ABSTRACTS OF THE FOURTEEN INTERNATIONAL CONFERENCE ON WEB HANDLING

June 8-10, 2015

Web Handling Research Center
Oklahoma State University
Stillwater, Oklahoma

TABLE OF CONTENTS

DIMENSIONAL STABILITY OF SUBSTRATES FOR PRINTED ELECTRONICS

By

Dilwyn P. Jones
Emral Ltd.
UK

ABSTRACT

Substrates for flexible displays must retain registration between multiple process steps. Although polyester substrates offer cost and handling advantages, their dimensions are affected by tension, temperature and humidity. This paper will summarise the understanding of viscoelasticity, thermal and hygroscopic expansion, shrinkage, and their anisotropy in polyester. Thermomechanical and Dynamic Mechanical Analysis data are particularly useful to understand and predict substrate behaviour.

These effects have been mitigated in sheet processing by laminating the film to a glass sheet: however, a thermal cycle produces bowing distortion that can make subsequent steps impossible. A model for the development of bow from differential thermal expansion, and its relaxation and setting-in by the viscoelastic polymer layer properties, will be outlined. The bow direction and trends are predicted well but the absolute accuracy is not perfect. The model is useful in developing thermal and constraint conditions during fabrication.

Finally, key points for maintaining dimensional stability and preventing wrinkles during roll to roll processing will be summarised. It is particularly important to control tension during drying steps at elevated temperature: high levels can obliterate the benefits of expensive “heat-stabilised” substrates.

REDEFINING OUR RULES OF THUMB

By

Ronald J. Lynch
RJLynch & Associates, LLC
USA

ABSTRACT

Rules of thumb are common in web handling for good reasons. Many of the theories of web behavior are still under investigation and often are complex and a function of properties that are difficult to measure. Because of this, we rely on simple rules of thumb to estimate what are acceptable tensions in a web path. To be safe, these rules of thumb are often very conservative. As we push webs to run faster and more efficiently, we need to refine these rules to meet the new challenges. I wouldn't want to fly in an airplane that was designed with rules of thumb developed years ago for other materials, and I wouldn't want a converting line designed the same way. This paper goes beyond rules of thumb and presents several factors that can help us understand what tensions are right for our webs. It also identifies some area where the knowledge gaps still need to be filled.

IMPACT OF WEB PERMEABILITY ON HIGH SPEED WEB TRANSPORT

By

Paul D. Beuther and Neal J. Michal
Kimberly-Clark Corporation
USA

ABSTRACT

Measurements of drag on a moving web in a multi-span festoon show a stronger than expected dependency on the porosity of the web with a highly non-linear relationship. The experiments suggest a wall shear stress 3-4 times larger than non-porous webs or historical Couette flow data for solid walls1. Previous DNS studies2 of boundary layers with passive porous surfaces predict a much smaller increase in wall shear stress for a porous wall of only 40%. Other DNS studies3 of porous walls with periodic transpiration do show a large increase in drag under certain periodic conditions of modest amplitude. Although those results are more aligned in magnitude with this study, the exact reason for the observed high drag for porous webs in this present study is not understood because there was no external disturbance applied to the web. Previously reported experimental data4 reported a strong linear correlation between wall shear stress and web permeability. The present paper refines those measurements in more detail and shows a highly non-linear relationship between wall shear stress and permeability, but we offer no physical explanation for this relationship. It can be hypothesized that natural flutter of the web results in a similar mechanism shown in the periodic DNS study, but when the natural flutter was reduced by increasing web tension, there was only a small decrease of the drag.

Because of the prevalence of such flows in many industrial processes using festoons for web accumulation, and the large drag increase that accompanies porous webs, the topic is a very relevant problem. With multiple parallel spans in a festoon, any transpiration in one layer must act in the opposite manner on the adjacent span. This coupling may play a role in the amplification of the drag. Higher drag through a festoon creates processing limitations for light weight porous webs such as non-wovens by restricting maximum speeds or requiring higher than desired web tension to process at high speeds. A festoon is a series of many parallel web paths between idler rolls resulting in a multiple set of planar Couette flows between the moving webs. Length/gap ratios approach 100, with distance between the webs ranging from several millimeters to several hundred millimeters.

1. L.A.Dorfman “Hydrodynamic resistance and the heat loss of rotating solids”, 1963, Edinburgh, Oliver and Boyd.
2. J.Jimenez, M.Ulhmann, A.Pinelli, G.Kawahara, “Turbulent shear flow over active and passive porous surfaces”, 2001, JFM Vol 442.
3. M.Quadrio, J.M.Floryan, P.Luchini, “Effect of streamwise-periodic wall transpiration on turbulent friction drag”, 2007, JFM Vol 576.
4. Beuther, P.D., “Measurements of wall shear stress in a planar turbulent Couette flow with porous walls”, presented at the annual meeting of the APS/DFD, published in the Bulletin of the American Physical Society, Vol, 58, No.1 8, November 2013.

EXPLICIT SIMULATIONS OF WEB TRANSPORT THROUGH PROCESS MACHINES USING PERIODIC MEDIA ANALYSIS TECHNIQUE

By

Boshen Fu and Neal J. Michal
Kimberly-Clark Corporation
USA

ABSTRACT

In this paper, the periodic media analysis (PMA) technique in Abaqus/Explicit [1] has been applied to simulate multiple cases of web transport through process machines. The Abaqus models for web transport developed in the Web Handling Research Center (WHRC) at Oklahoma State University (OSU) all have long free upstream spans, which are required to achieve steady state for post-simulation analysis. This increases model size and complexity, induces longer simulation run time and limits applications of simulations. The primary goal of introducing PMA to web handling modeling is to create simulation models which take shorter time to run. The PMA technique is a Lagrangian technique that offers a Eulerian-like view into a moving structure. Models created using this technique have smaller sizes, and the simulation run time is significantly reduced compared to OSU models [2]. In this work, the moment transfer due to roller misalignment case has been modeled using the PMA technique. The results, e.g. lateral displacements and moment distribution, are compared to OSU model results and experimental results. The comparisons show good agreements. More importantly, the PMA model takes a much shorter time (about 40% less) to conduct. Two more cases, actual wrinkle formation and web with non-uniformity running through rollers, have been modeled using PMA as well. The simulation results from the actual wrinkle formation case agree with the wrinkle failure criterion [3] based upon Timoshenko's shell buckling theory [4]. The web with non-uniformity case indicates the capability of PMA to study complex web structures.

1. Abaqus Analysis User's Manual, Section 10.5, 2014.
2. Fu, B., Reddy, A., Vaijapurkar, S., Markum, R. and Good, J. K., "Boundary Conditions that Govern the Later Mechanics of Flexible Webs in Roll to Roll Process Machines," ASME Journal of Computational and Nonlinear Dynamics, Vol.9, 2014.

3. Fu, B. and Good, J. K., “Web wrinkling resulting from moment transfer”, Proceedings of the Twelfth International Conference on Web Handling, Web Handling Research Center, Stillwater, Oklahoma, June, 2013.
4. Timoshenko, S. P. and Gere, J. M., Theory of Elastic Stability, 1st Ed. McGraw-Hill, New York, 1987.

EXPLICIT SIMULATIONS OF CAMBERED WEB STEERING

By

Boshen Fu[1] and James K. Good[2]
[1]Kimberly-Clark Corporation
[2]Oklahoma State University
USA

ABSTRACT

Cambered webs are common in the web handling industry. The mechanics analysis of stressed cambered webs has been reported by several publications [1]-[3]. The majority of the test data that exist demonstrate that cambered webs steer towards their longer side. A closed form solution [4] and numerical methods [5]-[9] have been focused on the lateral behavior of the cambered web as well, but have provided no explanation of steering toward the longer side. The work that has been done focused on analyzing or modeling a cambered web span. The results from the current work demonstrate that camber in a web causes slippage between webs and rollers that produce lateral steerage. To better understand cambered web response under tension, studying the lateral mechanics of a cambered web passing over aligned rollers is major focus of this work. Abaqus/Explicit [10] has been used to model cambered web and the transit of the web over a series of rollers. An Abaqus user defined subroutine, VUAMP, has been used to develop the first successful simulation of a web position guide interacting through contact friction with a web. This capability was needed such that a cambered web could be presented with known orientation and initial conditions to a test span where the web steering behavior resulting from camber could be studied. Simulation results are compared to experimental results [3]. The boundary conditions, which govern the steering of a cambered web in a test span, have been concluded based upon this analysis.

1. Shelton, J. J., "Effects of Web Camber of Handling", Proceedings of the Fourth International Conference on Web Handling, Oklahoma State University, June 1997.
2. Swanson, R. P., "Mechanics of Non-uniform Webs", Proceedings of the Fifth International Conference on Web Handling, Oklahoma State University, June 1999.
3. Swanson, R. P., "Lateral Dynamics of Non-uniform Webs", Proceedings of the Eleventh International Conference on Web Handling, Oklahoma State University, June 2009.

4. Benson, R. C., "Lateral Dynamics of a Moving Web with Geometrical Imperfection", Journal of Dynamic Systems, Measurement, and Control, Vol.124, 25-34, March 2002.
5. Jones, D. P., "Web Sag and the Effect of Camber on Steering" Proceedings of the Ninth International Conference on Web Handling, Oklahoma State University, June 2007.
6. Olsen, J. E., "Lateral Mechanics of An Imperfect Web", Proceedings of the Sixth International Conference on Web Handling, Oklahoma State University, June 2001.
7. Olsen, J. E., "Shear Effect and Lateral Dynamics of Imperfect Webs", Proceedings of the Seventh International Conference on Web Handling, Oklahoma State University, June 2003.
8. Olsen, J. E., "Lateral Mechanics of Baggy Webs at Low Tensions", Proceedings of the Eighth International Conference on Web Handling, Oklahoma State University, June 2005.
9. Olsen, J. E., "An Updated Model for Lateral Displacement of Non-uniform Webs", Proceedings of the Tenth International Conference on Web Handling, Oklahoma State University, June 2009.
10. Abaqus Documentation/Abaqus Analysis User's Manual, 2012.

DEVELOPMENT OF INTELLIGENT PLASTIC FILM WINDER "WINDSTAR"

By

Hiromu Hashimoto[1], Yasumasa Tominaga[2], and Ryo Morikawa[2]
[1]Tokai University
[2]Fuji Kikai Kogyu Co., LTD.
JAPAN

ABSTRACT

A plastic film (termed "web" below) is used for high-performance materials, packaging materials and a wide range of other applications because of its thinness and flexibility. In particular, application to high-functional devices such as photovoltaic cells and electric vehicle lithium secondary batteries has been being expecting because of growing concern about environmental problems over recent years. Web is suited to continuous production processes, and further because it has the advantage of being easily conveyed into subsequent processes by winding it into a roll. The wound roll of web is transferred through the subsequent processes and undergoes each one successively until it is turned into the final product. Hence, for maintaining the quality of the web, it is extremely important to prevent defects such as slippages and wrinkles during the winding.

In past researches related to the winding, it has been confirmed that occurrence of these defects in the wound roll is closely connected with the winding tension, and that inappropriate stress conditions in the roll. For these problems, authors proposed a technique for optimizing the winding tension to prevent slippage and wrinkles in the roll, and the effectiveness was verified. With this technique, however, it has not consider the environment during continuous web transfer in the real manufacturing process. Consequently, there is a possible that winding of the web onto the core will be unstable. As a result, a difference between the theoretical value and actual value of internal stress will occur, and the technique's advantageous effects cannot be fully exerted. Accordingly, we stabilized web transportation during web transfer, and then carried out a comparison of the prior situation with the results of tests conducted on a real winder into which such stabilization had been incorporated as an optimizing function. On the other hand, in the authors experience of applying various different winding conditions, there are cases where winding cannot be executed using pre-set winding conditions in real winding processes. This is because the length of web that is wound varies due to adjustments during operation in processes other than winding. In the conventional optimized winding conditions, the winding radius at the end of winding is calculated as a

fixed value. If the winding length is changed during production, the internal stress of the wound roll will become inappropriate. Hence, there remains the issue that such conditions can only be extended to a limited range of production processes. The ability to cope flexibly with changes in the winding length is important in order to utilize functions for optimizing tension and nip-load. Thus, a new optimization technique needs to be discovered that can be used to resolve this type of problem that occurs during production.

In the present study, we examined the conditions for winding optimization, including winding length change, in view of the situation as described above. In this paper we report on our endeavors to develop a winder that incorporates software for automatically preventing winding defects.

FRICTION CHARACTERISTICS BETWEEN THIN PLASTIC FILM AND STEEL ROLLER

By

Hiromu Hashimoto and Yuta Sunami
Tokai University
JAPAN

ABSTRACT

To establish the new technology named Roll-to-Roll Printed Electronics, which can be applied to manufacture the high functional thin film based devices, it is needed to combine the roll to roll transportation system and coating technology effectively. For that purpose one of important factors to be considered is the effect of friction characteristics between the thin plastic film and steel roller. In past research, however, as far as authors know, there is no research which describes friction characteristics between thin plastic film and steel roller. In this paper, the static friction between the plastic film and steel roller was measured by pulley method while changing film thickness of film, roller surface roughness, web tension, and relative humidity, respectively.

The experimental apparatus consists of a roller, test films, weight, isolation chamber and a humidifier and these components comprise a simple system in which a pulley method is implemented for friction measurement. The test roller was cylindrical which was fixed in the experiment. Five specimens of polyethylene terephthalate (PET) film were used in tests. In this experiment, first a piece of the test film was put on the roller and then identical weights were set up at the ends of the film. After that, the weight (T_{exit}) was increased at one end of side by slowly adding water to a container suspended from film's end. The exit tension T_{exit} increase was continued until the test film started to slide on the test roller. After obtaining the inlet and exit tensions, the static friction coefficient, μ_s, was calculated by the Euler's belt formula.

In the experiments, the relative humidity of ambient air was changed with a humidifier in increments of 5[%] from 40 [%] to 80 [%] because static electricity correlates strongly with humidity, and inlet tension was changed within range of T_{inlet} = 6, 12, 25 [N/m].

From the experiment, it was found that both the decrease in the film thickness and roller surface roughness have an effect of an increase in the static friction coefficient. This results obtained are considered to be influenced by deformation of the film. When the load is applied to film, then the film is deformed along with the roller surface asperities. As a result, real contact area is increased and it covers more closely the roller

surface asperities using thin film and the roller with smooth surface, as compared to results of using thick film and the roller with rough surface. When the film is pulled tangentially, the asperities behave as an anchor. The static friction coefficient was increased t due to “anchor effect” between the deformed film and asperities. Moreover, the tendency is probably more pronounced under low tension and high humidity.

Furthermore, we proposed prediction model of friction coefficient considering the effect of film thickness. As a result, the model can be predicted qualitatively the actual phenomenon.

OPTIMIZATION OF WINDING CONDITIONS FOR PREVENTING ROLL DEFECTS CAUSED BY THERMAL-VISCOELASTIC PROPERTY AND EXPERIMENTAL VERIFICATION

By

Hiromu Hashimoto
Tokai University
JAPAN

ABSTRACT

Plastics films are used in many products to high functionality flexible devices such as optical film, lithium-ion secondary battery and fuel-cell stack. Recently, increases in demand of the products are expected because of increasing electronic devices and fuel cell vehicle. The devices have being manufactured by roll to roll system. In this system, the films are finally wound in the shape of roll. The wound roll is shipped to the store and transportation, in some cases, heat-treated under the various temperatures. Then internal stress of wound roll will be changed due to thermal strain and viscoelastic properties over time. As a result, those elements causes to wound roll defects such as slippage and wrinkling. For the problem, thermo-viscoelastic model of internal stress of wound roll was presented. On the other hand, in our past study, the optimization method of winding tension was proposed for preventing roll defects. However, they had not considered the thermo-viscoelastic property yet. Therefore, this paper describes optimization method of winding tension and for preventing the wound roll defects by thermo-viscoelastic property.

Before considering the thermos-viscoelastic property, the creep compliance change was measured by compression/tensile creep tests under various load stress and temperature conditions to investigate the creep behavior of a polypropylene film as test film under the conditions, winding tension T_w = 100 N/m, nip load L = 235 N/m and ambient temperature change after wound DT = 10 K. From the experimental results, magnitude of the change was affected by these conditions. In order to apply the effect into winding model, an empirical formula was obtained based on the experimental results. It is possible to estimate the creep compliance values on arbitrary stress/temperature condition and was expressed by generalized Voigt model. The predicted values generally correspond to the experimental values.

In the present optimization method, the wind-up tension is gradually changed 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.

To confirm the effectiveness of optimization, the internal stress of wound roll was measured on the above conditions. Moreover, impact experiment was carried out whether wound roll has suitable friction force for preventing the slippage.

As a result of optimization, the wind-up tension was gradually decreased in the radial direction, and was finally significantly increased. This is because of preventing the slippage and winkling simultaneously. Moreover, it was confirmed that theoretical results showed in fairly good agreement with the experimental results. From the impact experiment, it was found that there is no risk of occurring the slippage in the case of optimal tension, whereas the slippage was occurred using the wound roll winded taper tension.

A STUDY ON STRIP CROSSBOW CORRECTION FOR UNIFORM COATING WEIGHT CONTROL

By

Changwoon Jee
POSCO
SOUTH KOREA

ABSTRACT

In coating process of continuous galvanizing line, transverse crossbow is frequently found in the case of thick gage or high strength steel processing. This transverse crossbow arises due to the unbalanced residual stress distribution along the thickness, which is made by elasto-plastic behavior that the steel strip experiences during roll to roll transportation under continuous steel strip processing such as surface cleaning pre-treatment, annealing heat treatment or strip deflection under zinc pot dipping. Because this crossbow makes air knife zinc wiper to strip distance uneven in strip transverse direction, it is impossible to get the uniform transverse coating weight distribution. In order to correct the crossbow of steel strip at the zinc coating position, correction roll displacement is used. While the mathematical model that calculates the crossbow using theoretical elasto-plastic and experimental background is used for the proper roll displacement determination, it is very difficult to guarantee the accuracy of its calculation because of many uncertain parameters. In this study, a model adaptation method was developed to enhance the steel strip crossbow estimation accuracy using the coating weight data which was logged with a few model parameters in real coating process, and coating weight estimation model. This estimation method was applied to the classified operation results of thick gage and high strength steel strip to verify the model estimation performance. The analysis of this application results shows the improved accuracy of the crossbow calculation. Furthermore, with this results, future works for refining the developed model approach as well as the achievement with it will be discussed in this paper.

PREDICTION METHOD OF WINDING PARAMETERS IN SHRINK SLEEVE LABEL CONVERTING PROCESS WITH DATA MINING TOOLS

By

Krzsztof Krystosiak and Wojciech Werpachowski
Warsaw University of Technology
POLAND

ABSTRACT

Main steps of the shrink sleeve labels production process are four typical production stages which result in a finished product like wounded roll of sleeve. These stages are: printing, slitting, seaming and inspection. The common feature of mentioned steps of the production process is winding from roll to roll (R2R) and that is typical for flexographic printing process. Winding quality of rolls on every stage of the process and beam quality are essential to achieve optimal quality of shrink sleeve labels and roll to roll winding process without any problems. In case of the quality should be noted that significant factors which has influence for winding quality are initial tension parameters and winding speed which maintain appropriate web tension in the process. Winding quality issues indicate one basic problem which is incorrect tension parameters setup on converting machines. There are two problems related to incorrect tension parameters: too high or too low tension. Both of them are causes of occurrence of different defects. The most important parameter characterizing of winding quality is free from significant defects both: in manufacturing process and in final application process, like: glued of sleeve layers, telescoping, film blocking, film web deformation (stretching), web wrinkling, damage of sleeve edge (U-fold), or finally wound damage.

In manufacturing practice of most big printing companies there are collected data, records of process parameters. Gathering information from them in form of developed models and rules is the subject of interdisciplinary field of science like data mining which uses statistical methods or Artificial Intelligence, like Artificial Neural Networks, Decision Trees, Expert Systems and many other. Effect of using data mining tools will be quality improving of shrink sleeve labels and winding process and also reduction manufacturing costs.

This paper describes developed models of Artificial Neural Networks (ANN) to be used for prediction of initial tension parameters and winding speed for each every new design of shrink sleeve label. Every one design of shrink sleeve label has a lot of factors. Some of them are more significant, some of them less. The aim of this paper is to choose significant factors and build a model of ANN in learning process with using collected

data. Finally when ANN model will be computed, it can be used for prediction of key winding parameters of new shrink sleeve label designs. This will brings for company saved time for experimental selection during converting of winding parameters like tension and speed and also will be minimized risk of occurrence of defects with incorrect winding parameters.

Application of ANN in order to optimizing of shrink sleeve labels winding quality brought a positive effect. Preliminary studies on historical data from converting process proved that this method can be useful for prediction of optimal initial winding parameters like tension and speed based on few vital factors determining the converting process. The study of this paper demonstrated, that the model of Artificial Neural Networks found dependencies occurring in winding process.

THE MOVING WEB INSTABILITY CAUSED BY THE BENDING DEFLECTION OF THE SUPPORT IDLE ROLLER

By

Li'e Ma, Mingyue Shao, Jimei Wu, Shanhui Liu, and Dingqiang Liu
Xi'an University of Technology
CHINA

ABSTRACT

The moving web is the transported through a lot of rollers in the roll to roll process machines. These rollers are usually driven rollers, dancer rollers and idle rollers. The number of the idle roller is the largest. The kind of roller is a thin and long part. The bending deflection can be produced by the own gravity and the web tension. The investigation focus on the dynamics of the idle roller and the web stability. The relationships between the roller dynamic and the speed and tension of the web are developed. The effect on the instability by the diameter of the idle roller, the length of the idle roller, the roller wall thickness, the surface properties of the roller and the web are discussed. The best parameter combinations of the web and roller are given.

CONTAINERBOARD AND PRINTING PAPER WOUND-ON-STRAIN MEASUREMENTS ON A PILOT WINDER

By

Marko Jorkama and Pekka Palo
Xi'an University of Technology
POLAND

ABSTRACT

Wound-On-Strain (WOS) measurement arrangement was set up on a single drum pilotwinder in the Winding Research Center of Valmet in Finland. The measurement was implemented with two Laser Doppler Velocimeters (LDV) – one measuring the paper web speed from the unwind or wind up roll surface and the other from the free web between the unwind and wind up. The measurement set up where one LDV is in the unwind enables also the WOS measurement of rolls produced with other winders while the set up where the LDV is in the wind up is convenient for winding parameter trials.

Comparison of these two measurement provide valuable information of the viscoelastic properties of the wound roll. The measurement set up will be presented in detail. The source and corrections of several error terms are discussed. Also the influence of repeatedly using the same paper roll in the trials is demonstrated. Typical WOS curves for containerboard rolls run with two-drum winder are presented. The influence of the web tension, nip load and winding force on WOS is demonstrated and compared to the results of previous studies. As the roll diameter vary in large extent from 100 mm to 1400 mm during the measurement sequence, the influence of the roll diameter on WOS becomes clearly visible in otherwise steady conditions.

MODEL-BASED CONTROL OF LATERAL WEB BEHAVIOR – AN INTERCONNECTION OF TWO WEB GUIDING SYSTEMS WITHIN PACKAGING MACHINERY

By

Andre Philipp and Chang You
Robert Bosch Packaging Technology BV
THE NETHERLANDS

ABSTRACT

Within packaging industry mostly web materials are used to form bags or similar shaped packages. In order to professionally convert these materials and achieving increasing quality requirements of bags, detailed knowledge of lateral web dynamics is mandatory. One major problem of vertical form fill and seal machines is accuracy of the lateral web positioning process of multi-layer webs. To obtain a high quality bag with minor visibility of inner web layer, positioning accuracy has to be ±0.5 mm. Due to different converting steps within a vertical form fill and seal machine and necessity of positioning for each step, more than one web guiding system is required. This leads to the major problem, which is solved within this paper: the combination of two web guiding systems within a vertical form fill and seal machine.

First of all this paper shows some of the most important milestones within research work of lateral web dynamics presenting the current state of the art. A special approach of hybrid modeling the lateral web behavior is established as well. Thus, a hybrid model of a rotating frame system can be introduced. Direct use of the model within a machine control leads to the hybrid modeling approach. Measurements and simulation results are matching with less than ±0.5 mm difference.

After introducing the hybrid modeling approach of a rotating frame system, interconnection strategies of a lateral moveable web roll system and the mentioned rotating frame system are given. To reach the target of combining these systems with the mentioned positioning accuracy and usability of a certain controller directly on a machine control unit, different types of controllers are developed and evaluated. A PID-controller analyzed firstly in this paper shows good results but doesn't achieve the target accuracy. The next investigated controller is a model-based control algorithm. This uses the simulated lateral web behavior, induced by the lateral movable web role, to predict and calculate the needed movement of rotating frame system in order to e.g. compensate the movement. With this method, results in the needed accuracy range are achieved and assured by measurements. However, the issue of exceeding the accuracy level due to differences between simulated and real web behavior still exists.

A controller containing a tuned PID-controller and a model-based control algorithm is investigated at the end of this paper via a simulation and achieves the accuracy range of ±0.5 mm despite of high position differences between simulated and real web behavior.

Summarized, the paper presents simulation and control methods of lateral web behavior, which can be directly computed and used on a machine control unit with very good results.

MEASUREMENT AND QUANTIFICATION OF BAGGY WEBS

By

Ronald P. Swanson
3M Company
USA

ABSTRACT

Webs that have crossweb variation in machine direction length are commonly called "Baggy Webs". All real webs have some degree of bagginess. When the bagginess exceeds some quantity, web handling problems such as wrinkling and lateral motion begin to appear.

There have been many articles, technical papers and patents on the subject of web bag measurement. This paper will summarize the measurement methods in the open literature. Mathematical techniques will be presented to analyze these measurements. A new concept of "Web Bag Strain" will be presented for the "Quantification" of Baggy Webs.

A BELATED APPRECIATION OF LISA SIEVERS' THESIS

By

Jerry Brown
Essex Systems
USA

ABSTRACT

In her 1987 thesis, Lisa Sievers described three dynamic multi-span models for lateral web behavior.

- Convecting string with zero bending stiffness
- Euler-Bernoulli beam with bending stiffness and no shear
- Timoshenko beam with both bending and shear

The last two transferred the bending portion of lateral deformation across rollers. In the Timoshenko model, which included shear and is the main result of her work, only bending deformation is transferred.

Although Sievers built on the work of everyone who preceded her, she creatively reanalyzed everything she used and put it on a more rigorous mathematical footing. This deserves a wider appreciation.

In an effort to make the results of her thesis more accessible, it is reviewed and the Timoshenko model is recast into a form which facilitates analytical comparison with Euler-Bernoulli beam models in current use.

A COMPARISON OF MULTI-SPAN LATERAL DYNAMICS MODELS

By

Jerry Brown
Essex Systems
USA

ABSTRACT

It's obvious that when a web changes its lateral position at a roller, subsequent spans will be affected. Less obvious, is the fact that transient stress variations will also affect downstream spans. Multi-span models are designed to account for both effects by incorporating a method for transferring the lateral displacements and deformations over rollers.

In her 1987 thesis, Lisa Sievers described three multi-span models.

- Convecting string with zero bending stiffness
- Euler-Bernoulli beam with bending stiffness and no shear
- Timoshenko beam with both bending and shear

With the Timoshenko model she was able to account for a phenomenon called weave regeneration in which an oscillatory lateral disturbance would reappear downstream of a web guide which had corrected it.

Then, in 1989, Shelton, Young & Kardamilas (SYK) published a description of an Euler-Bernoulli multi-span model and applied it to common roller configurations such as pairs of parallel rollers, displacement guides and steering guides. It transfer's lateral bending deformation across rollers and is functionally identical to the Sievers Euler-Bernoulli model. A notable feature of the SYK model is the way it uses transfer functions to interconnect the spans.

In this paper, Sievers' Timoshenko model is recast into the same analytical form as the SYK model and a similar interconnection strategy is developed. Then, the two models are compared quantitatively in several applications, using a differential equation solver (FlexPDE).

WEB INSTABILITY AT OPEN DRAW AND ITS IMPACT ON PAPER MACHINE EFFICIENCY

By

Frederic Parent
FPInnovations
CANADA

ABSTRACT

The concept of paper machine efficiency includes several aspects, from production loss, paper breaks, maintenance, down-time, etc. Efficiency is mostly affected by machine down time, resulting from maintenance work and web breaks. One of the main factors affecting breaks is the web instability at open draws on paper machines, especially at the wet-end. Web instability at the open draws can originate from different sources, from paper properties variations to paper machine equipment to pulp quality. Often, the root cause of the instability can be difficult to identify because of the lack of information or tools that could help to understand the relation linking web instability to paper breaks and paper machine efficiency.

Several studies in the literature have shown the importance of reducing paper properties and machine variability at the open draw to maintain good runnability and reduce breaks. Although many studies or specifically developed equipment have aimed at understanding and improving web runnability at the open draw, the means can be either too costly or too complex for papermakers. Hence, the development of accessible, simple and affordable tools to monitor and characterize open draw stability became of high interest. One of the objectives of the work presented in this paper is to actually quantify the open draw stability through some key parameters identified as such in the literature: release angle, paper solids and draw variations.

There are probably other parameters that will affect open draw stability, but we have decided to focus first on these ones and see if lower variability of release angle, paper solids and draw variations would contribute to fewer web breaks and better machine runnability. Empirical studies completed in paper mills are presented to assess variability of these key parameters at different types of open draws, before and after changes on paper machines such as a new press cover, drive modifications or new controls installation. More importantly, links could be made between reduced variability at open draws and the amount of web breaks following these changes.

FAST WINDER CHANGE WITH REDUCED INFLUENCE ON FILM TENSION

By

Günter Oedl and Stefan Schuster
Brückner Maschinenbau GmbH & Co. KG
GERMANY

ABSTRACT

The current developments in film production lead to faster lines (up to 550 m/min), thinner gages and the need for fast roll changes.

The inline roll change for turrent winders consists of mainly the steps:

- Retraction of contact roller (layon roller), turrent movement, moving cutting arm to film, bringing layon roller to empty core and finally cut film.
- Every step has some influence on the film path length. For a constant production speed (which is mainly the case) these changes in film length must be compensated by changing the winder speed. As for film lines the inertia of the winding roll is significant high (steel winding core weighs 5 to and film can contribute another 10 to) the change in speed of the winding roll need a significant force.
- The base case is that the steps are done one after the other and that all steps are done in a slow speed and winding torque is maintained constant during winder change. Therefore the additional force needed for slowing down (or speeding up) the winder roll is transferred by the film tension, which will show big and fast changes. As we all know the film tension will always affect the behaviour of film and can lead to various effects, problems or even breaks.
- Increasing the speed of turrent movement is desirable, because this cuts the time and amount of film being lost during winder change. Adversely the change in film path will occur in shorter time and therefore the influence in force will be bigger and more abrupt.

In this work the interactions of this system (movement of turrent, layon roller and cutting arm) are analysed in a combined way. A specially developed simulation serves for this purpose. This calculates all effects and it is able to present the results in a clear graph. An animated movement of the whole process and each individual movement are also possible. At the beginning, the process of turning and cutting is analyzed, how it is implemented in the current production plants. The results obtained, are consistent with

the practical experiences and problems of these systems. In a further step, the knowledge gained will be used to optimize the process taking place in such a way that minimizes the impact on the film. An optimization algorithm in the simulation calculates the movement of axes in such a way that the influence on the film tension is minimized (no rapid changes). Further on as the system is known with this simulation, the winding torque can be set in such a way that the wound in tension can be held constant or to any other desired function.

TIN-CANNING DEFECTS IN THIN FILM WINDING

By

Timothy J. Walker[1] and Kevin A. Cole[2]
[1]TJWalker and Associates, Inc.
[2]Optimation Technology
USA

ABSTRACT

In winding thin films, especially at larger diameters and higher speeds, rolls may form uniform width machine direction buckles. Commonly referred to as tin-canning defects, they may form across the entire width of the roll or appear in local widthwise bands. Tin-canning defects may also vary in intensity or breadth by location around the roll circumference or by radial position in the roll, upon observation of unwinding rolls. Tin-canning defects are common in films, but can also appear in thin foils and papers, both coated and uncoated.

Though this defect is widely known, there is a scarcity of published information about its causes and remedies.

In this study of nipped center winding, we explored the formation of tin-canning defects as a function of tension, nip load, nip roller design, and pre-wind spreading, judging the defect both immediately after winding and 24-hours after winding.

WINDING PROCESS CALIBRATION AND COMPARISON

By

Timothy J. Walker
TJWalker and Associates, Inc.
USA

ABSTRACT

Manufacturing of flexible packaging products is a multi-step process, running first through coater-laminators, followed by slitter-rewinders. Each of these steps finishes with winding, hoping to pass on quality rolls to the next process step and final customer.

Many winders, especially older equipment, control the winding process by setting variables that have limited or no indication of the winding process in engineering units. To recommend changes in winding, the first step is to understand and calibrate the current winder conditions. Knowing 'as-is' winding conditions allows for comparing winder-to-winder processes, correlating winding differences to roll defect occurrences, modeling of winding processes (combined with material properties), and engineered advice for improved winding.

This paper reviews the calibrating and comparing of winding conditions (tensions, torques, nip loads) across three winders from three different equipment suppliers and how this knowledge was used to improve roll quality.

LATERAL DYNAMICS OF A WEB TWIST

By

J. Carrle and S. Lange
Procter & Gamble Company
USA

ABSTRACT

Twists are sometimes used to turn or provide passive lateral control for narrow webs in cases where space for a sufficient twist span length (to avoid a wrinkle) is achievable. This paper describes the results of a study of the lateral dynamics of a web downstream of a 90 degree twist in response to a lateral disturbance upstream using the finite element method. Specifically, the frequency response for downstream lateral position was modeled as a function of the web velocity to disturbance frequency ratio, span length-to-width ratio, as well as wrap angle and material stiffness. Excellent attenuation of the disturbance amplitude is predicted by the model, with the resulting frequency approximately equal to the input frequency.

PULL ROLLERS: PLAIN, VACUUM AND UNPORTED

By

Kevin Cole
Optimation Technology
USA

ABSTRACT

The role of a pull roller in a web machine is identified. The ability of pull rollers, plain or vacuum type, to permit tension differences is explained. Three types of pull rollers are described. Among them is the unported roller that utilizes holes and grooves to increase effectiveness. This paper, while providing theoretical and experimental details on pull roller design, will also serve as a useful tutorial for those interested in learning about the practical design and operational aspects of pull rollers.

THE IMPACT OF THICKNESS MEASUREMENT ON RESIDUAL STRESSES DUE TO WINDING

By

J. K. Good, C. Mollamahmutoglu, R. Markum and J. W. Gale
Oklahoma State University
USA

ABSTRACT

Axisymmetric winding models were initially developed to deal with web thickness variations that were manifested in the machine and cross machine direction. The web thickness variation is a prime input to these models. Small web thickness variations can integrate during winding to produce large residual stress variation in the wound roll. Web thickness measurement in process lines employ sensors that scan over the web width while the web is moving in the machine direction. Spatially this provides a measure of web thickness in a zig-zag pattern. This thickness variation is used as a control feedback parameter that control a forming or coating die lip to reduce the web or coated web thickness variation. The scan rate of the sensor will typically be set to capture thickness data at a frequency higher than the frequency response of the control/actuator system. Is thickness data captured spatially at this rate for the process sufficient for input to the axisymmetric winding model? This publication addresses this problem. The web thickness variation of an existing web was fully mapped in the machine and cross machine directions. This data was interrogated to determine what thickness data would have been recorded at varied scan rates. The full map of thickness data was input to the winding model as well as data that would have resulted from various rates of zig-zag scanning. Results show that as the rate of zig-zag scanning increase, that the residual winding stresses converge toward the stresses produced by the input of the full thickness map. Model results were compared to test results for validation.

THE COUPLING OF WINDING MODELS AND ROLL QUALITY INSTRUMENTS

By

C. Mollamahmutoglu, O. Bulut, S. Adari and J. K. Good
Oklahoma State University
USA

ABSTRACT

Winding models have been under development for roughly 50 years. These models have become mature in their ability to predict the internal residual stresses within a wound roll as a function of winder type, winder operating parameters, web and core material parameters and non-uniformity inherent in the web. The internal stresses are useful when predicting winding defects. The majority of the instruments that have been developed to infer the quality of rolls wound in production environments are dynamic hardness testers that provide output in unique units. These devices are very useful in the production environment for studying cross machine direction (CMD) variation of hardness in wound rolls. This variation could have resulted independently from web tension, nip load, web thickness, modulus or length non-uniformity in the CMD. It could also have resulted from combined non-uniformity from all of these sources but hardness testers have no means to determine the source of hardness variation. The coupling of winding models and dynamic roll hardness testers will move roll quality improvement to an advanced diagnostic level. We will demonstrate that it has become possible for winding models which have been extended with dynamic impact models to provide estimates of hardness in the unique units of any test instrument. Our goal is to promote improvement in roll quality by the combined use of winding models and dynamic hardness testers to minimize wound roll defects.

AN AXISYMMETRIC TRANSIENT THERMO-ELASTIC WINDING MODEL

By

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

ABSTRACT

Winding models have been under development for roughly 50 years. These models have become mature in their ability to predict the internal residual stresses within a wound roll as a function of winder type, winder operating parameters, web and core material parameters and non-uniformity inherent in the web. The internal stresses are useful when predicting winding defects. The majority of the instruments that have been developed to infer the quality of rolls wound in production environments are dynamic hardness testers that provide output in unique units. These devices are very useful in the production environment for studying cross machine direction (CMD) variation of hardness in wound rolls. This variation could have resulted independently from web tension, nip load, web thickness, modulus or length non-uniformity in the CMD. It could also have resulted from combined non-uniformity from all of these sources but hardness testers have no means to determine the source of hardness variation. The coupling of winding models and dynamic roll hardness testers will move roll quality improvement to an advanced diagnostic level. We will demonstrate that it has become possible for winding models which have been extended with dynamic impact models to provide estimates of hardness in the unique units of any test instrument. Our goal is to promote improvement in roll quality by the combined use of winding models and dynamic hardness testers to minimize wound roll defects.

THIN TAPE TRACTION OVER A GROOVED ROLLER

By

Tugce Kasikci and Sinan Muftu
Northeastern University
USA

ABSTRACT

Traction between a thin, O(5 μm), tensioned tape and a grooved roller is studied. In the slow tape speed limit, tape contact over a grooved roller is studied analytically. A closed form relationship for the belt-wrap formula for grooved rollers is developed. In this range, air lubrication effects can be negligible and tape-to-roller contact is dominated by tape deflection in the lateral direction. At operational tape transport speeds, O(1-5 m/s), a relatively wide range of design parameters (groove width, land width) and device parameters (velocity and tension) were used to characterize the traction of a thin tape over a grooved roller. It was shown that air lubrication effects reduce the contact force, however the underlying effects of tape mechanics are not entirely eliminated. This work contributes to our understanding of traction mechanics of thin webs over grooved rollers, which has been understudied in the past, and helps in picking design parameters for improved traction.

DESIGN OF TENSION CONTROL SYSTEMS TO MINIMIZE INTERACTION AND DISTURBANCE PROPAGATION IN WEB PROCESS LINES

By

Pramod R. Raul and Prabhakar R. Pagilla
Oklahoma State University
USA

ABSTRACT

In roll-to-roll systems (R2R), a controller is designed for each section or tension zone based on measurement of web tension and speed from that section; this is typically referred to as decentralized control. This is particularly suitable for R2R systems because of their structure and for ease of implementation. Since the material is transported from the unwind to the rewind through the process sections, the entire machine can be divided into several sections and decentralized controllers are utilized for each section. It is important to understand the transport behavior from each section to other downstream sections, that is, interaction between different sections, and how disturbances are propagated. Design of tension controllers that minimize disturbance propagation will aid in the improving the processing of the material.

In this paper, we will first investigate minimization of interaction between subsystems of R2R systems when decentralized feedback and feedforward controllers are employed. In particular, we will consider a new interaction metric for dynamical systems which will quantify the amount of interaction; and show how model-based feedforward action can be gainfully employed to minimize disturbance propagation. We will also discuss control strategies that will minimize disturbance propagation. To evaluate the proposed designs and recommendations, we will show results from extensive experiments conducted on a large experimental web platform.

ROLL SPEED AND WEB TENSION REGULATION USING TWO DEGREE OF FREEDOM CONTROL SYSTEMS

By

Pramod R. Raul and Prabhakar R. Pagilla
Oklahoma State University
USA

ABSTRACT

In this paper, we first consider the problem of load speed regulation in a two inertia system consisting of a motor shaft connected to the load shaft via a mechanical transmission. The problem is reminiscent of a material roll (load) connected to the motor shaft through a belt-pulley and gear transmission system. In typical industrial speed control systems, the motor shaft speed is controlled under the assumption that the load shaft speed is indirectly controlled at its desired value scaled by the transmission ratio. In the presence of the transmission dynamics introduced by compliance and backlash, regulation of motor shaft speed does not translate to regulation of roll speed. The problem is further exacerbated when there are disturbances on the roll. One must consider the transmission dynamics in developing a control system that can provide the desired performance for the roll speed. We propose a two degree of freedom control system that utilizes measurement of motor shaft and roll shaft angular velocities in developing a control action necessary to regulate the load speed. The control system consists of both feedback and model-based feedforward actions, i.e., two degree of freedom control. The model-based feedforward action is generated by utilizing the model and adaptively estimating the disturbances on the roll. We have conducted experiments on a web machine to evaluate the performance of the proposed approach. Experimental results indicate improved roll speed regulation in the presence of disturbances, which will be presented and discussed. Utilizing the improved roll speed regulation scheme a tension control strategy is also proposed and experiments were conducted with web transport. Experimental results indicate improved tension regulation with such a strategy, which will be presented and discussed.

CONTROL OF STRIP TENSION IN THE HEATING/ COOLING SECTIONS OF CONTINUOUS ANNEALING LINES USING MODEL-BASED TENSION ESTIMATION

By

Youwei Lu[1], Changwoon Jee[2], and Prabhakar R. Pagilla[1]
[1]Oklahoma State University, USA
[2]POSCO, SOUTH KOREA

ABSTRACT

Continuous annealing lines are productive manufacturing lines used by steel making companies for the manufacture of thin steel sheet products. In these lines, the steel strip is continuously heated and cooled depending on the heat processing cycle required for a particular product. The heating/cooling cycle plays a critical role in programming the material properties of sheet products. The annealing furnace consists of several heat transfer sections, such as heating section, soaking section, rapid cooling section, and cooling section. By transporting the steel strip through the annealing furnace, concentrated uneven stress in the strip resulting from cold rolling process is relieved and new material property specifications, such as tensile strength, yield strength or ductile strength, are obtained.

To improve transport behavior through the furnace, all the rollers are independently driven by a motor which are used to control strip speed and tension. Although rotational speed is measured for each driven roller shaft, tension measurement is spatially intermittent and located between any two heat transfer sections because of the inability to reliably measure tension within each heat transfer section. Since tension measurement is not available within the heat transfer sections, control of tension is challenging in these sections. An algorithm that provides tension estimation within each transfer section based on the model and tension measurements between each section is beneficial in regulating tension within acceptable levels in each section. In addition, due to heating/cooling of the strip during transport, changes in the physical and mechanical properties of the strip material must be accounted for in the design of tension control systems. In this paper, a dynamic model that provides the speed and tension behavior of the transported web through the heating or cooling section will be developed. Based on this model a tension observer will be designed for estimation of tension in each of the spans within the heat transfer section. A control system for each driven roller will be designed to regulate web speed and tension and results of computer simulations of the model and the control system will be presented and discussed.