MEASUREMENT OF WEB FEED RATES IN RUBBER COVERED NIP ROLLER APPLICATIONS AND THE IMPACT ON WRINKLE FORMATION

By

K. A. Cole[1] and T. J. Walker[2]
[1] Optimation Technology, Inc.
[2] TJWalker + Associates, Inc.
USA

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.

NOMENCLATURE

A	nip width
E	Young's modulus
E_0	Young's modulus for rubber without confinement effects
F	nip load
r_1	nip roller radius (including cover)

r_2 uncovered roller radius
t nip roller cover thickness
V_1 nip roller surface velocity, outside of the nip
V_2 uncovered roller surface velocity, outside of the nip
V speed in the nip, assumed equal to V_2
δ nip roller centerline engagement due to nip load F
θ angle subtended by the nip assuming no circumferential strain
ν Poisson's ratio
IRHD International Rubber Hardness Degree (Shore A)

INTRODUCTION

Nip rollers are used extensively in the web handling industry for a wide range of applications. Generally, nip roller configurations can be categorized into two general classes [1]. Web transport deals with web handling processes where the intention is not to permanently deform the web while web processing, as the name implies, deals with web handling processes where the intention is to modify the web in some way. Examples of the first class are tension isolation drives, pressure rollers for prevention of air entrainment on rollers and on winders and web cleaners and examples of the second class include calendaring, rolling and laminating. These two classes can be further delineated by the range of loading required to achieve the process objectives. In the former class, loadings are relatively light, of order 2 kN/m or less while in the second class, loadings are much higher, of order 500 kN/m and up.

This paper concerns the first class of nip roller applications. In these systems, nip rollers provide very useful process functions but must be properly designed, engineered and implemented to avoid negative effects such as web wrinkling in wide web applications. Owing to typically high friction within nips, effects which otherwise might be of little or no consequence can become very important. Roller alignment, web planarity and roller deflection all become more critical due to the unforgiving nature of rubber-covered nip rollers. One feature of rubber-covered nip rollers, the focus of this paper, is the tendency of such nips to convey webs at speeds that are slightly different than surface speed of the roller outside of the nip. This effect, referred to as creep, results from the nearly incompressible nature of the rubbers typically used to cover nip rollers.

This effect is well understood and much work is available in the literature documenting the source of the behavior. Stack [2] provides a detailed discussion of the effects of nip parameters on media transport in individual sheet applications. Rice [3] documents an in-depth empirical study on conveyance in nips where the effectiveness of various web spreader devices are evaluated as to their ability at preventing nip roller conveyance wrinkles. In his paper, he discusses creep as a beneficial effect under certain process conditions. Balaiyan [4] provides a very detailed study of the lateral tracking behavior of an unevenly loaded nip. The relationship between differential creep and lateral tracking is developed and is shown to arise due to bending effects induced into the upstream web span.

The purpose of the paper is to present results that extend the work previously cited. While it is understood that creep and the variation across the width of the roller due to uneven end loading can generate lateral tracking and wrinkles, it is unclear how to manage this effect so as to decrease or control this sensitivity.

The contents of this paper are as follows. First, a discussion of the basics of nip mechanics is presented. Next, methods are described for measuring nip load, nip engagement and creep. Results are then presented for two asymmetrical nip roller systems. Empirical results are then presented for a conventional nip roller cover design and for a novel nip roller cover design that provides the ability to control and manage creep so as to alter the sensitivity of the nip roller system. Observations and conclusions are presented throughout. The empirical results presented in this paper provide the framework for the future development of predictive models capable of treating the effects demonstrated herein.

NIP MECHANICS FUNDAMENTALS

When webs are conveyed by rubber-covered nip rollers, it is often the case that the speed of the web is different from the nominal surface speed of the rollers away from the nip (Stack et. al. [2]). This behavior is influenced by a number of factors, including the physical properties of the rubber coverings, geometric characteristics such as cover thicknesses and roller diameters and process conditions such as the engagement of the rollers and tension difference in the web across the nip rollers. Owing to this behavior, nip systems are often comprised of one rubber-covered roller and one roller without a rubber covering. The web is typically wrapped over the uncovered roller and if the nip roller pair is a drive, the uncovered roller is usually driven. This being said, deleterious effects due to the inherent tendency of the rubber-covered roller to travel at a different nominal surface speed compared to the web speed can still be present. Two examples are: (a) small relative motion (e.g., micro-creep) in the machine direction leading to the potential for abrasions and dirt generation and (b) differential relative motion in the transverse direction leading to an increased risk of the formation of unwanted lateral tracking and wrinkling. Transverse direction effects can arise due to differing amounts of roller engagement due to roller core bending effects. This follows from the fact that the differential surface speed is a function of roller engagement.

Figure 1 shows a cross sectional view of a rubber-covered roller (number 1) loaded against an uncovered backing roller (number 2). No web is in the system. Prior to contact,each particle on the surface of each roller rotates at the same surface speed, V. Assuming roller 2 to be driven, it will still travel at the same surface speed after the rollers are brought into engagement by an amount, δ. Therefore, $V_2 = V$. However, V_1 will no longer be equal to V. To determine V_1, it is noted that the characteristics of the rubber covering on roller 1 determine the circumferential strain that develops within the contact, or nip, zone. The angle, θ, is defined as the angle subtended by the nip zone in roller 1 assuming that there is no circumferential strain in the cover. Under this assumption, the nip width is equal to $r_1\theta$ and the interval of time required for roller 1 to rotate through this angle is found from the following:

$$\Delta t = {}^{r_1\theta}/_{V_1} \qquad \{1\}$$

Owing to the coupling between radial and circumferential strains, the actual nip width, *A*, will be different than the theoretical nip width by some nominal amount, ε, which we refer to as the creep of the system:

$$A = (1 + \epsilon) r_1 \theta \qquad \{2\}$$

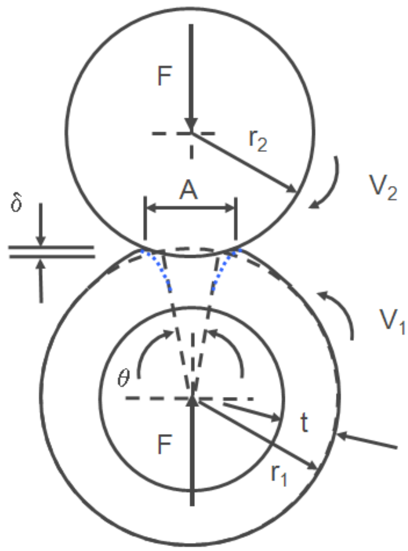

Figure 1 – Nip roller system cross-sectional view

The creep is the average circumferential strain in the nip zone which, as we shall next show, relates to the speed of roller 1. Owing to mass conservation, a particle on the surface of roller 2 must travel through the actual nip in the same interval of time as roller 1 rotates through θ:

$$\Delta t = A/_{V_2} = A/_{V} \qquad \{3\}$$

Combining equations {1} through {3} yields the surface velocity of roller 1 in terms of the creep:

$$V_1 = V/_{(1 + \varepsilon)} \qquad \{4\}$$

Equation {4} indicates that for positive creep, the rubber-covered roller will travel at a slower speed than the drive roller and that for negative creep, the rubber-covered roller will travel at a higher speed than the drive roller.

For linear elastic materials, there are two material constitutive properties that influence the relationships between engagements, loads and creep within a system such as shown in Figure 1. The first, Young's modulus, *E*, is roughly a measure of radial stiffness and the second, Poisson's ratio, ν, is a measure of compressibility.

Good [5] provides detailed information about both of these properties. In that work, it was shown that for natural and synthetic rubbers, Shore A (i.e., IRHD) hardness measured with a hand-held instrument is adequate to predict Young's modulus. The relationship between Shore A hardness and modulus was found to be given by the following expression (equation {1}, [5]):

$$E_o = 145.7e^{0.0564*IRHD}\ (kPa) \qquad \{5\}$$

where the subscript indicates modulus excluding confinement effects. Suitable modifications to account for confinement in the nip zone are provided (equation {5}, [5]).

For linear elastic materials, a value of Poisson's ratio approaching 0.5 corresponds to an incompressible material. Materials such as polyurethanes and rubbers have a Poisson's ratio approaching 0.5. Owing to the incompressible nature of these types of typical roller coverings, radial strains due to roller engagement leads to significant positive circumferential strain resulting in positive values of creep.

At the other extreme, open cell foams have a Poisson's ratio approaching 0. In this case, creep may actually be negative resulting in a roller covered with such a material going faster than the driven roller. One such case will be examined in the work that follows.

MEASUREMENT OF LOAD/ENGAGEMENT/NIP WIDTH AND CREEP

Experiments were conducted in the Media Conveyance Facility to obtain experimental data to study the behaviors described in the previous section. A nip roller module duplicating the configuration shown in Figure 1 was constructed on the Thin Web Rewinder (TWR). A picture of the module is shown in Figure 2. The configuration consists of an idling lower uncovered roller and an upper roller with a rubber covering. Both are driven at a constant machine speed by means of a 12 micron PET web wrapped partially around the lower uncovered roller. Nip force is controlled by two air cylinders mounted at either end of the live-shafted rubber-covered nip roller. The nip roller is attached to twopivoting arms which maintain alignment and provide a reference to measure roller engagement using mechanical dial indicators.Nip width is measured using the Tekscan™ I-Scan measurement system. This system consists of sensors that detect pressure changes as an electrical resistance drop through a conductive ink.

Creep was measured using a "*spindown tester*". A spindown tester is an electronic instrument intended for accurately measuring the angular velocity and angular acceleration of a roller. It requires an optical sensor, a spindown tester electronics box, and a standard computer ("PC") with a serial port. The measurement is accomplished by using a non-contacting optical sensor to provide an electrical voltage signal, or pulse, for each revolution of the roller. The spindown instrument contains a quartz-crystal-controlled master clock that runs at 2,457,600 Hz. This master clock drives a 36-bit counter. Every time a pulse from the sensor is detected, the content of this counter is latched into a 36-bit register. This register then remembers the count at the time of the pulse for a short while – long enough to transmit the stored 36-bit value to a computer.

The computer then remembers the value indefinitely, along with that of all the other revolutions. This has the effect of storing the time of the occurrence of every roller revolution to an accuracy of about 0.4 microseconds.

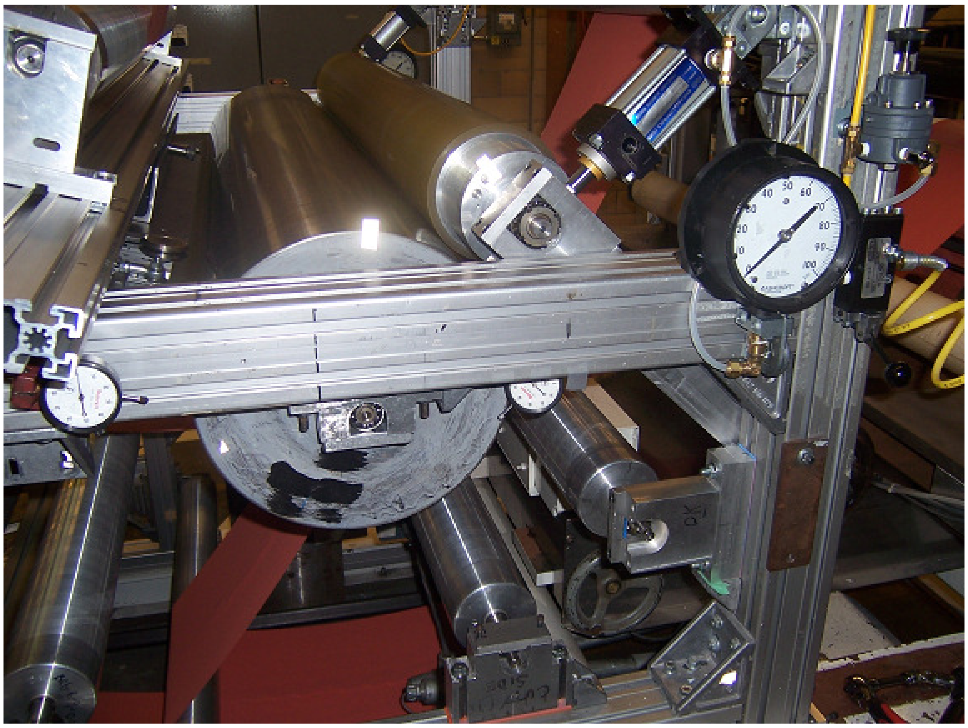

Figure 2 – Nip module Setup on TWR, West Elevation

The 36-bit “times” of every revolution may then be regenerated in the computer and divided by 2,457,600 to give a time in seconds for the occurrence of every roller revolution. The roller’s angular velocity can be estimated by $v = \frac{2 \cdot \pi}{\Delta t}$ (radians/second), where Δt is the time difference between the start of one roller revolution and the start of the next revolution in seconds. The time at which this velocity is deemed to have occurred is estimated by the average of the start time of the revolution and the start time of the next revolution, and is designated as t_v. Then the roller’s angular velocity is estimated by $a = \frac{\Delta v}{\Delta t_v}$ rad/sec^2 . The time at which this acceleration is deemed to have occurred is the average of the two Δt_v values used in the calculation of the acceleration. Velocities and accelerations measured in this fashion exhibit no systemic errors under constant acceleration. They do exhibit a bias error under constant jerk conditions (i.e., a ramp of acceleration).

Creep can be computed from a knowledge of the rotation times for the two rollers according to the following equations:

$$t_1 = {}^{2\pi(1+\varepsilon)r_1}/_{V} \quad \{7\}$$

and

$$t_2 = {}^{2\pi r_2}/_{V} \quad \{8\}$$

giving:

$$\varepsilon = {}^{r_2 t_1}/_{r_1 t_2} - 1 \quad \{9\}$$

LOAD/ENGAGEMENT/NIP WIDTH AND CREEP RESULTS

Measurements were made on four different nip systems. First, nip width, centerline engagement, and creep were measured as a function of end loading on two nip systems. The first system consisted of a single durometer rubber-covered nip roller nipped against a hard metal roller and the second system consisted of a specially constructed dual durometer covered nip roller nipped against the same hard metal roller. Figure 2 shows the first system. Second, nip width and nip pressure as a function of nip loading along with empirical wrinkling measurements were made on a second set of nip systems. The third system consisted of a symmetrical pair of single durometer rubber-covered nip rollers (different construction from the roller just mentioned) and the fourth system consisted of a symmetrical pair of the dual durometer nip rollers (same construction as the roller just mentioned). A list of the geometric and material properties of the rollers used in these tests are presented in Table 1. A summary of the tests and measurements made are presented in Table 2. In this section, the nip width, engagement and creep results for the first two nip systems are presented. In the next section, the empirical wrinkling study performed on the third and fourth nip systems is described and nip width/pressure and wrinkling observations are presented.

Roller Type	Shell Diameter, mm	Wall Thickness, mm	Face Length, m	Bearing Offset, mm
Single Durometer (1)	133.6	3.175	1.448	38.1
Single Durometer (2)	158.5	3.175	1.480	38.1
Dual Durometer	132.4	3.175	1.448	38.1
Hard Roller	320.5	3.175	1.448	38.1
	Roller Diameter, mm	Cover Thickness, mm	Durometer, Shore A	Poisson's Ratio
Single Durometer (1)	152.7	9.5	50	0.46
Single Durometer (2)	180.0	10.7	56	0.46
Dual Duro – inner	168.3	16.4	15 - 20	0.20 - 0.35
Dual Duro - outer		1.5	60 - 90	0.46

Table 1 – Nip Roller Geometric and Material Properties

System	Roller Combination	Measurements Made
1	Single Durometer (1)/Hard Roller	Load, Nip Width, Engagement, Creep
2	Dual Durometer/Hard Roller	Load, Nip Width, Engagement, Creep
3	Single Durometer (2) Symmetrical Roller Pair	Nip Width, Pressure, Empirical Wrinkling
4	Dual Durometer Symmetrical Roller Pair	Nip Width, Pressure, Empirical Wrinkling

Table 2 – Roller Combinations Evaluated

The following three figures show results from the first two roller combinations for which measurements were made. Figure 3 shows nip load versus centerline engagement for the each nip systems. As can be seen in the figure, the dual durometer covering is significantly more compliant compared to the single durometer cover. For a given nip loading, this will lead to significantly more roller engagement and as shown in Figure 4, a much larger nip width. Correspondingly, the pressure developed in the nip will be much lower. If the process requires a certain nip pressure to be developed, either more nip force will be required or changes will have to be made to the design of the dual durometer cover. Figure 5 shows creep as a function of nip load. These results show that the single durometer roller has positive creep (indicating that the roller surface of the rubber-covered roller outside of the nip is moving slower than the metal backing roller) while the dual durometer roller has negative creep (indicating the opposite – that the roller surface speed of the rubber-covered roller outside of the nip is moving faster than the metal backing roller).

The implication of this behavior is interesting. Should these nipped roller systems be conveying web with sufficiently high machine direction stiffness, then the speed of the web will be different than the speed of the rubber-covered nip roller outside of the nip. For the single durometer case, the roller will be going slower and for the dual durometer case, the roller will be going faster. Several interesting behaviors can be deduced from this observation. First, when the roller is going slower than the web, the machine direction relative motion between the web and roller will favor acceptable interaction between the web and roller when the web wraps the roller upstream of the nip. This is because the web will tend to be moving faster than the roller. On the other hand, when the roller is going faster than the web, the machine direction relative motion between the web and roller will be more likely to lead to the formation on a bubble in the wrapped zone upstream of the nip.

The opposite is true for wrap on the rubber-covered roller downstream of the nip. Now, the formation of a bubble will be more likely when the roller is going slower than the web and less likely when the roller is going faster than the web. Thus, should wrapping of the rubber-covered nip roller be desired (e.g., perhaps to achieve greater tension isolation in a nipped roller drive), then the single durometer roller should be wrapped upstream of the nip and the dual durometer roller should be wrapped downstream of the nip while in each case, the opposite side should be unwrapped.

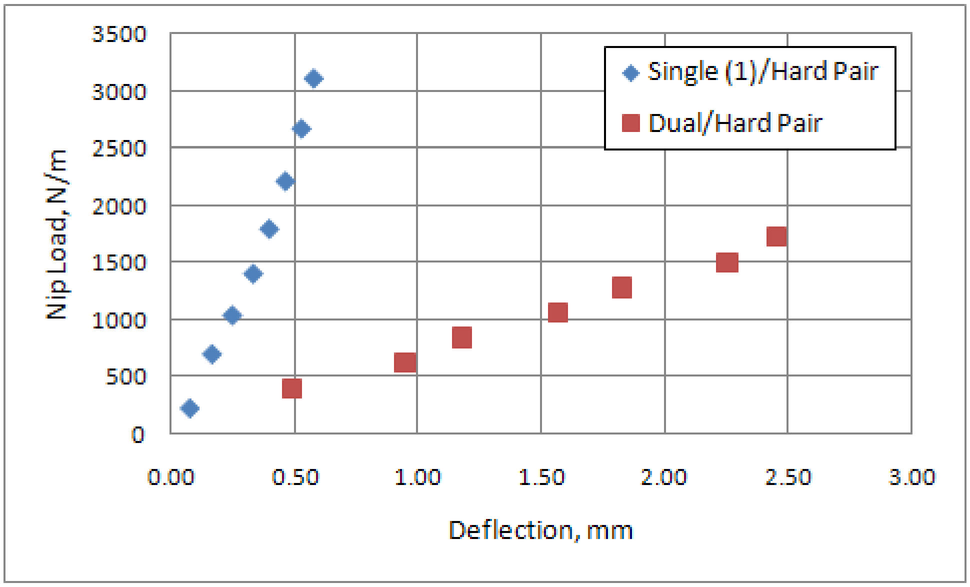

Figure 3 - Nip Load vsEngagement, Asymmetrical Nip Roller Pair

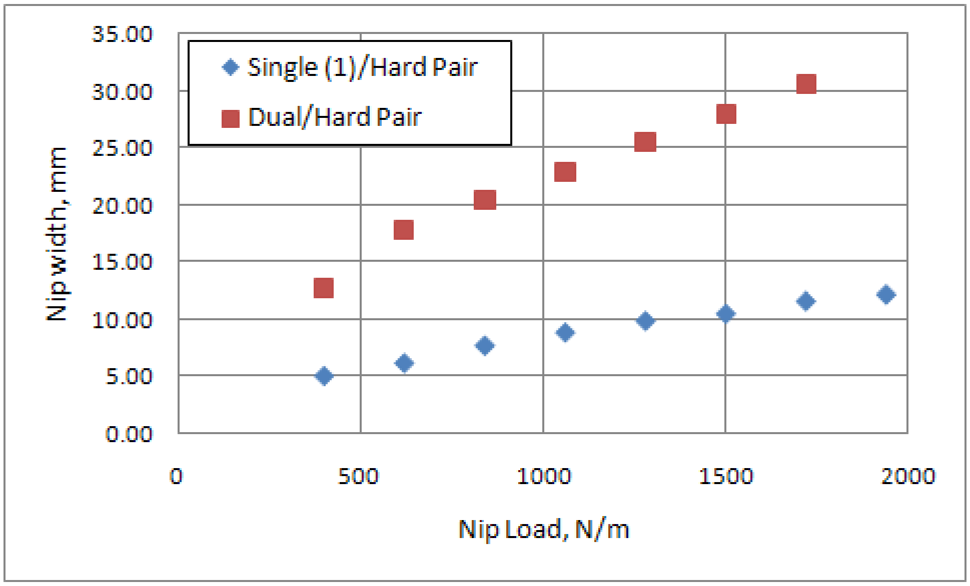

Figure 4 - Nip Width vs Nip Load, Asymmetrical Nip Roller Pair

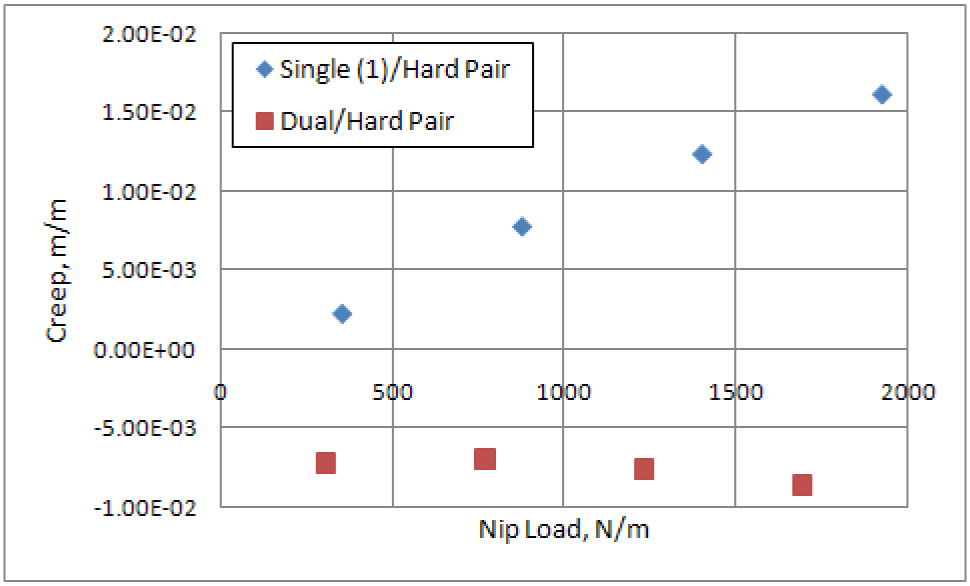

Figure 5 - Creep vs Nip Load, Asymmetrical Nip Roller Pair

A further interesting consequence of the behavior observed in Figures 3 and 5 has to do with the performance of a nipped roller system undergoing axial roller deflection in the transverse direction (TD) of the machine. In [5], a method is presented to compute variations in roller engagement across the width of a pair of nip rollers due to the combined effects of the radial nip load/engagement characteristics of the rubber cover and the TD bending characteristics of end loaded roller shells. In that analysis, it would be expected that the relative variation in centerline engagement and nip load would be significantly reduced for a nip roller system with a relatively compliant nip cover system. Such is the case, as will be shown in the results in the next section, and when combined with the results of Figure 5, this reduction of nip load variation will lead directly to a significantly reduced variation in web speed across the width of the roller in cases where the creep translates to web speed. Two such cases are of interest: (a) where friction between the web and the rubber-covered roller is greater than the friction between the backing hard nip roller and (b) where the system is composed of a pair of symmetrical rubber-covered rollers. Other cases exist but these are adequate to consider for illustrative purposes. In these cases, the lateral tracking and troughing performance can be predicted using models developed to analyze the behavior of tapered rollers where the variation in creep can be thought as equivalent to the imposition of widthwise variable strain arising from the taper geometry since both equivalently induce a moment onto the web as it passes onto the downstream roller. Thus, the single durometer system will be expected to be more sensitive to uneven end loading compared to the dual durometer system and further, since the slope of the creep curves are reversed, it would be further expected that troughs and wrinkles would orient in opposite directions for the same orientation of uneven loading. Such is the case as again will be shown in the next section. Since these two designs bracket the functional dependence of creep with respect to load, an intermediate design can be found where the slope of the creep curve is zero. This would lead to the favorable case where trough formation due to uneven loading would be eliminated.

The source of negative creep in the case of the dual durometer cover system is primarily due to the interaction of the upper stiff layer with the lower compressible layer. As the system is nipped, most of the compliance arises from compression of the lower layer. The upper layer will tend to bend much like a beam so as to conform to the surface of the hard metal roller. During thisengagement, the outer surface of the upper layer will behave like a beam being loaded by end moments. Consequently, the outer surface will experience compressive strain – hence, the creep will be negative as the empirical results demonstrate.

EMPIRICAL WRINKLING EXPERIMENTS

In this section, a description of a wrinkling studythat was performed on nip systems 3 and 4 as identified in Table 2 is presented. Based on the significantly different creep performance of the two types of nip rollers, it is of interest to study the conveyance characteristics of nip systems comprised of the two different types of nip roller designs. Reference [2] discusses the tendency of misaligned nips to skew sheets of paper. Transport of flexible thin webs were not considered in that work. The study described here was conducted on the TWR with the following variables held constant during the trials: web thickness = 15 micron (60 gauge), web width = 1.10 m, line speed = 15.2 mpm and web tension = 131 N/m. The following variables were allowed to vary for each nip configuration: web path configuration, nip end loading level and nip end loading skew.

Figure 6 shows a west elevation of the three web configurations that were considered. In the first case, the incoming web wraps the upper nip roller by 70 deg. In the second, the incoming web is slightly (20 deg) wrapped on the lower nip roller. The third web path is essentially the same as the second with the exception that the web wraps a bowed roller prior to entry into the nip. The bow magnitude was held constant at 6 mm over its 1.6 m face length during the experiments. The bow plane was set at the manufacturer recommended orientation (e.g., the plane of the bow is perpendicular to the wrap angle bisector with the center high point pointing in the direction of web travel). Table 4 gives additional geometric details of the various web paths studied.

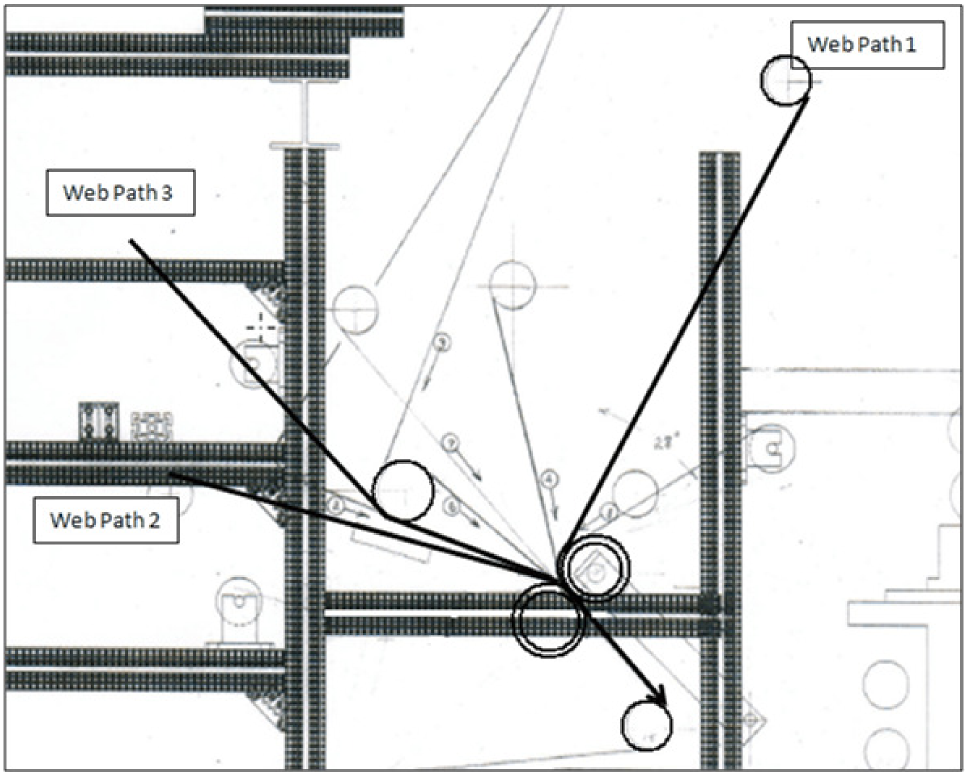

Figure 6 - Web Wrinkling Trial Web Path Configurations, West Elevation

Thread Path Number	Upstream Span, m	Downstream Span, m	Test Roller Entrance Wrap, deg	Test Roller Exit Wrap, deg	Bowed Roller Wrap, deg
1	1.27	0.36	70, upper	30, lower	na
2	1.27	0.36	20, lower	30, lower	na
3	0.46	0.36	20, lower	30, lower	30

Table 3 - Web Wrinkling Trial Web Path Geometry

The trials conducted during the experiment are presented in Table 4. For each trial, the web line was allowed to come to equilibrium and visual observations of troughing and wrinkling upstream and downstream of the nip were made. Of special importance were whether or not troughs and wrinkles were present and how they were oriented and in which direction they were traveling when present. In addition to visual observations, video cameras were positioned to record the behavior of the web into and out of the nip for all cases.

Trial No.	Nip System	Roller Configuration	Web Path	East, N/m	West, N/m
1	3	Single Durometer (2) Symmetrical Roller Pair	#1, 90 deg wrapped nip roller	900	900
2				1260	540
3				540	1260
4				540	1620
5				1620	540
6	4	Dual Durometer Symmetrical Roller Pair	#1, 90 deg wrapped nip roller	920	920
7				1290	550
8				550	1290
9	3	Single Durometer (2) Symmetrical Roller Pair	#2, straight w/out bowed roller	900	900
10				1260	540
11				540	1260
12	4	Dual Durometer Symmetrical Roller Pair	#2, straight w/out bowed roller	920	920
13				1290	550
14				550	1290
15	3	Single Durometer (2) Symmetrical Roller Pair	#3, straight with bowed roller	900	900
16				1260	540
17				540	1260
18	3	Single Durometer (2) Symmetrical Roller Pair	#3, bow orientation rotated	900	900
19	4	Dual Durometer Symmetrical Roller Pair	#3, straight with bowed roller	920	920
20				1290	1290
21				1290	550
22				550	1290
23	4	Dual Durometer Symmetrical Roller Pair	#3, bow orientation rotated	920	920

Table 4 – Nip Roller Wrinkling Study Test Conditions

Prior to conducting the wrinkling experiments, the nip widths and pressures were measured for both nip systems using the Tekscan™ I-Scan measurement system. Sensors were placed at three locations across the width of the nip and measurements were made at two levels of equal end loading. Both nip systems were measured. The results from these measurements are shown in Figures 7 through 10. The first two figures show results for nip system 3 (single durometer nip roller system) and the second two figures show results for nip system 4 (dual durometer nip roller system). The x axis is oriented in the machine direction and the scale has been shifted so that the results at the three locations across the width (east, center, west) can be plotted on the same figure. In addition, the y axis scaling has been held constant for the two levels of loading for each system (but different between nip system 3 and nip system 4). By means of these adjustments, visual comparisons between the results from the two systems can readily be made.

Many of the observations made in the previous section are apparent in these results. First, the nip widths for the single durometer system are significantly lower than those of the dual durometer system owing to the reduced stiffness of the dual durometer coverings. Second and consistent with the first observation, the nip pressures are much lower for the dual durometer coverings. The stiffer single durometer covering reacts strongly to crossweb roller deflection, creating approximately four times average pressure at the edges and one quarter average pressure at the roller's centerline.Further, the shape of the nip pressure distribution is significantly different for the dual durometer nip coverings. The pressure is no longer parabolic, as one would expect for a standard nip but instead is much flatter and in some cases, seems to hint of a concave shape with the edges of the nip having slightly larger pressure than in the middle of the nip. This is consistent with expected behavior since to first order the stiff outer cover on the dual durometer nip roller will act somewhat like a beam and therefore transmit sub layer radial stresses outboard of the nip to the edges of the nip. The reacted force will have an appearance of a concentrated reactive shear force. One final observation consistent with the previous section is that the variation in nip width and pressure along the axis of the nip is greatly reduced for the dual durometer nip system. In each case, the difference between the east and west ends compared to the center is much less in the cases of the dual durometer nip system compared to the single durometer nip system.

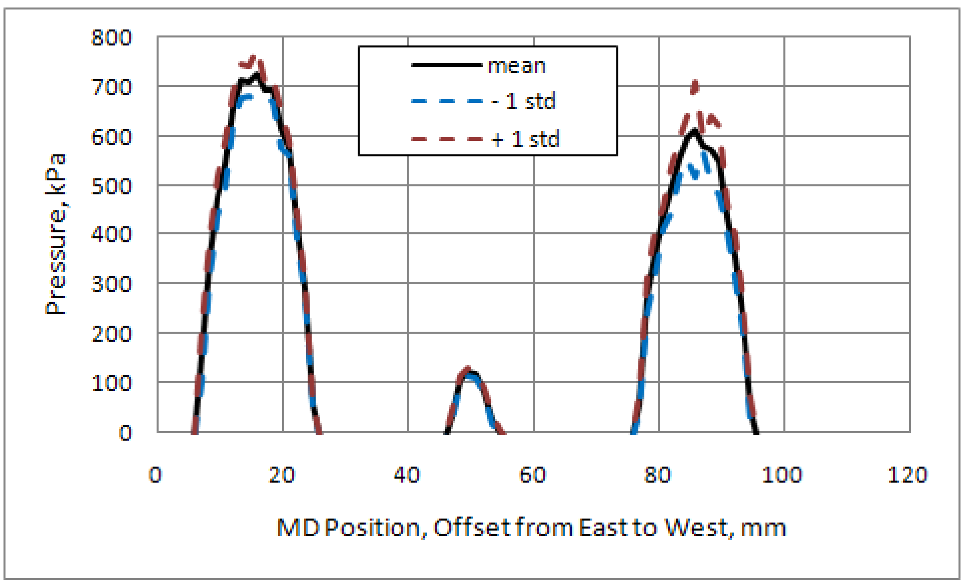

Figure 7 - Nip Pressure vs MD Position, Single Durometer (2) Symmetrical Roller Pair, 1620 N/m Loading

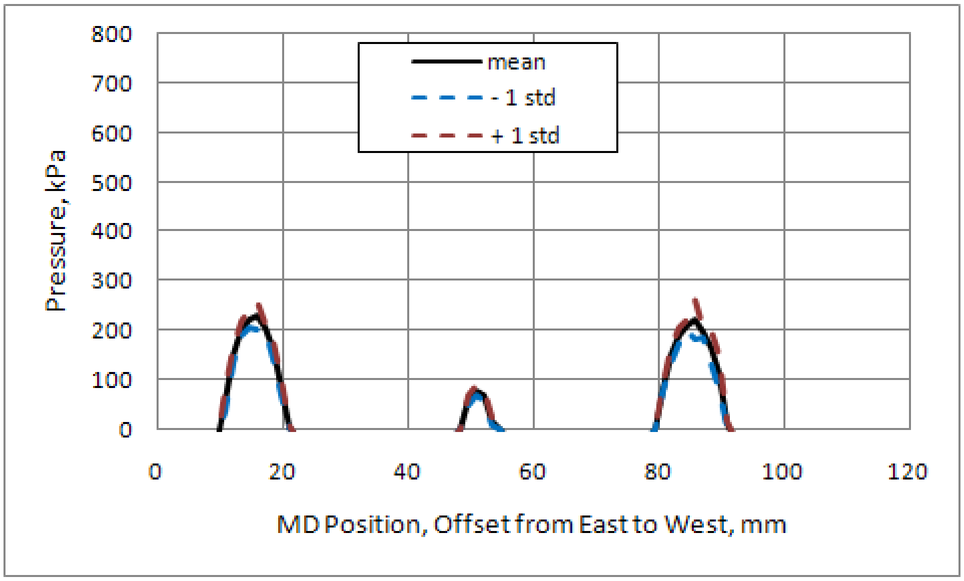

Figure 8 - Nip Pressure vs MD Position, Single Durometer (2) Symmetrical Roller Pair, 540 N/m Loading

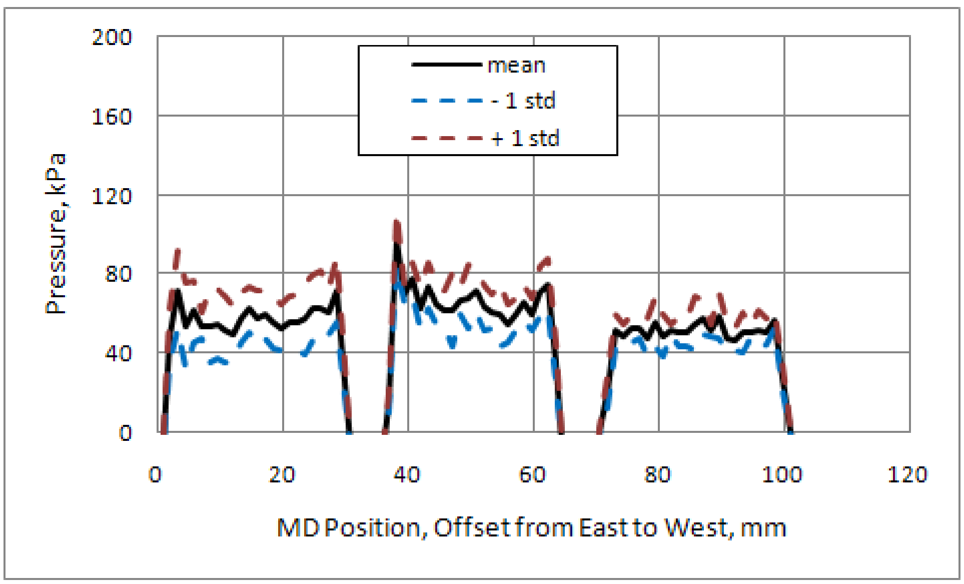

Figure 9 - Nip Pressure vs MD Position, Dual Durometer Symmetrical Roller Pair, 1620 N/m Loading

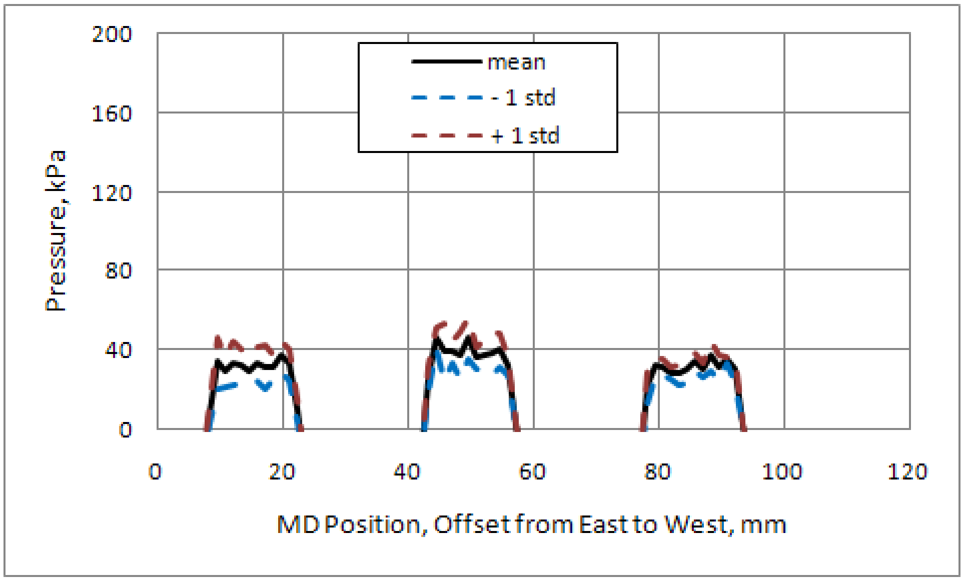

Figure 10 - Nip Pressure vs MD Position, Dual Durometer Symmetrical Roller Pair, 540 N/m Loading

Table 5 summarizes the results of the troughing and wrinkling trials. In addition to the qualitative observations presented in the table, the following more general conclusions can be given based on the testing:

Web Path 1:

- single durometer pair acts like a non-slipping tapered roller consistent with high side tracking, results biased by baggy west edge, wrinkles seen at exit
- dual durometer pair acts like a misaligned roller since the effect of creep is nearly eliminated, a few wrinkles seen at exit

Web Path 2:

- single durometer pair similar in performance to 70 deg wrapped single durometer nipped roller pair
- dual durometer pair behavior consistent with creep performance but this implementation not as robust as previous dualdurometer configuration

Web Path 3:

- single durometer pair much more effective for this configuration compared to the previous case, a few wrinkles at exit
- dual durometer pair in this configuration the best configuration so far, able to keep both entrance and exit clean

From these results, the following recommendations regarding the use of nip rollers can be given:

1. single durometernip rollers should not be wrapped after the web exits the nip – this can lead to the risk of the formation of creases and bubbles due to the web trying to run faster than the nip roller
2. dual durometer nip rollers should not be wrapped before the web enters the nip – this can lead to the risk of the formation of bubbles due to the nip roller trying to run faster than the web
3. dual durometer nip rollers, properly designed and built, can provide improved performance compared to singledurometer nip rollers owing to decreased variation in creep along the axis of the roller
4. dual durometer nip rollers are less sensitive to axial misalignment due to reduced cover stiffness and decreased variation in creep along the roller axis

Trial No.	Nip System	Web Path	East, N/m	West, N/m	Observations
1	3	#1	900	900	clear upstream, wrinkles moving east at exit
2			1260	540	drawlines upstream pointed east, wrinkles moving west at exit
3			540	1260	drawlines upstream pointed west, wrinkles moving east at exit
4			540	1620	more than trial 2
5			1620	540	more than trial 3
6	4	#1	920	920	roller acts as a gatherer due to underdrive, drawlines in center into nip, wrinkles in center out of nip, also observed some bagginess on upstream side into nip
7			1290	550	misalignment drawlines point west, wrinkles moving east at exit
8			550	1290	misalignment drawlines point east, wrinkles moving west at exit
9	3	#2	900	900	clean upstream, a few wrinkles moving east at exit (baggy web on west observed)
10			1260	540	creep drawlines pointed east, wrinkles moving west at exit (few)
11			540	1260	creep drawlines pointed west, wrinkles moving east at exit (many)
12	4	#2	920	920	more drawlines upstream and wrinkles in center at exit, roller acting like a gatherer due to reversed creep
13			1290	550	cleaned up the entrance by slowing the east down more to compensate for baggy west edge, some wrinkles at exit moving west
14			550	1290	made entrance worse because baggy west was slowed down more than east

15			900	900	very clean upstream, a few wrinkles moving east at exit (baggy web on west observed)
16	3	#3	1260	540	slowed down the west, more bagginess into the west side of the nip
17			540	1260	sped up the west which compensated for the bagginess, more wrinkles moving east at exit
18	3	#3, bow rotated	900	900	bowed roller collects wrinkles which spread out onto the nip rollers, exit wrinkles gather
19			920	920	best implementation both upstream and downstream
20	4	#3	1290	1290	upstream bagginess visible on west, downstream still clean
21			1290	550	west clears up due to reduced underdrive, downstream still clean
22			550	1290	clean both sides
23	4	#3, bow rotated	920	920	similar to previous case but exit wrinkles don't laterally move as much

Table 5 – Nip Roller Wrinkling Study Results

CONCLUSIONS

The mechanics of end loaded nip roller systems were empirically studied. Methods were presented for characterizing the load, engagement, nip width and creep performance of nip roller systems. Creep was defined as the tendency of nip covered rollers to run at a different surface speed compared to web being conveyed in a symmetric nip roller system or to an uncovered roller in an unsymmetrical nip system. Results were presented for two types of nip roller cover designs and for two different nip roller configurations.

Machine direction results were presented for asymmetrical nip roller pairs comprised of single durometer and dual durometer nip roller cover designs loaded against an uncovered metal roller. The radial stiffness of the single durometernip roller system was significantly higher than the dual durometernip roller system as expected based on cover material property differences. The single durometernip roller system exhibited positive creep (nip roller moved slower than the hard backing roller) and the dual durometernip roller system exhibited negative creep (nip roller moved faster than the hard backing roller). These characteristics were explained in terms of nip mechanics in the case of the single durometer cover and in terms of beam deflection in the case of the dual durometer cover.

The differences in machine direction creep were used to explain troughing and wrinkling performance of two symmetrical end loaded nip roller systems conveying thin flexible PET. Results from an empirical study were presented that demonstrated that a single durometer nip roller system performed like a spreader roller under even end loading and like a tapered roller under uneven end loading as expected. The dual durometer nip roller system, owing to the negative creep, performed like a deflected roller under even end loading and like a misaligned roller under uneven end loading. Incoming roller wrap affects the dual durometer nip roller system sensitivity while the single durometer nip roller system behavior is largely wrap independent. Results further demonstrated that the dual durometer nip roller system in combination with an upstream bowed roller performed better than the single durometer nip roller system in the same configuration.

From the learning's of this work, optimized conveyance performance can be achieved by judicious selection single durometer nip roller entry and exit spans and wraps and of dual durometer cover properties.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Robert Updike who assisted with the experimental results and American Roller Company who manufactured the dual durometer nip roller coverings.

REFERENCES

1. Roisum, D.R., "The Mechanics of Web Handling", Tappi Press, Atlanta, Georgia, 1998.
2. Stack, K.D., et. al, "The Effects of Nip Parameters on Media Transport", Proceedings of the 3rd International Conference on Web Handling, Oklahoma State University, Stillwater, Oklahoma, June 1995, pp. 382-395.
3. Rice, B.S., "Wrinkle-Free Conveyance in Nips" , Proceedings of the 8th International Conference on Web Handling, Oklahoma State University, Stillwater, Oklahoma, June 2005, pp. 141-152.
4. Balaiyan, K., "Lateral Steering of the Web in a Differentially Loaded Nip of Rubber Covered Rollers", Masters Degree, Oklahoma State University, Stillwater, Oklahoma, 2005.
5. Good, J.K, "Modeling Rubber Covered Nip Rollers in Web Lines", Proceedings of the 6th International Conference on Web Handling, Oklahoma State University, Stillwater, Oklahoma, June 2001, pp. 159-177.