval halving method to determine the critical TD stress. Results from the model will be presented. It turns out that a simpler, analytical “draped beam” model gives similar dependence on parameters but over-predicts the value.

Once a wrinkle initiates, it may grow to a size where it is more visible, but has limited length and is restrained against further growth. Further increase in compression enables it to grow by relieving the TD compressive stress in both the lifted-off region and the neighboring web still in contact with the drum. It will also extend in the machine direction (MD). In vacuum coating, wrinkling causes a loss in thermal contact with the cooled drum, the web heats up, expands and the wrinkle grows catastrophically.
ABSTRACT

Crowned rollers are known to center running belts by observation. Crown can be an unintentional artifact of rollers whose surfaces are machined on lathes while supported at their ends. The bending stiffness of the rotating roller allows the roller to deflect away from the cutting tool. If centering is desired the crown may be intentionally cut into the roller surface.

Webs have small finite buckling strength. The same steering forces that will center a belt on a crowned roller may buckle or wrinkle a web. The objective herein is to demonstrate modeling methods that can be used to determine when the crown level will induce buckles or wrinkles in a web or a belt.

THE BEHAVIOR OF WEBS TRANSITTING CROWNED ROLLERS

By

S. Vaijapurkar, J. A. Beisel, and J. K. Good
Oklahoma State University
USA
ABSTRACT

A flexible web unavoidably deviates from its prescribed (linear) path during processing. The lateral web dynamics can be caused by tilt of rollers, web defects, off axis motion of the reels and other factors. In this work we present a generalized model of web transport between two reels, supported by numerous rollers. The mechanics of the web between the two reels is represented by a single partial differential equation, hence coupling of web-spans or lack thereof can be predicted. Web-to-roller interaction is modeled by assuming that tape sticks to the roller surface. The results of this general model are compared to the well-known model by Shelton and Reid (SR), which is applicable in the free span between two rollers. Good agreement between the present model and SR-model is found when the upstream free-span is stiff (or the downstream free-span is compliant), when the wrap angle is large and lateral bending rigidity is high. The present model otherwise predicts coupling of the mechanics of the free spans. The model is flexible to consider a variety of imperfections related to the web geometry and the path components. The lateral motion of a weaved web which is transported on a path with tilted rollers is simulated. The amplitude and the direction of the scatter wind due to this effect are predicted. In general the model shows that the coupling between the upstream and downstream web spans around a roller should not be neglected.
USING ROLL HARDNESS TO SCREEN FOR EXCESSIVE WEB BAGGINESS

By

Amy Thuer
Avery Dennison
USA

ABSTRACT

Various methods are available for quantifying bagginess. But they can be tedious and impractical in a production setting. Often one just needs to know if a roll is too baggy to run without wrinkling during converting. Screening rolls offline can save time and reduce scrap when the alternative is loading the roll and making machine adjustments on the fly to eliminate wrinkles from baggy edges.

In this paper a method for correlating average roll hardness and cross direction hardness profile to runnability using intraclass correlation and binary logistic regression tools is described. Here runnability means running near target line speed without wrinkling. The outcome is the probability that a particular roll will exhibit enough bagginess to impact runnability. Then the decision to reject the roll without running can be made depending on how much risk is acceptable. This information can then be relayed to the web supplier to help reduce bagginess at its source.
EVALUATING THE IMPACT OF NON-UNIFORM PAPER PROPERTIES ON WEB LATERAL INSTABILITY ON PRINTING PRESSES

By
Frédéric Parent and Jean Hamel
FPInnovations
CANADA

ABSTRACT

Lateral instability of the paper web during printing may lead to several quality issues such as print misregistration, wrinkles, tracking issues, etc. The problem often leads to paper rejects and claims from printers. There is limited information available to paper producers on paper wandering during printing. The problems may come from the equipment, lateral control or could be even the paper web itself. An empirical study was completed with numerous paper producers to evaluate the impact of non-uniform paper properties, both cross and machine direction, on web lateral instability on printing presses. The key component of the study was to quantify web instability. To do so, portable positioning edge sensors were used during printing runs, as well as on lab equipment, to quantify the amplitude and frequency of any lateral movement. Concurrently, apparatus such as Tapio™ and one-of-a-kind paper roll testing equipment were used to measure paper properties and assess their variability. Lateral displacement and paper non-uniformity and variability were then correlated. In many cases, lateral instability of the paper on printing equipment was related to the non-uniformity of the cross-direction tension profile of the paper. Other contributors to lateral instability were the periodic variability of basis weight and fiber orientation in the machine direction. In this article, case studies of mills that have worked on reducing properties non-uniformity will be presented as well as the impact it had on web lateral stability.
WEB WRINKLING RESULTING FROM MOMENT TRANSFER

By

Boshen Fu and James K. Good
Oklahoma State University
USA

ABSTRACT

Considerable research has been focused on the impact of roller misalignment on web instability. Early work focused on the prediction of trough instabilities in the entering span, just upstream of the misaligned roller [1]. Later works involving misaligned [2] and tapered [3] rollers proved that the trough instability was a required precursor for the occurrence of wrinkles on the misaligned or tapered roller. The compressive stress required to induce web wrinkles on a roller can be 2 orders of magnitude larger, in the absolute sense, than the compressive stress required to precipitate trough instabilities in a web span. These works [2][3] found the out-of-plane web deformation due to troughs was responsible for creating the larger compressive stresses that would finally result in wrinkles whenever the misalignment or taper became sufficient. The three works referenced thus far all rely upon an assumption that the friction forces between the web and the upstream roller, which separates the entering and pre-entering spans, are sufficient to prevent moment transfer. The lateral deformation of the web in the pre-entering and entering spans as a result of moment transfer has been another focus of web handling research [4][5]. This publication will focus on the impact of moment transfer on web wrinkling. It will be shown that troughs may now occur in both the pre-entering and entering spans. It will also be shown that wrinkles can precipitate on either the misaligned roller or the roller upstream of the misaligned roller. It will be shown that these behaviors can be predicted and the predictions will be validated by test results. It will be shown that as a result of moment transfer the roller misalignment to induce wrinkles can be less than the misalignment required to induce wrinkles when moment transfer does not occur.
ABSTRACT

In the contact patch between a web and a roller, there may be regions of stick and microslip or full slip. Within the stick zone, the velocities of web and roller surface match, but in the microslip zone they differ by a small amount as the web deforms. Analysis of the stick zone indicates an upper limit to the shear stress in the web, determined by friction. As the web steering in the incoming span is increased, the shear stress increases to satisfy the condition of velocity matching. Eventually, friction in the stick zone cannot support the shear stress and a microslip zone forms on entry, resulting in a change in the behavior in the span. The influence of web bagginess and roller profile on the shear stress limit is analyzed.

An exit microslip zone will normally be present, as the web changes tension or develops shear stress and bending moment as a result of steering in the outgoing span. Attempts to analyze this with a beam model, as used in a free span, will be described. However, the requirement to match conditions at the start of the span is impossible to meet, so partial width microslip zones are postulated.

Work continues to understand these microslip zones.
THE EFFECT OF WINDER TYPE AND WEB MATERIAL PROPERTIES ON
WOUND-ON-TENSION

By

Y. Ren, B. Kandadai1 and J. K. Good
Oklahoma State University
USA

ABSTRACT

The choice of winder type for various web materials has long been a qualitative
discussion. Web materials are vast and hence the range of web material properties is also
vast. Valid but conflicting opinions for an optimal winder type have been developed from
experience bases that represent this vast range of web materials. The purpose of this
publication is to quantify how the internal stresses in wound rolls are affected by winder
type and web material properties.

1 B. K. Kandadai works as a Mechanical Engineer at Kimberly-Clark Corporation.
LONGITUDINAL SLIP IN ROLLING CONTACT

By

Uta Fügmann and Wolfgang Beier
Chemnitz University of Technology
GERMANY

ABSTRACT

In printing machines incorporating indirect printing technology, the image or pattern is first printed onto a blanket cylinder having an elastic rubber surface. Subsequently, the pattern is transferred to the substrate. When the surface of the blanket cylinder is covered with incompressible elastic material, a high tangential load develops at the blanket-substrate nip, which may either lead to longitudinal sliding of the mentioned printing element or cause tearing of the substrate. The described tangential load developing at the printing nip could be significantly reduced if the lining of the blanket included a compressible layer. The elastic material at the nip could now bear the tangential forces since the compressible layer could absorb them. In the printing result however, although quite minimal, the longitudinal slip can still be seen.

Study of the geometrical analysis and movements involved at the nip between the rigid and flexible contact presented an explanation.

For the geometric analysis of processes taking place at the nip, standard reverse kinematic transmission has been utilized. The flexible cylinder is taken as a fixed element while the rigid cylinder has been rolled as a planetary gear about a rolling contact. Both cylinders have bearer-to-bearer contact. Therefore they roll without any slip, ensuring a precise ratio of the angle of rotation. In order to achieve a defined contact pressure between the cylinder jackets, the projection above the bearer surfaces of the flexible and rigid cylinder have been measured, the sum of which is the metric pressure. When the rigid cylinder is rolled around the fixed flexible cylinder, each point on the surface of the rigid cylinder follows a path, the locus of which, when represented graphically forms an extended epicycloid.

The presented method of calculation, using the extended epicycloid apart from theoretically determining the slip, presents the ability to minimize the same.
ABSTRACT

High quality plastic films are produced using the cast or blown film extrusion processes. Several kinds of resins are coextruded in a film of up to 11 layers to generate the best technical properties at competitive costs. A state-of-the-art film for food packaging has 5 layers including a 3-10 µm thin oxygen barrier layer of the high cost ethylene vinyl alcohol copolymer. The film is pre-treated for the subsequent processes of printing and lamination. The biggest challenge in this context is that some winding defects are able to destroy complete rolls. Two of the most common winding defects for barrier films are cross direction wrinkles and air knots.

Cross Direction (CD)-wrinkles are directly related to the blown film process, though they might be detected only after lamination. The core area is especially prone to these kind of wrinkles, but they can appear everywhere in a roll. A measurement device for the roll hardness is established and used to document the aging of the rolls. In addition to that, the core pressure is measured and analyzed. A high resolution thickness scan of a complete roll shows the web’s thickness profile and how it is affected by the oscillation.

Air knots are small spot-like air entrapment zones between the web layers of the roll which can deform the film permanently in combination with the pressure build-up inside the roll. This defect can occur on film rolls of very different resins. Furthermore, the effect is influenced by the pre-treatment process that modifies the surface structure of the web. Experimental winding tests and analytical winding models are used to investigate the correlation between pre-treatment dosage and air knots.
ABSTRACT

Stress levels and profiles in the vicinity of contact between a wound roll and a nip or a rigid surface are important for the quality of the product during manufacturing or storage stages. Excessive or insufficient pressure and stress levels can cause structural damage. This can be crucial for webs that have been recently coated and for all webs that are susceptible of wringing where web layers may fuse or bind together. Herein an efficient computational approach is introduced based on the finite element method for the calculation of stresses in the wound roll which are resulting from contact with a rigid flat surface, a rigid roller or a roller covered with a rubber layer. Compaction experiments carried out on polyester and newsprint webs are used to verify the method. The method accounts for the state dependency of the radial modulus which being affected locally by both winding and contact pressures. It was found that the shear modulus of the stack is important in predicting the contact behavior and had to be determined. The developed numerical tool is used to analyze the stress changes in a wound roll due to contact with a rigid or rubber covered nip roller.
ABSTRACT

In the winding process, the quality of the roll is directly related to its stress state. The winding tension and nip-load are the most significant parameters which play an important role in the stresses generated within a roll during winding. If the stresses exceed a critical value, defects can appear in the roll and make the web non usable.

This work concerns the optimization of the maximal dispersion of the tension and nip load references. It consists to find automatically the maximum and minimum limits for the tension and nip load references, so that all curves ranging between these two limits or thresholds generate radial and tangential stresses located in another gauge fixed in advance, in accordance with the mechanical behavior of the material. The results lead to a practical gauge optimization of the reference tension and nip load for industrial applications.
WINDING is a dynamic process. The final roll is the product of all that happens during the winding process from roll start to final cutoff. Nearly all roll measurement methods try to characterize a roll's structure after winding is completed, like understanding why a plane crashes from diagnosis of the debris. What winding needs is the equivalent of a 'black box,' a monitoring device to record the dynamic nature of the winding process. Using thin resistance-based pressure sensors and wireless data collection, we will show the changes inside a winding roll as a function of key winding variable, including product properties, winding torque and nip loads, winding speed, and rotation position.
WEB TENSION REGULATORS – CONTROL HEURISTICS

By

Clarence Klassen, P. Eng.
KlassENgineering Inc.
CANADA

ABSTRACT

Classical Control Theory using closed-loop controllers has been applied to drives for web handling beginning in the 1940’s. Back then the mathematics was ahead of the tools for analysis as well as the modeling and the drive control equipment available. Nevertheless, using frequency domain analysis such as Bode Plots, and well thought out heuristics, strategies were developed for web tension control that were successful in developing the web handling drive systems at that time and continuing to the present. The control strategy heuristics developed in the 1940’s are still in widespread use today although with newer equipment. It may be that these heuristics are so ingrained, that first principles are being forgotten or ignored.

Newer drives, controllers and tension measurement have resulted in drive systems with better specifications, but improvements in tension control may not be evident. Modern Control Theory state-space controllers are now available, but must be implemented in ways that do not ignore the web tension control strategies developed over the past 60 years. At a minimum, we expect new controllers will provide improved performance over classical controllers. This paper documents the classical heuristics developed for and used in drive systems for web handling machinery. It will discuss some practical concerns of implementing modern tension control algorithms in the web handling industry. These concerns include engineering and commissioning of the web tension control.
ABSTRACT

Web handling is filled with myths and folklore about things to do and not to do, about how to design web paths, and about how to handle specific situations. The folklore and myths are often industry specific and many web handlers rely on their industry's folklore to do their work. In 40 years of web handling, the author has heard many of these myths. We have all heard the myths from, "Every driven roller needs to run faster than the last," and "Idlers add tension to a web," to "It ain't rocket science." Folklore is not always wrong and not every myth is busted. Some have a grain of truth or apply only in very specific situations. This paper discusses several of the more common web handling myths and uses simple formulas and logic to explain their origins and understand their validity.
ABSTRACT

The primary focus of web handling is often on tension control; however, equally important to almost any web handling or winding process is to maintain machine (MD) and transverse direction (TD) control of the web. This paper outlines a guide to loss of control or position of the web in both the machine and traverse direction on in handling over rollers or winding rolls. For each category of MD/TD errors in handling/winding, this paper covers: measurement, problems, root causes, and solutions tailored to each specific mechanism. This paper is not seeking to review the equations of traction or lateral control, which have been covered in many previous works, but to focus on the common problems of MD and TD control and target appropriate solutions.
ABSTRACT

The methods for calculating the catenary droop of a wire or cable hanging from fixed supports are well understood. For many common web materials, catenary droop or sag is not a consideration but for webs having a significant lineal mass density and low web tension, catenary droop may be significant. Applying the well-known catenary equations to a web handling system with roller supports poses some interesting computational challenges and also some unexpected results. A computational method will be presented that can reliably solve the catenary equations for an arbitrary web span geometry. Catenary sag (from a straight line web path), web tension along the web span and the length of web hanging in the span can all be obtained from this solution method.

METHOD FOR CALCULATING CATENARY WEB SPANS

By

James N. Dobbs and Daniel H. Carlson
3M Company
USA
ABSTRACT

The influence of increasing temperature on the strength and relaxation of wet never-dried paper was studied using C-IMPACT, a tensile tester equipped with a special heating chamber. The heating device formed a small climate chamber around the paper sample and raised the temperature of the paper to the target temperature of 30-70 degree Celsius within a couple of seconds. The heating chamber made fast heating possible without detectable moisture loss. The tests were performed only in the machine direction of the paper samples.

The results showed that temperature had a significant influence on the straining, relaxation and re-straining behavior of wet paper. Increasing temperature decreased the tensile strength and stiffness of wet paper, but did not affect strain at break. However, due to mechanical conditioning, tensile stiffness in the re-straining of wet paper depended only marginally on temperature.

Increasing temperature strongly increased the apparent relaxation rate. In this study, the apparent tension relaxation rate was obtained by fitting a log-linear function to the relaxation data. The initial 2 seconds of tension relaxation were omitted from the curve fitting because in the other case (pre-straining) heating started after 1 second of relaxation. The data between 2 and 4 seconds was used for the analysis. Depending on the temperature, 30-70% of initial tension was lost during the first 4 s. The observed short time scale phenomena in wet paper have practical significance for fiber webs dried under tension in paper machines. Most of the observed changes due to increased temperature seem to originate from the properties of wet fibers and, especially, from the softening of fiber wall material.

Temperature has strong influence on wet paper tensile behavior at temperatures used in industrial processes. The results clearly show that effects of temperature on wet paper occur relatively fast. Temperature should therefore be taken into account in studies related to processes involving variable temperature conditions, in the same manner as dryness in the case of variable moisture content of wet paper.
ABSTRACT

Nip rollers are used extensively in converting processes; however, correct design and usage of these types of rollers requires a sound understanding of the mechanics of the nip in both the machine and cross-width directions. This behavior is difficult to predict owing to the nonlinear nature of the contact region and the near incompressible material characteristics of typical nip roller coverings. This paper is a companion to a paper presented at IWEB11 where experimental data characterizing web feed rates, nip pressures and wrinkling in nip rollers comprised of single and dual durometer cover systems was presented. In this paper, modeling techniques are developed for predicting nip pressures and nip roller feed rates in both the machine and cross-width directions. The models presented include the ability to analyze roller coverings engineered with the ability to control nip roller feed rate while retaining desirable nip pressure characteristics. Parametric studies demonstrating the influence of many of the material and design parameters of nip rollers on nip roller feed rate and nip pressure are presented. Nondimensionalized parameters are also developed to assist engineers in the design of nip rollers to insure suitable performance.
ABSTRACT

VTT together with several companies in the printing value chain have studied web handling through the printing press. Studies have focused on the web tension formation mechanisms in printing which have an effect e.g. on color register problems, on web wandering and on web breaks in printing presses. Trials have been carried out on a printing press and in laboratory, and modeling of web tension through printing nips has been performed. Printing method used was heatset offset printing. Modeling work was carried out by finite element method (FEM). In the model, the printing press is considered to consist of an infeed unit and four printing units. Each printing unit consists of two rubber-covered cylinders (printing blankets) through which the paper web passes. The printing blankets were modeled as a triple-layer structure.

Results reveal how printing nips and paper properties have an effect on web tension in printing presses. The modeling results and experimental measurements correlated well. Results suggest that, between printing units, the feeding properties of printing blankets have a decisive effect on web tension. Printing blankets cause draw differences between printing units and the paper web reacts to these draws to a magnitude defined by its tensile stiffness.

In a case study, the modeling knowledge gained was applied to study plastic foils deformation in printed electronics. In printed electronics, the register accuracy requirements are much stricter than in traditional printing which makes great demands on the printing process and on web materials stability. In order to obtain a clearer impression of the web deformations in printed electronics a temperature-dependent plastic material model was developed and implemented in a finite element software. With the aid of the finite element code, a coupled thermal-stress problem, in which a plastic web is cyclically heated by dryers, was simulated. Experimental tests were carried out with a specially designed stress-strain apparatus (C-Impact).

Results obtained in the case study suggest that material properties should be taken into account when controlling web transport of printed electronics.
GUIDELINES FOR ALLOWABLE IN-PLANE ROLLER MISALIGNMENT USING WRINKLING AND WEB BREAK MODELS

By

D. R. Roisum, Ph.D.
Finishing Technologies, Inc.
USA

KEYWORDS
In-plane, roller, alignment, standard, measurement, wrinkling, web_breaks

ABSTRACT

While we have had wrinkling and web break models for a quarter century and the means for precision roller alignment for a half century, no consistent recommendations have been made as to allowable tolerances for roller misalignment. The lack of consistency is not so much due to variability of web properties or web machine specifics. Rather, it is mostly due to cultural reasons. The paper industry typically specifies what it could do rather than necessarily what it should do and is a fraction of one hair’s breadth for dry end equipment. The converting industry, in contrast, is largely silent on the subject of alignment and thus leaves it to every individual involved to figure out or, more likely, guess at what needs to be done.

This paper proposes guidelines for allowable in-plane roller misalignment, the more critical of the two directions, based on well-tested wrinkling and web break models. The wrinkling criteria is lack of wrinkles crossing a roller at any value of tension. The web break criteria is limiting maximum tension (at the outside of the bend) to twice the average and thus keep the inside of the bend from going into compression. For those who do not wish to use models, an experimental technique to obtained allowable in-plane misalignment is also described. For those who do not wish to use either models or experiment, a set of quality classes is described that captures best practices in some of the more common web applications.

This paper also includes a few parametric studies revolving around some of the more common materials such as paper and thin films that will show what sensitivities are important and what might be safely ignored. All of this is aimed at what should be done, i.e., when should a roller be moved. Finally, a brief review of alignment methods and tools describe what we could do in a commercial setting. In other words how close can we expect roller alignment to get when we choose to move a roller.
FULLY R2R GRAVURE PRINTED SMART TAGS
AND RELATED WEB HANDLING CHALLENGES

By

Gyoujin Cho
Sunchon National University
KOREA

ABSTRACT

Although a smart tag which can communicate with a smart phone via NFC (Near Field Communication) has been considered as a core tool for bringing up the ubiquitous society, the difficulties in integrating 13.56 MHz RFID (Radio Frequency Identification), sensors and signage altogether on plastic foils with extremely low cost (< 0.5 $) nullify its role for the realization of the ubiquitous society. In this presentation, three key issues of R2R gravure such as overlay printing registration, web tension control and surface roughness of printed layers will be introduced as challenges to be overcome in the production of inexpensive smart tags on flexible plastic foils. The integration of those devices (RFID, sensors and signage) on the plastic foils will be successfully demonstrated using fully gravure printed 96 bit RFID tag, RF-QR tag and RF-Sensors. Those tags contain printed key device units such as 13.56 MHz modulating TFT, digital logic gates, 96 bit memory, cyclic voltammetry, electrochromic display, and rectifier for the wireless power transmission via NFC (13.56 MHz). The detail specifications of R2R gravure and printed key device units for the printed smart tags will be presented as well.
ABSTRACT

Flexible printed electronics is touted to be a significant part of the future of the roll-to-roll (R2R) printing industry. Electronic devices, such as RFID tags, low-cost displays and lighting devices, polymer solar cells, sensors, etc., can be manufactured on a flexible substrate using roll-to-roll machines. In recent years there has been a significant focus towards printing electronics on a flexible substrate using R2R printing methods. These studies have primarily dealt with the feasibility of printing electronic components such as thin metal lines, electrodes, capacitors, thin film transistors, etc., on the flexible substrate. In order to realize the goal of low cost printing of electronics on a flexible substrate using R2R techniques, the web handling aspects related to R2R printing have to be addressed adequately. This paper focuses on the web handling aspects related to R2R printing by analyzing the print registration process using mathematical models and by studying control schemes to improve print registration.

In order to achieve the goal of printing electronics on a flexible substrate, print registration quality has to be significantly improved by refining the techniques involved in conventional printing processes. The quality of print registration or the registration accuracy can be increased by a combination of proper machine design, proper process design and advanced control system design. In this paper all three aspects are addressed in detail. The passive control of print registration using proper machine design and process design is analyzed based on creation and propagation of tension disturbances within print units; and active control of print registration using a closed-loop registration control system is analyzed based on dynamic stability, ease of control design and implementation, and tension disturbance propagation behavior within print units.
ABSTRACT

Dimensional analysis technique is often used to reduce the number of parameters and variables in governing equations of a physical system and to obtain relationships between those parameters and variables that characterize the behavior of the system. It can be applied to interconnected dynamic systems to obtain dimensionless form of equations and to assist in scaling of systems. Roll-to-Roll (R2R) systems are interconnected dynamic systems consisting of several interconnected R2R subsystems formed by unwind, process stations, and rewind for transport of web materials through processing machinery. Dimensional analysis may be used as an effective tool in R2R systems to obtain a compact representation of the governing equations and to reduce the effort needed to redesign the system and retune parameters and reference variables when configuration changes are needed. For example, in the event of changes in the web material or web flow path or scale up, retuning of existing control systems to preserve performance may be achieved using dimensional analysis.

In this paper, we investigate the application of dimensional analysis for R2R systems. First, dimensional form of governing equations for web tension and speed are transformed to non-dimensional form using dimensional analysis, and discussions are provided to highlight their usefulness in further analysis and design of R2R systems. Second, two specific cases are considered to show application of dimensional analysis to R2R systems: analysis of an accumulator and redesign for capacity scaling and scaling of process and controller parameters of an example R2R system for a change in the web material. In the first case, we provide results from model computer simulations to evaluate the method, and in the second case, results from experiments conducted on a large R2R platform are presented and discussed. Further, frequency response experiments are conducted for a subsystem of web spans and rollers for different materials to also evaluate the results of applying dimensional analysis to R2R systems.
ABSTRACT

Web handling systems are very common in industry for metal, paper, textile and polymer material treatments. The key variables to monitor and control are the web speed and web tension in each span. The objective is to reach the expected web speed while maintaining web tension in an acceptable range around the tension reference. Nevertheless, the longitudinal web dynamic behavior is sensitive to parameter variations or parameter uncertainties, as for example the web elasticity, the web speed, the roll radius.

The implemented control strategy is a classical one: a first loop ensures roller speed control whereas the external loop ensures web tension control. The web tension controllers are automatically synthesized using an optimization approach. The influences of parameter variations are studied firstly on the open-loop system and then on the closed-loop behavior.
ABSTRACT

Periodic oscillations in the tension signal are frequently observed in roll-to-roll manufacturing due to the presence of many rotating elements which are often non-ideal, such as out-of-round material or eccentric rolls. In certain situations the amplitude of the oscillations is large enough to affect normal operation of the web line. The proportional-integral-derivative (PID) feedback control algorithms that are commonly used for tension regulation do not have the dynamic complexity to compensate for such periodic disturbances. In this paper we investigate a two-degree-of-freedom controller which has two control actions, feedback and feedforward. The feedforward part is adaptive and is designed to provide control actions to compensate for periodic oscillations. Several issues must be considered when designing a control algorithm for the attenuation of periodic oscillations. First, since the control algorithm is executed in real-time using a real-time system which may have restrictions on the sampling period, the complexity of the algorithm must be such that the control action can be computed in a time period that is less than the sampling period, and the sampling period for most systems is typically in the range of tens of milliseconds. Second, it is desirable to have a feedforward algorithm that can be implemented in parallel with an existing feedback control scheme for tension and speed regulation without the need to retune and redesign the existing scheme. Further, it is desirable to have an algorithm that is understandable to practicing engineers who may have limited or no advanced controls background other than an undergraduate course in control systems.

Considering the aforementioned issues, an adaptive feedforward (AFF) algorithm that can work in parallel to an existing feedback control systems is developed for control of web tension and to attenuate periodic oscillations. The essential ingredient of the AFF algorithm is the estimation of amplitude and phase of the periodic oscillations based on which a feedforward compensating control action is generated. The action of the AFF algorithm is such that retuning or redesign of the existing feedback controller is not required. Several different configurations of the AFF for different scenarios in terms of where to apply the feedforward action in the control system are investigated.
Extensive experiments are conducted on a large web platform with different scenarios and by transporting two different web materials at various speeds. Results from these experiments are presented and discussed. Experimental results show the effectiveness of the proposed AFF algorithm to attenuate tension oscillations.
ABSTRACT

Web tension and speed are two key variables to be monitored and controlled in order to achieve the expected final product quality. One of the main objectives in web handling plants is to reach an expected web speed while maintaining the web tension within an acceptable range around the tension reference in the entire processing line. In the recent years, many works have focused on the topic of web tension control and have proposed various ways to enhance the performance: $H_\infty$, optimal state feedback, neural network, etc. But the common practice in industrial web transport systems remains the use of decentralized PI-type controllers.

An improved design methodology of these PI controllers with fixed-order and -structure synthesis approaches has been made. Nevertheless, despite high performances for a nominal working point, it has been noticed that the closed-loop system performances depend on the web elasticity since the dynamic behavior is strongly affected by the Young’s modulus. Consequently the emphasis of this contribution is on the automatic tuning of PID (or PI) controllers for web processing plants that guaranty good performances of the closed-loop system.
ABSTRACT

Transport and processing of low modulus web materials is a challenging task. By low modulus webs we refer to those materials whose modulus of elasticity is several orders of magnitude lower than those of metals, such as the non-woven webs used as base materials in many disposable hygiene products. To facilitate contact with roller surfaces while maintaining adequate web tension, low modulus webs are often transported in the high strain region of the stress-strain curve which is typically nonlinear in that region. As a result of transport in the high strain region, the material undergoes substantial dimensional change when compared to its relaxed state. Further, being porous and non-homogeneous, transport of these webs presents additional challenges when certain processes require humid and heated environments. Much of the reported work in the literature has treated the transport behavior uniformly for all webs under the assumption that web transport takes place in the low strain region and there is negligible change in the physical dimensions of the web between the relaxed and strained conditions. In this paper, we investigate the efficacy of existing models for low modulus webs and derive and evaluate improved governing equations for web strain and tension by considering the aforementioned issues.

We consider three key issues in this study for low modulus webs. First, transport in the high strain region is considered when the materials exhibit nonlinear and viscoelastic behavior. Second, in-plane biaxial strain is considered in the development of the governing equation for web strain in the transport direction. Governing equations for web strain and tension are developed and evaluated using parameter sensitivity analysis and both time and frequency domain computer simulations under typical scenarios of transport and machine and environment induced disturbing forces. Third, the effect of moisture and heat diffusion in fibrous and porous non-woven webs on longitudinal web strain is considered. Moisture and heat diffusion is studied using known non-Fickian models which better represent the diffusion behavior in porous, fibrous materials.
ABSTRACT

In roll-to-roll (R2R) manufacturing the presence of non-ideal elements, such as out-of-round or eccentric rolls, induces periodical oscillations in the web tension signal. Model simulations based on ideal elements do not exhibit these tension oscillations but can only follow the measured tension signal in an average sense. In order for the models to predict these measured tension oscillations due to non-ideal elements, the derivation of governing equations must consider a mechanism to include the correct behavior of the non-ideal transport elements. Continuing with our previous work on this topic presented at previous IWEBs, we present additional results that provide improvements to the web span tension governing equation which can better predict measured tension signals. In particular, this work is useful for tension control in the unwind section of the web line when the unwind material roll is often out-of-round.

The governing equation for web span tension is typically derived using the law of conservation of mass by considering a control volume enclosing the web span, i.e., at any instant of time the variation of web mass in the control volume is equal to the difference of the incoming and outgoing material flow rates. If the web span is between two ideal elements the only way to induce changes in web span tension is with an imbalance in the web material flow. For ideal elements it is easily shown that the material flow rate is proportional to the difference of the peripheral velocities of the web on the surface of the rolls adjacent to the web span. When an out-of-round roll is at one end of the web span, two aspects make the derivation of the web tension governing equation different from the ideal case. First, because of the out-of-roundness of the roll, the span length adjacent to the roll is time-varying; variations in the span length induce web tension variations that are not associated with an imbalance in material flow. Second, the material flow rate is not proportional to the peripheral velocity of the web on the out-of-round roll and must be computed explicitly. Given a measure of out-of-roundness of the roll, due to the complexity of the problem it is difficult to derive a closed form expression for the material flow rate as a function of the roll position and velocity. A numerical algorithm for the computation of the material flow rate is presented in the paper. Based on the
computation of the material flow rate and the algorithm for the computation of the span length adjacent to an out-of-round roll which was presented in the previous IWEB, a new governing equation for web tension is developed. Using this new governing equation a dynamic model for an experimental web line is developed and model simulations are conducted. To corroborate the model, experiments are conducted on the web line with an out-of-round unwind material roll. Comparison of the results from model simulations and experiments are presented and discussed.