THE EFFECT OF NIP LOAD ON WOUND-ON-TENSION IN SURFACE WINDING

By

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Chapter 1

Introduction:

Several products are produced in the form of a web. The webs are wound on a core, so they can be shipped to other manufacturers. These manufacturers will unwind and rewind the web through different processes. There are several configurations used in winding webs, such as center winding, center winding with a lay-on nip roller, and surface winding. A web is a continuous thin flexible material. Most webs are stored in the form of a roll. This study deals with surface winding exclusively.

A single roll is first made from raw materials. That roll might be unwound, coated, and rewound. The same roll might then be unwound, printed, and rewound. The web may be printed on through several processes. After printing, the web could be cut and staked like newspapers. Several different companies may wind and unwind a single roll. Since the roll must be wound several times, the integrity of the roll must remain high.

A nip roller which impinges the winding roll is often used to reduce air entrapment in rolls wound of impermeable webs. The nip roller also can serve to increase the wound-on-tension in the outer layer of a winding roll. Increasing wound-on-tension by a nip is a practical solution to improving roll quality. The tension induced by the nip increases the wound-on-tension above and beyond the tension seen by the web in the web line, when center winding with a lay-on roller. The higher wound-on-tension is produced from what is called nip induced tension (NIT). The rolling nip serves to cause the outer layers of the winding roll to slip on those layers beneath. For center winding with an impinging nip, the effect of the nip on the wound-in-tension and the radial pressures produced, thereby, are well known.

Surface winding and center winding, with an impinging nip roll, look very similar in terms of the winding machinery. The only difference is that all center winders apply torque to a core and the web winds up upon the core whereas surface winders apply the torque to the impinging nip and the core free wheels. Empirical evidence has shown that the internal stresses produced within rolls wound by center winding are very different than the stresses produced by surface winding.

The objective of this research is to determine why rolls wound by surface winding methods are so different from those wound by center winding methods.

Chapter 2

Literature Review

Pfeiffer [1] was the first to discuss qualitatively that rolls wound with a nip appeared to be much harder than those wound in similar conditions without impinging nips. This statement applied to rolls which were either center wound or surface wound with an impinging nip.

These findings were confirmed by experiments conducted by Rand and Eriksson [2]. In this study, strain gages were attached to the web and the strain recorded as the web proceeded onto the winding roll and under the impinging nips. As a result of these experimental studies, Rand and Eriksson came to the following conclusions:

a. As the web goes around the surface driven nip, the web tension drops to a minimum.
b. The nip then elevates the wound-on-tension to a much higher tension than the web line tension.
c. The wound-on-tension becomes reduced as a result of increased radial distance from the nip.

Good and Wu [10] studied the mechanism for wound-on-tension for center winding with a lay on roll. The mechanism found to be responsible was an elongating strain induced in the outermost layer due to the impinging nip. This elongation can induce an increase in WOT that is limited by friction between the first and second layers of web beneath the nip (WOT = $\mu_k N/h$). Good and Fikes [11] proved with center winding experiments, where an impinging nip was employed, that the wound-on-tension was:

$$WOT = Tw + \frac{\mu_k \cdot N}{h} \qquad \{1\}$$

This model yields a WOT dependent upon web line tension which is contrary to reported surface winding cases. Again, Rand and Eriksson [2] indicated that in their surface winding experiments almost all web tension was lost after the web encountered the nip.

In 1977, Pfeiffer [3] developed a specialized winder, shown in Figure 1, to measure the wound-on-tension. The winder, in Figure 1 was developed as a test bed for rolls which were wound in Beloit's production facility winders, Pfeiffer's employer at the time. The production rolls could be unwound and the initial conditions under which the rolls were wound could be determined. Beloit engineers could then make recommendations to their customers on how to better wind their rolls. Pfeiffer also used this machine to experimentally determine the WOT associated with surface winding. Four types of paper webs 40 inches in width were wound. One web type which was tested was Canadian newsprint. The WIT-WOT (an acronym for wound-in-tension and wound-off-tension) machine measured the wound-on-tension by peeling off the outer layer of the web after it had contacted the winding roll and directing it around a load cell, prior to directing the web back onto the winding roll, again please refer to Figure 1. The load cell was used to measure the wound-on-tension of the outer layer of the roll after the web had passed under the nip roller. From the data analyzed for wound-on-tension, the form of the following empirical equation was derived by curve fitting the experimental data:

$$WOT = \frac{1}{B}\ln\left(\frac{N + A}{A}\right) + \frac{TN}{C + DN} \qquad \{2\}$$

where N = nip force (pli) and T = web line tension (pli)

The coefficients A-D for 32 lb. Canadian newsprint which were obtained through curve fits:

A = 17.02 (pli) B = 0.34 (1/pli) C = 17.29 (pli)

D = 0.83 F = 0.31

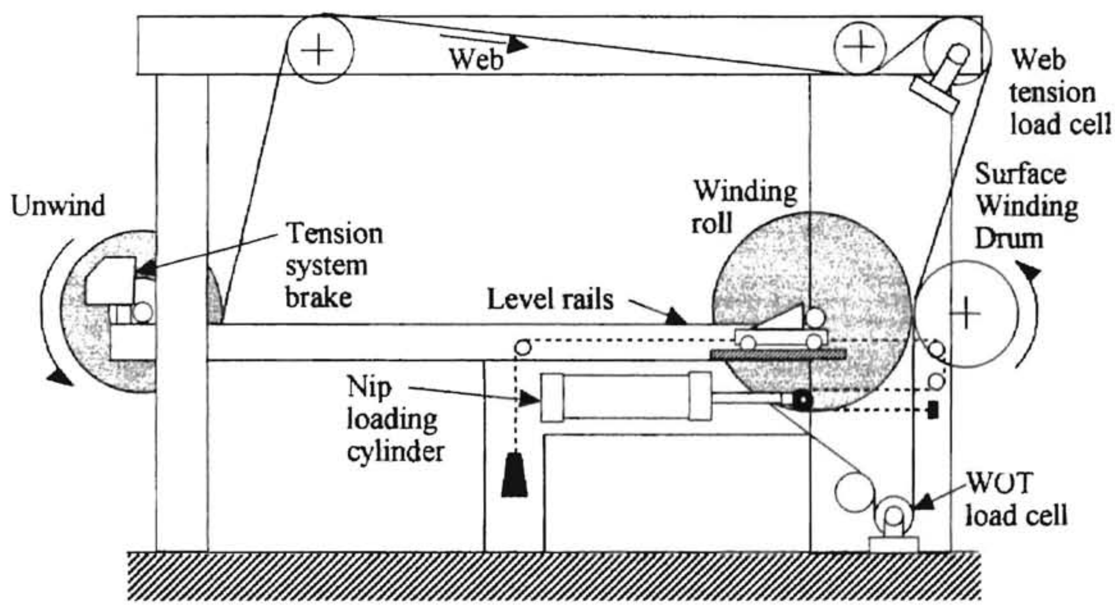

Figure 1: Pfeiffer's Winder Configuration

If these coefficients are input in equation {1} the curves shown in Figure 2 are produced. Pfeiffer [3] also eludes to a limiting factor for the wound-on-tension which corresponds to the following equation:

$$WOT \leq \mu_{st} N \qquad \{3\}$$

Thus, Pfeiffer is implying that the WOT cannot exceed the friction force between the layers beneath the nip. As webs are membranes, the web line tension cannot be less than zero. The Tw = 0 curve shows the absolute minimum WOT curve, although in practice it is difficult to wind webs with zero web line tension.

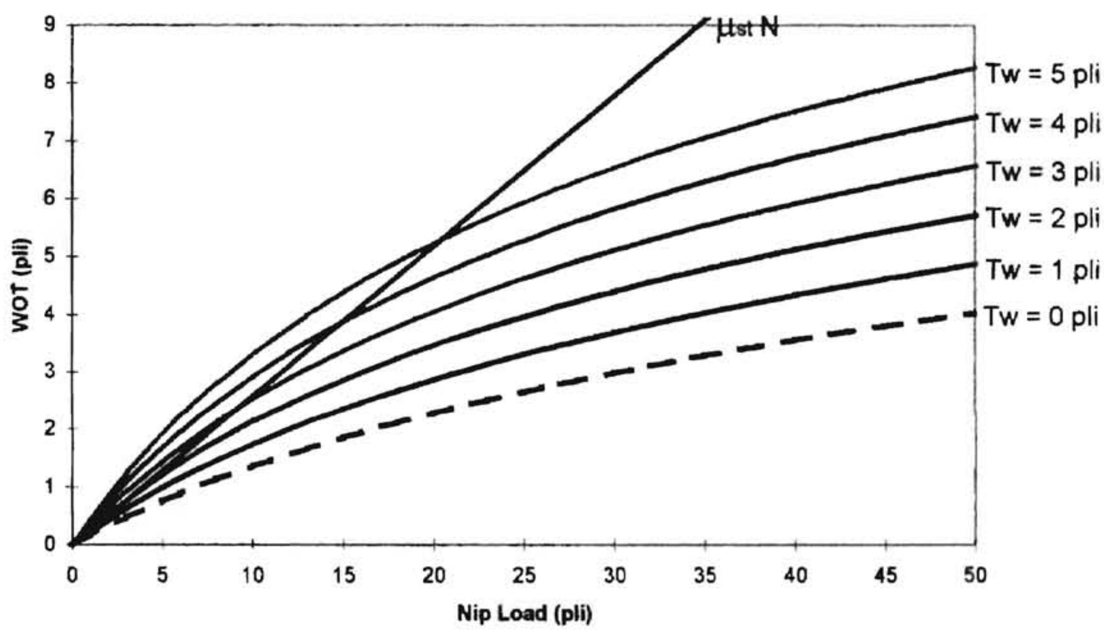

Figure 2: Pfeiffer's[3] WOT Curves

Raphael [6] published an empirical study on surface wound rolls. This study measured the interlayer pressure of surface wound rolls. A six inch wide roll was used for all the experiments. A pneumatic cylinder had been employed to supply the nip load during experiments, refer to Table 1. This experimental data showed that web line tension did not contribute significantly to wound-on-tension, and was predominantly a function of nip load. Raphael stated that the increase in wound-on-tension was due to the first layer advancing over the second layer, causing material to be rejected back into the incoming web span prior to the winder. This previous problem is only produced in surface winding and is not applicable to center winding with a nip roller. Raphael also concluded, from plotting the results of radial pressure through the roll, that these curves were similar to constant wound-on-tension center winding cases. Thus, the WOT could be predicted by executing a wound roll model, such as Hakiel's model [12], and iterating on the WOT until the radial pressure profile produced matched experimental data provided by pull tab measurements. This study concluded the following:

1. Surface winding is similar to center winding with a nip with constant web line tension, as both produce plateau pressure profiles. This further implies that the wound-on-tension is constant in both cases.
2. Wound-on-tension is not strongly related to web line tension.
3. Nip load has a greater effect on wound-on-tension than web line tension.

Nip Diameter (in.)	Nip Load (pli.)	Web Line Tension (lb.)	Material
3, 4, 5	4, 6, 8	4.2, 5, 5.3, 6, 6.7, 7.7, 9.5	Newsprint

Table 1: Raphael's Winding Conditions

In 1992 Markum [7] published a study on nip mechanics of nip induced tension. The tests were done on paper, under the conditions given in Table 2. He stated that nip induced tension (NIT) is a function of nip load and coefficient of friction. Also noted in his paper, NIT is not influenced by diameter which follows the center wound case, for the limited range of diameters tested. Markum stated that there was a loss in tension prior to the nip. This supports the findings of Rand and Eriksson [2]. This loss of tension in the web is caused when the web in front of the nip rollers is displaced in the nip direction which causes the web to experience a loss of tension. In addition Markum showed that slippage is occurring most of the time and therefore the kinetic coefficient of friction should be used when calculating NIT for center winding with an impinging nip. This supported the findings of Good and Fikes [11] but is contrary to the findings of Pfeiffer who felt that the static coefficient of friction should be used, as shown in expression {3}.

Nip Diameter (in.)	Nip Load (lb.)	Web Line Tension	Web Material
2, 4, 6, 8	2, 4, 6, 8	unknown	Newsprint

Table 2: Markum's Winding Conditions.

Cai [8] studied the effect of compliant nip coverings on the WOT for both center winding and surface winding conditions. Cai's experimental setup was very similar to that used in this research, and his winding conditions are shown in Table 3. A pneumatic cylinder was used to supply the nip load. The findings stated that the compliance of the nip did not make any substantial difference in the wound-on-tension. Cai [8] stated, "From the work done on both center winding with nip roller and surface winding in this research, it can be understood that the nip induced tension mechanics is the intrinsic property for winding with a nip roller, and the mechanics can be applied to both center winding with nip rollers and surface winding."

Nip Diameter (in.)	Nip Load (pli.)	Nip Compliance	Tw (pli)	Material Wound
5	6	Shore A (37, 46, 53)	1.4	Bond Paper

Table 3: Cai's Winding Conditions.

Vijayarangan [10] studied nip mechanics in surface winding. A flat nip mechanics test bed was used to evaluate nip load, nip diameter, and wrap angle on nip induced tension. In addition, a finite model was produced to study nip diameter effects on nip induced tension. Vijayarangan [10] continues on to discuss the influences of nip load and web line tension on the pressure profile of surface wound rolls. In conclusion Vijayarangan [10] stated:

1. Flat bed test results show center and surface winding fall within 5% of each other and saturated values for nip induced tension are equal to μN/h for center and surface winding.
2. The rate of nip induced tension depends on nip diameter for both center and surface winding.
3. Smaller nip diameters have a higher growth rate of nip induced tension than large diameters for center and surface winding.
4. Results show the following equation for WOT, first published by Cai [8], is not valid for surface winding.

$$WOT = \frac{Tw}{e^{\mu_{An}\theta}} + \frac{\mu \cdot N}{h} \qquad \{4\}$$

5. Surface wound roll pressure profiles are independent of web line tension for all nip loads lower than 10 pli while winding newsprint.
6. Surface winding was performed with 2.5 inch and 6 inch nip diameters and the influence of the pressure profile was negligible.
7. Hakiel's wound roll model, using an external boundary condition,

$$WOT = \mu_k N/h \quad \{5\}$$

predicts the radial pressure profile much better than expressions {1} or {4} for all web line tensions and nip diameters at loads lower than 10 pli.

Summary of Literature

The relevant literature can be summarized as follows:

1. Most sources conclude that at lower nip load levels web line tension has little or no impact on WOT in surface winding. Pfeiffer [3] showed a dependence on web tension at higher nip load levels.
2. No explanation has been provided, to date, which explains why the web line tension is lost from the WOT in surface winding.
3. There is some evidence that an increase in nip induced tension and WOT is obtained with a small diameter nip roller as compared to the large diameter nip roller.

Objectives of this Research

As stated in the *Introduction*, the objective of this research is to determine why rolls wound by surface winding methods are so different from those wound by center winding methods. The goal of this research is to be able to predict the internal stresses within surface wound rolls.

Chapter 3

Experimental Procedure:

To accomplish the goals, experiments were performed to verify that at lower nip loads the WOT in surface winding is given by expression {5}, and that at higher nip loads there might be some dependence on the web line tension as shown by Pfeiffer in expression {2}. Other experiments were performed to help ascertain what the source of WOT is in surface winding. Additional investigations are done to gain a better understanding of how the web line tension is related to WOT, including how web line tension is lost from the WOT at low nip loads and the impact of web line tension at higher nip loads.

During the winding experiments, the rolls were evaluated using four techniques including: wound-on-tension estimation, velocity difference measurements, torque measurements, and interlayer slippage. In Figure 3, the winder which was used for all experiments shows the web path and location of all primary functions used on the winder.

Wound-On-Tension (WOT) Estimation

This technique requires interlayer radial pressure to be measured with pull tabs (Figure 4). A pull tab is a thin piece of steel feeler gauge (1 mil. thick by 0.5 in. wide and

12 in. long) encased by a piece of brass shim stock similar in construction to that reported by Cai [8]. Several of the sources referenced [6,7,8,10, and 11] employ pull tab techniques and, therefore, the method will not be repeated herein. Each pull tab was tested after the roll is wound to produce discrete profiles of radial pressure as a function of radius in the wound roll. After the roll pressure is found, wound-on-tension is estimated using winding software such as *WINDER* developed at Oklahoma State University [13].

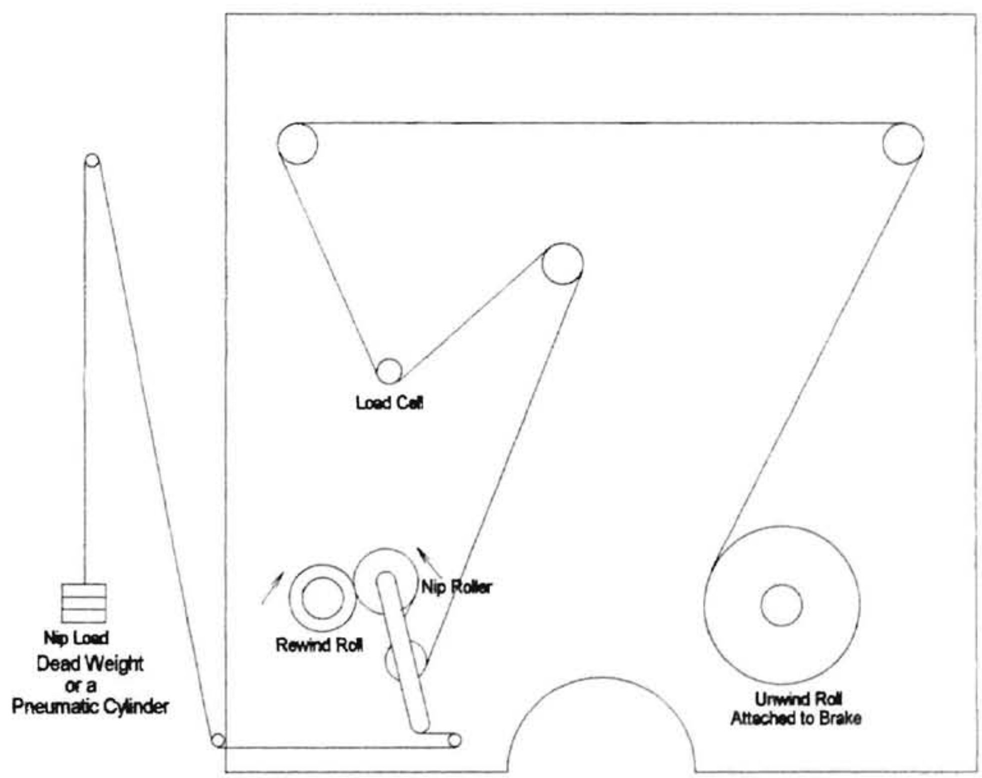

Figure 3: Winder Setup

WINDER is a software program that produces the radial pressure profiles as a function of inputs provided by the user. The user must input the WOT, Young's moduli in the radial and circumferential directions, beginning and ending wound roll radii, and the core stiffness. The WOT was adjusted until the average interlayer pressure equaled the average interlayer pressure obtained from the pull tab measurements. The rolls wound in these experiments were wound at low speeds. The newsprint web utilized has high permeability, thus entrained air was not a factor in these experiments. Entrained air in a roll decreases the radial pressures in the roll, which is undesirable in this research (i.e. it is desired to have the radial pressures to be dependent only on WOT since the WOT is being estimated from the radial pressure measurements). The input parameters, other than the WOT which was iterated upon, are given in Table 4.

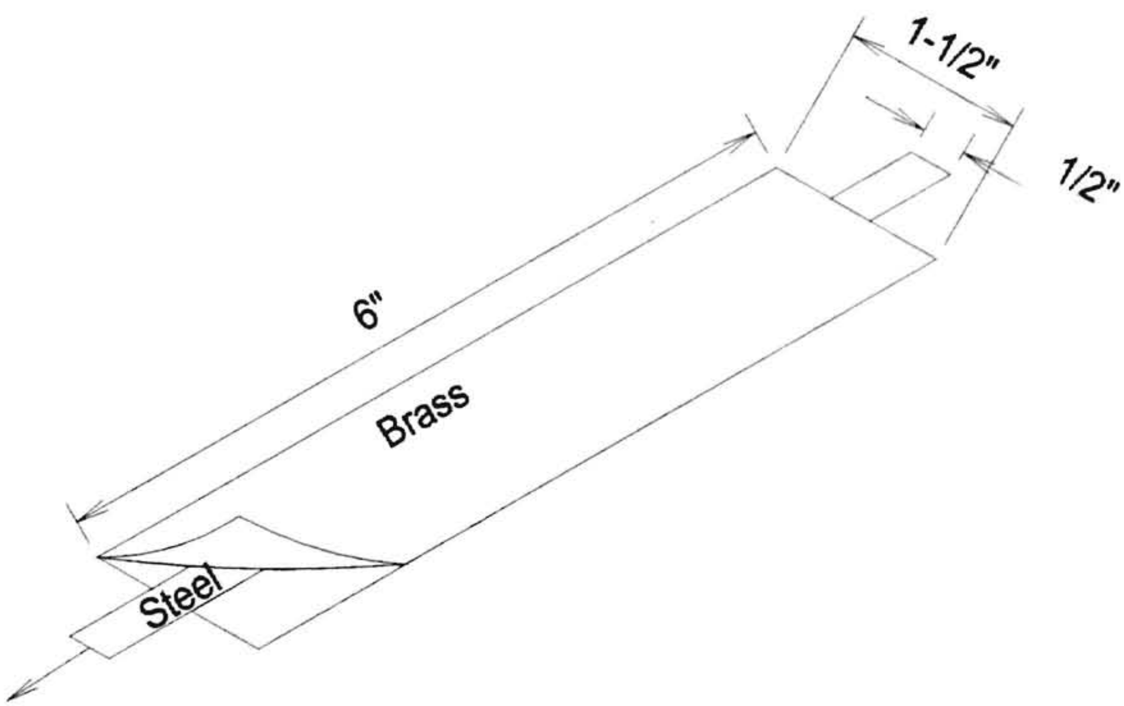

Figure 4: A Pull tab

$Er = 45.521 \cdot P - 0.46632 \cdot P^2 + 0.00226 \cdot P^3 psi$
web caliber 3.125 mils
$Et = 500000$ psi
Steel core Ec = 4000000 psi
Core Radius = 1.7 inches
Constant Linear Velocity = 50 ft/min.

Table 4: Input Parameters for WINDER.

Winding Torque

The torque required to wind the web was, also, investigated during the winding process. These measurements were made to see if there is any correlation between WOT and the winding torque. This is attractive as an experimental technique, as it is an easy measurement to make during the winding process. Torque was sensed by a LeBow 11045 shaft torque sensor of 500 in.-lb. capacity. A Measurements Group Model 3800 wide range strain indicator was used to indicate the torque sensed by the LeBow sensor, that was calibrated in in.-lb. of torque. The analog output was acquired through time by a LabView software program and an data acquisition card in a desk top computer. The torque transducer was calibrated prior to each winding. The calibration was performed by using a calibration resistor which sets an equivalent torque of 50.82 in.-lb. This calibration was verified experimentally by inducing 75 in.-lb. torque using free weights and a moment arm. The torque sensor was inserted inline between the drive motor and the driven nip roller, which provides the winding torque to the surface wound rolls.

Figure 5 is a sample torque curve during a particular test. The sample torque curve was taken with a 2.5 inch nip roller, 2.5 pli line tension, and 3.33 pli nip load. As noticed from Figure 5, the torque has a large fluctuation; this fluctuation was filtered out by using the "average" function in Excel. These torque fluctuations are due in part to the AC vector drive which provides the winding torque to the surface driven roll. Each fluctuation is due to the pole firing in the motor. Figure 5 shows several data points, as the torque data was acquired at one second intervals, and therefore several points could be averaged. This particular graph has 3594 points; from this many points, a good average should be produced fairly accurately. It should be understood that the torque which is being measured is an accumulated value. The surface driven drum must supply the torque required to pull the web off the unwinding roll, the torque necessary to overcome rolling resistance between the nip and winding roll, the torque necessary to overcome any bearing resistance, and the unknown influences to torque by the WOT.

Interlayer Slippage

Interlayer slippage which occurred during the winding process was detected by the J-line printer. The J-line printer is a tool devised to show slippage in a wound roll by shooting ink on the edge of the top layer at the same angular location during each rotation. A Gurley 8225-1250-CSPA encoder was attached to the end of the shaft of the winding roll. The encoder outputs an index pulse after every 360 degrees of rotation which is used to fire an ink-jet printing head such that a jet of ink is projected from the J-line printer on to the web winding into the roll. This method was developed at the WHRC and was first reported in the work of Giachetto [14].

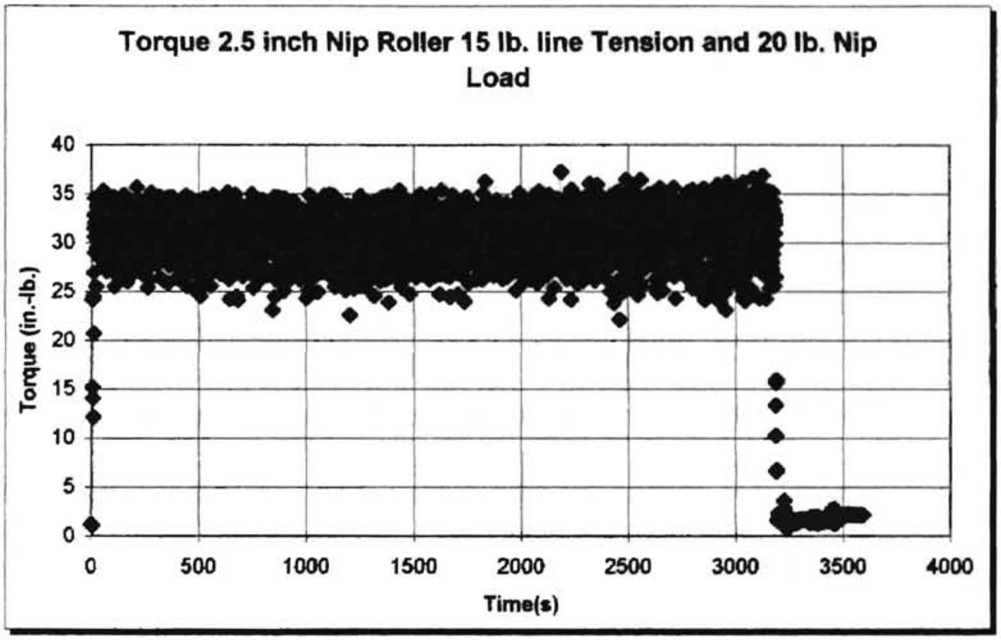

Figure 5: Sample Torque Curve

Snapped J-lines were also applied during the winding process [15]. Snapped J-lines are snapped from a bow with a cotton string covered in chalk. The bow is then very quickly set near the roll and snapped by hand to make a line on the roll. The snapped J-line is more traditional and more easily interpreted. Since snapped J-lines are more traditional they are used to evaluate the instantaneous J-line printer. The advantage of the J-line printer is that the user is allowed to evaluate the slippage continuously thoughout the roll.

Velocity of Nip vs. Wound Roll

The existence of J-lines and interlayer slippage is evidence that a velocity difference may exist between the web being transported in the web line and that web which is wound onto the wound roll. Two Gurley Teledyne 8225-1250-CSPA encoders were used to measure the velocity difference. One encoder was placed on the nip roll, but not on the web, the other encoder was placed on the winding roll. These tests were run for nip loads of: 2, 3.33, 5, 6.67, 10, 15, 20, 26.67, and 33.33 pli. The tests were all run with a 6 inch diameter nip roller. The encoders have a 10,000 pulse per revolution count which were counted and compared using two Hewlett Packard counters. A HP 5315B universal counter was used to evaluate the frequency ratio and a HP 5314A universal counter was used to find the frequency of the pulse on the nip roller. After the test was run the encoders locations were swapped to evaluate the accuracy of the encoders.

General Comments on Winding Experiments

The nip load was supplied by a rotating arm that had the same mechanical advantage on each side. This arm was connected to a cable from which the free weights were hung (Figure 3). When very high nip loads were required, a pneumatic cylinder with a pressure regulator was employed to supply the nip load. The nip force was checked using a hand held force gage. Three nip diameters were used in the investigation of surface winding nip mechanics, 2.5 in., 6 in., and 8 in.

Each wound roll was documented using a code. A typical code might read S600660A which breaks down as follows: S - stands for surface winding; the next two places stand for the roll diameter times ten; the fourth and fifth place stands for web line tension in pounds; the sixth, seventh, and (if no letter at the end) the eighth stand for nip load in pounds; and the letter at the end stands for which run it was associated with for repeated runs.

Chapter 4

Experimental Results

Winding Torque

Web line tension and nip load were varied in an effort to understand how these variables effect the torque required to surface wind a roll. The torque was acquired for each winding trial and, in addition, the torque was acquired while stepping the web line tension and nip load independently. Figure 6, Figure 8 and Figure 11 shows the relationship between winding torque and web line tension, for fixed values of nip load. Also, shown in these figures is the amount of torque required from the winder to overcome the torque due to winding tension. In Figures 6, 8, and 11 the measured torque is always in excess of the torque required to overcome web tension. Also, note that there is an offset in all the measured values, typically about 12 in-lb. Since this offset is reasonably constant, regardless of web line tension, nip loading, and nip diameter, it is believed to be the combined bearing resistance of all bearings between the nip roll and the LeBow torque transducer. Figure 7, Figure 9, and Figure 10 shows the relationship between winding torque and nip load for fixed values of web line tension. Web line tension has a much larger impact on winding torque than nip load. From Vijarangan [10], it is known that at lower values of nip load the WOT should follow expression {5}. It is not clear from Figures 7, 9, and 10 that the winding torque is related to the nip load.

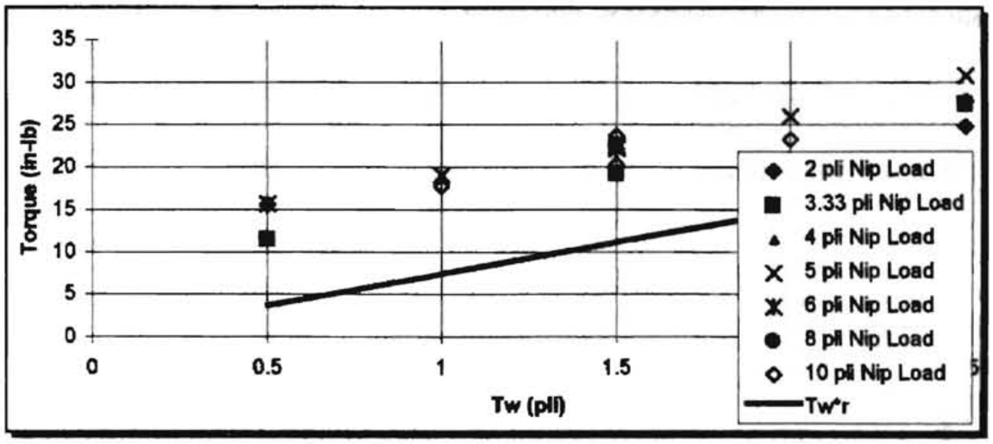

Figure 6: Winding Torque vs. Web Line Tension for the 2.5"O.D. roller

Thus, the winding torque associated with surface winding may have little influence on WOT, which is an important parameter for establishing wound roll quality. When center winding without a nip, the WOT is often estimated by measuring the current

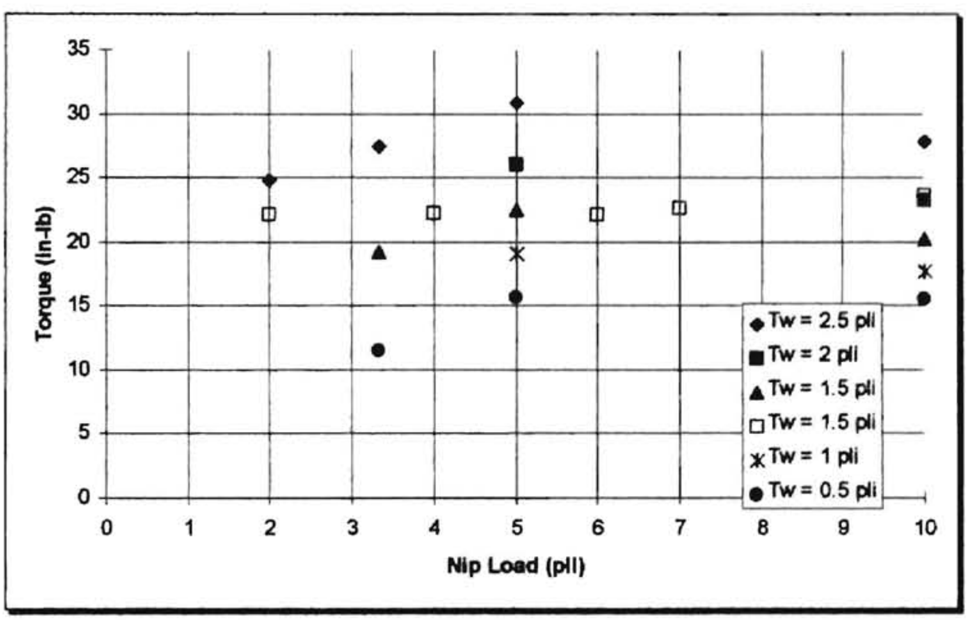

Figure 7: Winding Torque vs. Nip Load for the 2.5 in. OD nip roller.

drawn by the winding motor and inferring the winding torque. The winding torque divided by the current outer radius of the winding roll should be both the web line tension and the WOT when center winding. Thus, in center winding there is a direct relationship between winding torque and WOT.

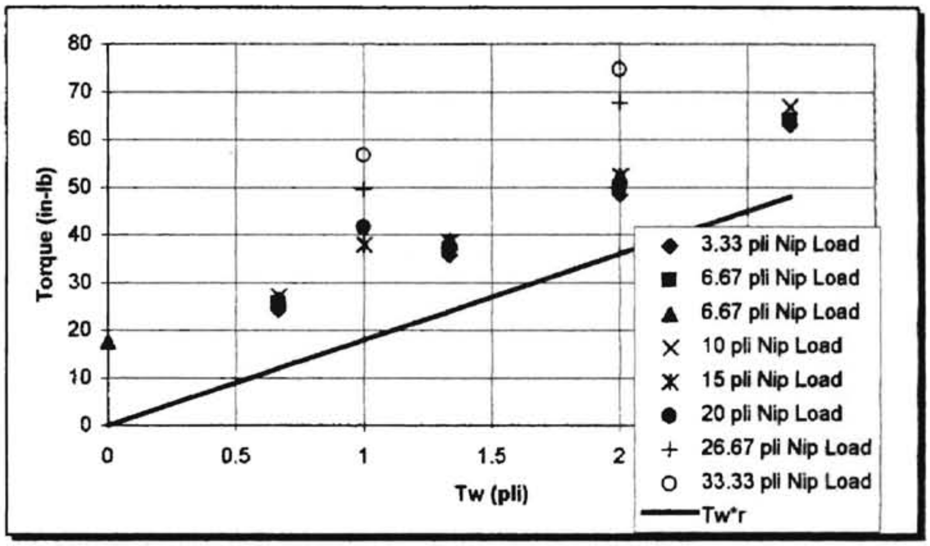

Figure 8: Winding Torque vs. Web Line Tension for 6" OD roller

Vaidyanathan [6] discussed rolling resistance of wound rolls of newsprint and made measurements of rolling resistance as well. He employed an equation for rolling resistance of the form:

$$\text{Torque}_{\text{Rolling-Resistance}} = 3.5 * \frac{2}{3\pi}\alpha\left[\frac{Na}{R^*}\right] w\, r_{\text{nip-roll}} \quad (\text{in}-\text{lb}) \qquad \{6\}$$

where α is a material loss factor, a is the half width of contact, R* is the equivalent radius of the nip and wound roll, and w is the web width. Substituting an α of 0.2 and using estimations of the half width of contact per expression {6}, Vaidyanathan [6] can be used to generate the torque associated with rolling resistance. This torque is then added to the torque required to overcome web tension. These calculated values of torque are compared to the experimental values for the 6 inch diameter nip in Figure 12. What is shown is that the calculated torque is of the same order of magnitude as those measured. The 12 in.-lb. of bearing resistance should be removed from the experimental data for a more valid comparison, but the point which is being made here is that the rolling resistance per expression {6} can easily account for the increase in winding torque with increased nip load shown in Figures 7, 9, and 10. This reinforces the point made previously that the winding torque may bear little relationship to the WOT.

roll diameter (in.)	Nip Loads (pli)	Tw (pli)
2.5	2, 3.33, 4, 5, 6, 8, 10	0.5, 1, 1.5, 2, 2.5
6	3.33, 6.67, 10, 15, 20, 26.67, 33.33	0.67, 1, 1.33, 2.67
8	3.33, 6.67, 10	0.67, 1.33, 2, 2.67

Table 5: Winding Parameters used in this study.

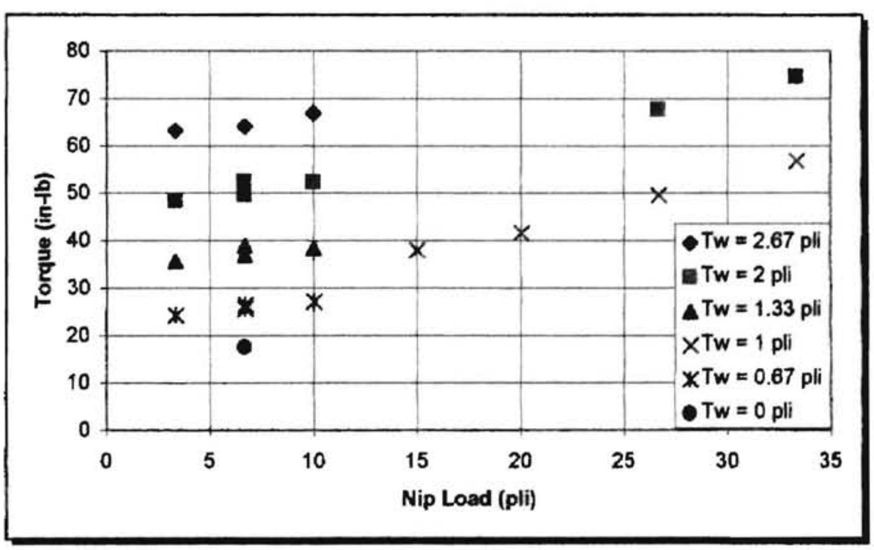

Figure 9: Winding Torque vs. Nip Load for 6" OD nip roller.

The winding parameters of all the cases wound are shown in Table 5. Some of the torque curves were run twice (Figure 14) to evaluate how they compared. The comparison torque windings had a maximum of 5%-6% difference. Therefore, the winding torque seems repeatable. The identical condition runs were acquired each time with a new calibration of the machine setup.

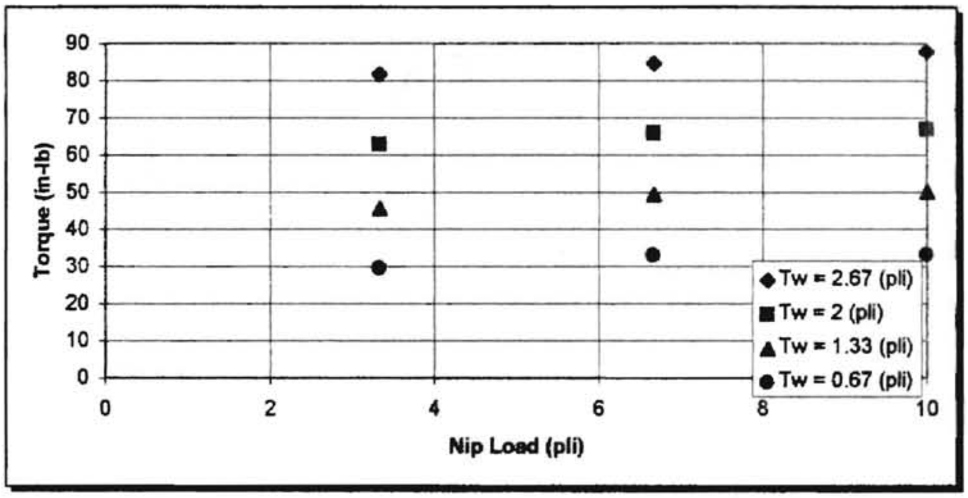

Figure 10: Torque vs. Nip Load for 8 inch nip roller.

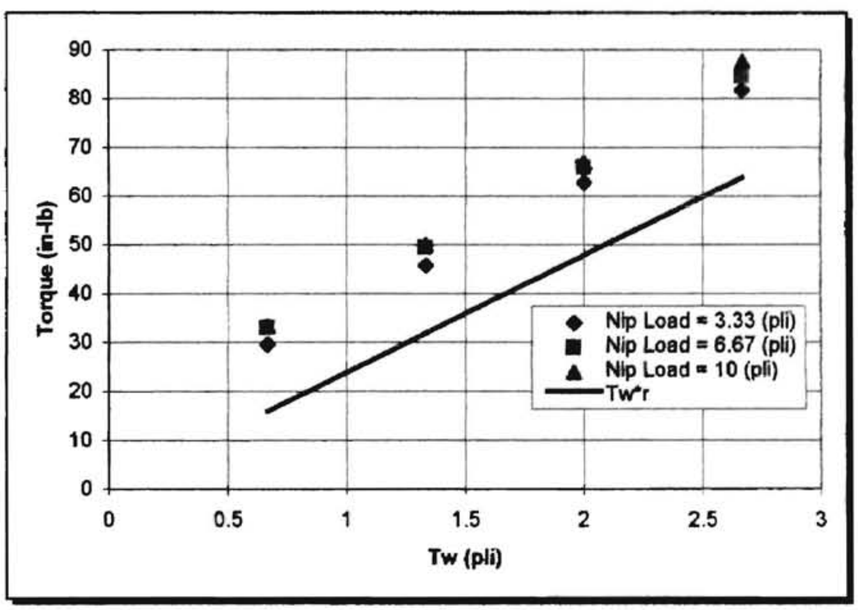

Figure 11: Torque vs. Tw for the 8 inch diameter nip roller.

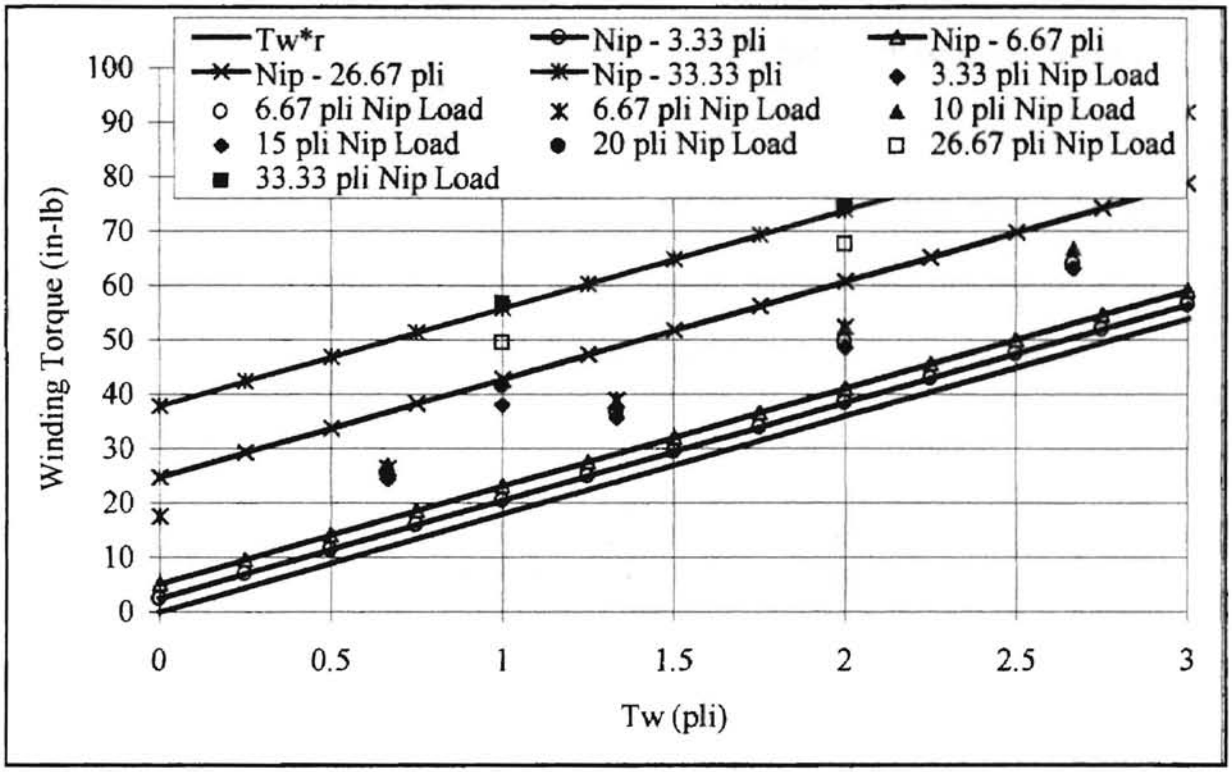

Figure 12: Comparison of Torque Calculated to Experimental Data from Figure 7

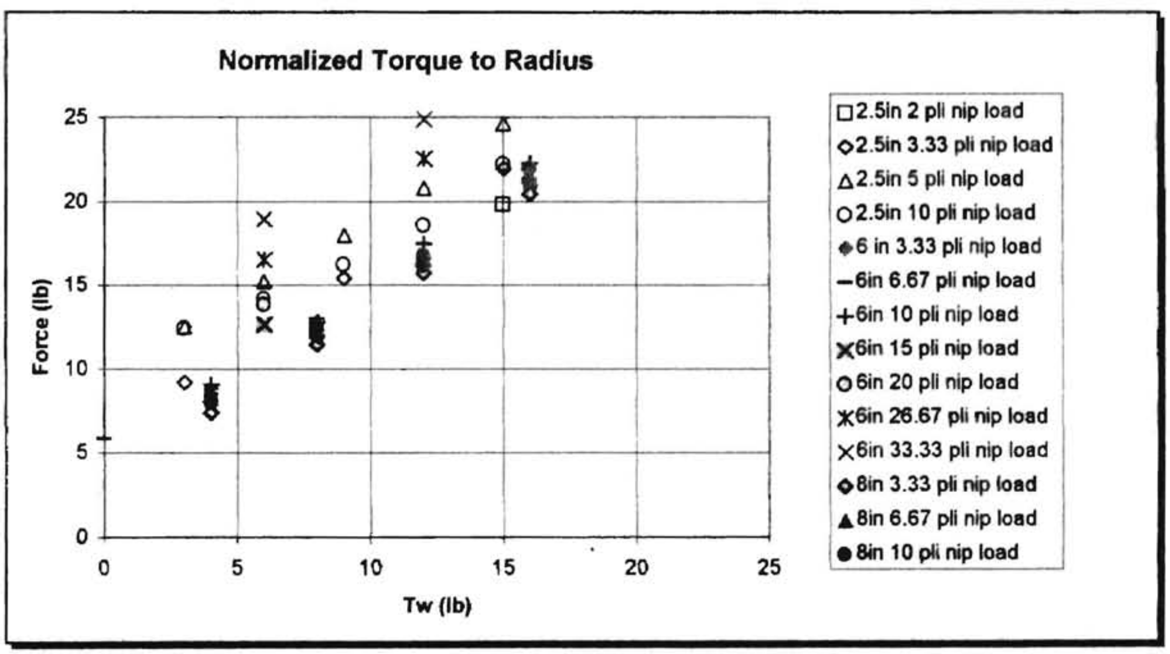

Figure 13: Normalized Torque with respect to Radius.

In order to get a better understanding of the torque curves, they were normalized by dividing by nip roll radius and compared (Figure 13). The parameter being plotted can be thought of as an equivalent winding force. Note that in this plot the units of Tw have become lb. rather than pli. This has the effect of condensing all the data into a tight band and, again, shows the strong dependence of the winding torque to web line tension as the slope of the data is very near one. There is still some vertical spread, due to rolling and bearing resistance, as discussed earlier.

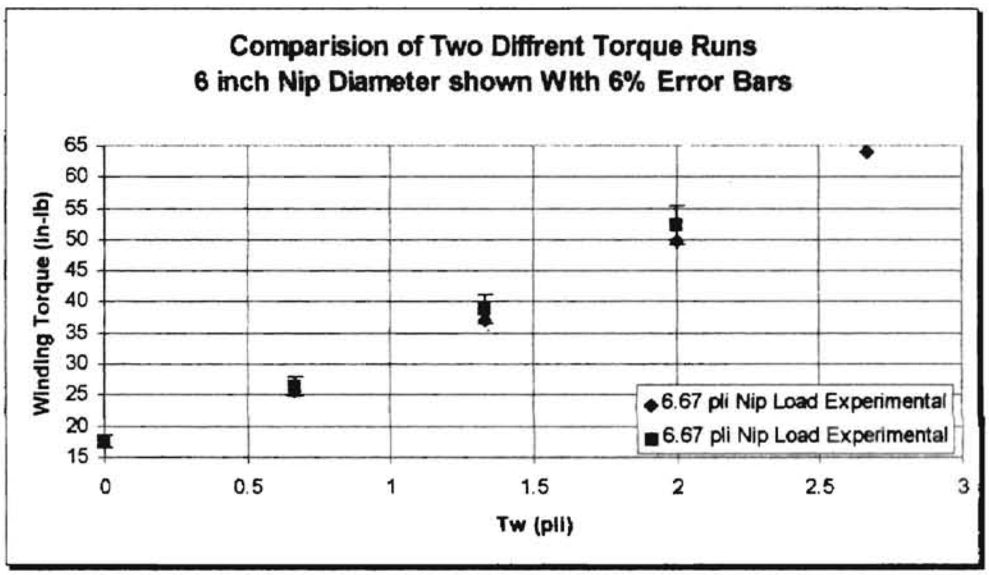

Figure 14: Comparison of two surface wound rolls under the same conditions.

Wound-On-Tension

The wound-on-tension was inferred using pull tabs measurements and the WINDER software, as discussed in the experimental procedure. This procedure was carried out on several rolls and those estimates of the WOT are shown below plotted upon Pfeiffer's curves [3] in Figure 15, for Canadian newsprint which has the same basis weight as the newsprint used in this study(52 gm/m^2).

The results substantiate the findings of Vijayarangan and Pfeiffer. At lower nip loads, the model proposed by Vijayarangan for the WOT which is also the current WOT algorithm used in WINDER for surface winding is valid. This model was proposed earlier as:

$$WOT = \mu_k N/h \qquad \{5\}$$

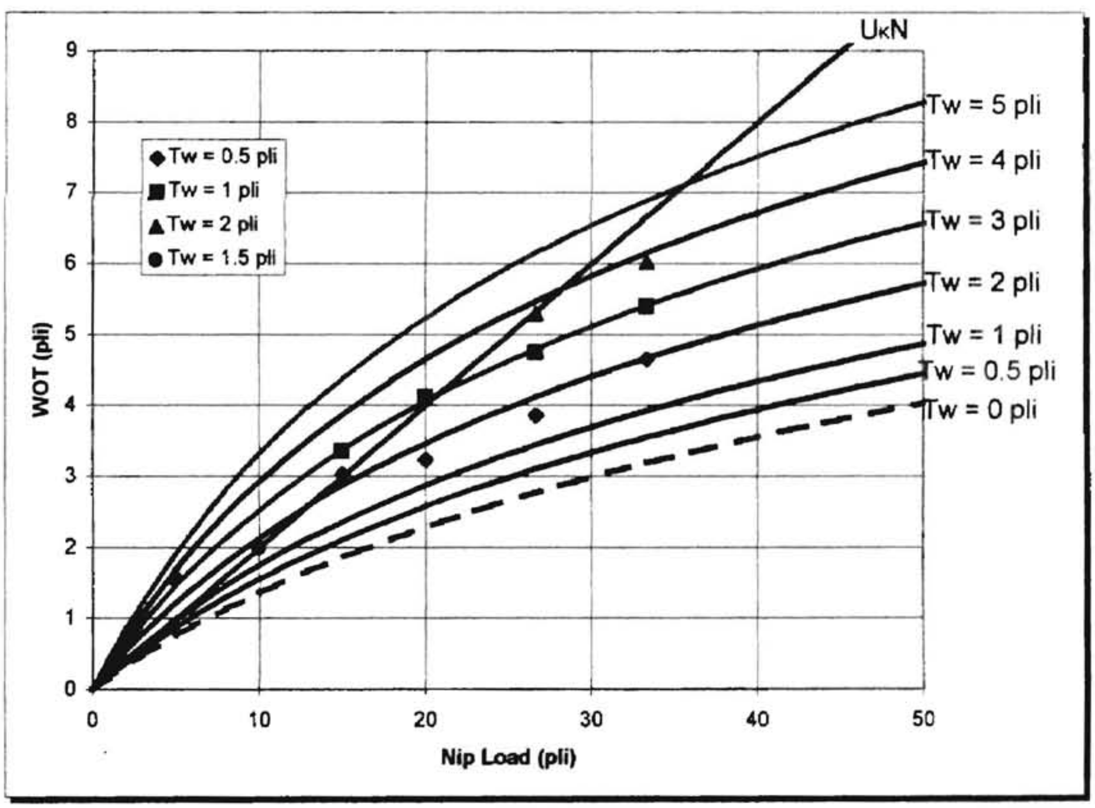

Figure 15: Wound-on-tension

At higher nip loads, the WOT becomes less than that prescribed by {5} and is dependent on the web line tension, as seen earlier by Pfeiffer. Although the data do not exactly coincide, it is difficult to make an exact comparison to Pfeiffer's curves as the kinetic coefficient of friction of his newsprint is not recorded. In addition, Pfeiffer used a nip roller of 13.46 inches in diameter compared to the 6 inch diameter used during these tests. The diameter difference could be another reason for the difference in the curves that Pfeiffer established and the experimental data taken in this study. Again, the important feature of the WOT data from this work is that it supports the claims previously made that at lower nip loads expression {5} is applicable while at higher nip loads the WOT becomes dependent on the web line tension, for unknown reasons.

All pull tab data which were collected for the various winding trials are given in Appendix A.

J-Line Printer

As discussed in the experimental procedure, two types of J-lines were used to detect interlayer slippage in the wound rolls. Trends that were noted were that the J-lines were typically quite deformed for cases in which the nip loads were low, see Figure 16, and that, at higher nip loads, the printed lines were almost radial, indicating little or no slippage, see Figure 17. This may well be one of the most important finds of this study as the indications are that at low nip loads a good deal of slippage is occurring within the roll while at high nip loads hardly any slippage is visible. This reinforces what was found in the WOT studies. At lower nip loads, the WOT tension is well modeled with expression {5}, which shows that the WOT is limited by the kinetic friction capacity between the first and second layers in the wound roll. Thus, the WOT must initially be higher than that proposed in expression {5} as the web first contacts the wound roll, but slippage occurs within the wound roll and the WOT reduces to the level which can be supported by friction{5}. At higher nip loads, the WOT must decrease to a level less than that given by {5} prior to contacting the winding roll, as relatively little slippage occurs within the wound roll. This, again, is reflected in the WOT data which as Pfeiffer's data shows a WOT dependent on web line tension but less than what is predicted by expression {5}.

All J-line data which was collected for the various winding trials are given in Appendix B.

Velocity of Nip vs. Wound Roll

At the higher nip loads, the J-line data have been indicative of little or no slippage within the wound roll. WOT data at the higher nip loads were less than predicted by expression {5} which is also indicative that slippage should not occur within the wound roll. Both Pfeiffer's WOT data and WOT data from this study (refer to Figure 15) indicate that at higher nip loads the web line tension seems to be directly related to WOT (i.e. an increase in web line tension of 1 pli. yields a 1 pli. increase in WOT). This aroused curiosity whether the nip was traveling at a different velocity than the web.

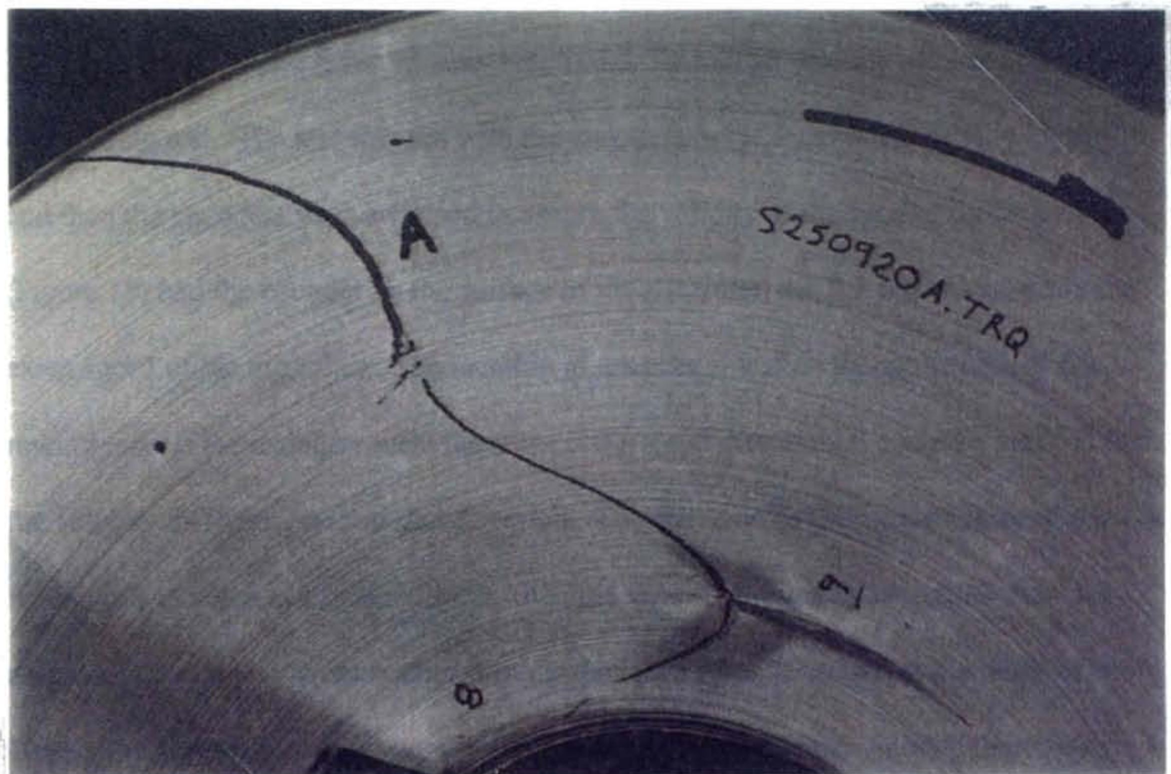

Figure 16: J-Line for a Low Nip Load Winding Condition

2.5 inch nip roller 1.5 pli. web line tension 3.33 pli. nip load

Figure 17: J-Line for a High Nip Load Winding Condition

8 inch nip roller, 2 pli. web line tension, 10 pli. nip load

The results of these tests indicate there is a difference in velocity between the nip and the winding roll. The test was run with the encoders in the locations shown in Figure 18 and then the encoders were swapped to ensure the validity of the results. Location A (Figure 18) had the encoder on the surface of the nip roller, not the web, to measure the exact speed of the nip roller. The location of encoder B is directly on the web of the rewind roll. If the encoders went the same differential direction, it could be verified that the velocity difference was in that direction. The encoders for both cases showed that the wound roll traveled at a faster velocity than the nip roller. Figures 19 and 20 show the results of these tests. What is interesting is that both plots show that at nip loads of about 10 pli., the periphery of the wound roll begins traveling at greater velocity than the nip. At nip loads less than 10 pli. there are mixed results, one case showing nip velocities in excess of the wound roll velocity and the second showing nearly identical velocities.

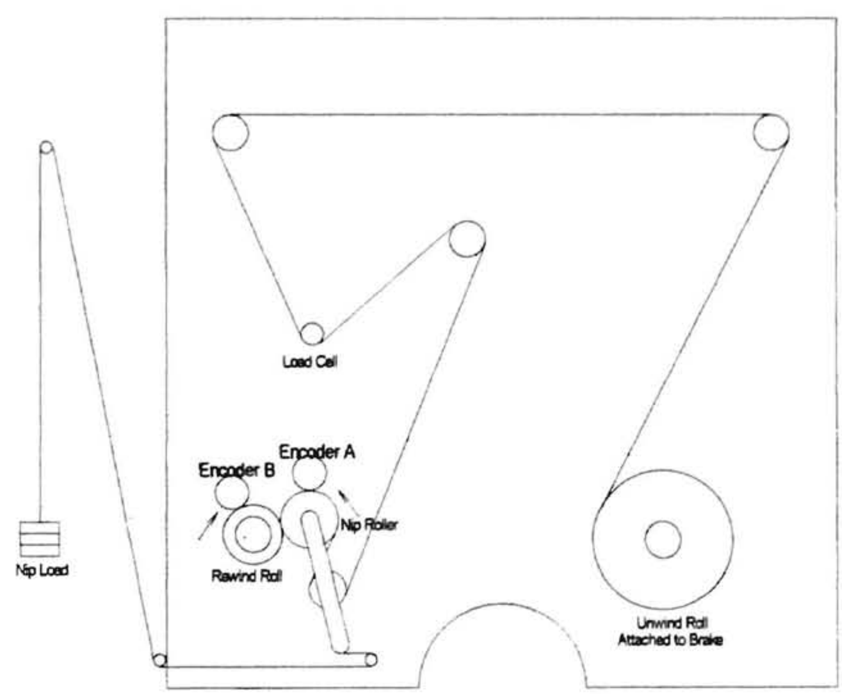

Figure 18: Location of the Encoders

Predicting Wound-on-Tension by Velocity differences

Wound-on-tension may be able to be evaluated from a velocity differential between the rewound roll and the nip roller. In web lines, an increase in velocity results in an increase in strain in the web.

The wound-on-tension is predicted from the velocity difference by using the following equation.

$$WOT = \frac{V_R - V_N}{V} E_t \qquad \{7\}$$

Tw	nip roll diameter	Nip Load variable	velocity constant linear	material
1 pli	6 inches	2 - 33.33 pli	50 ft/min	newsprint

Table 6: Winding conditions for velocity difference Experiments.

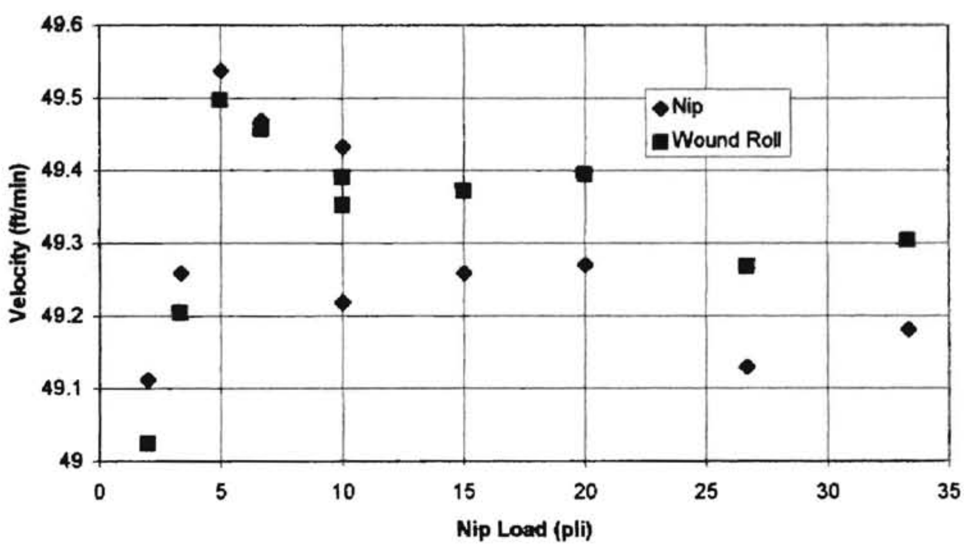

Figure 19 -Results of Velocity Tests - Encoders as shown in Figure 18

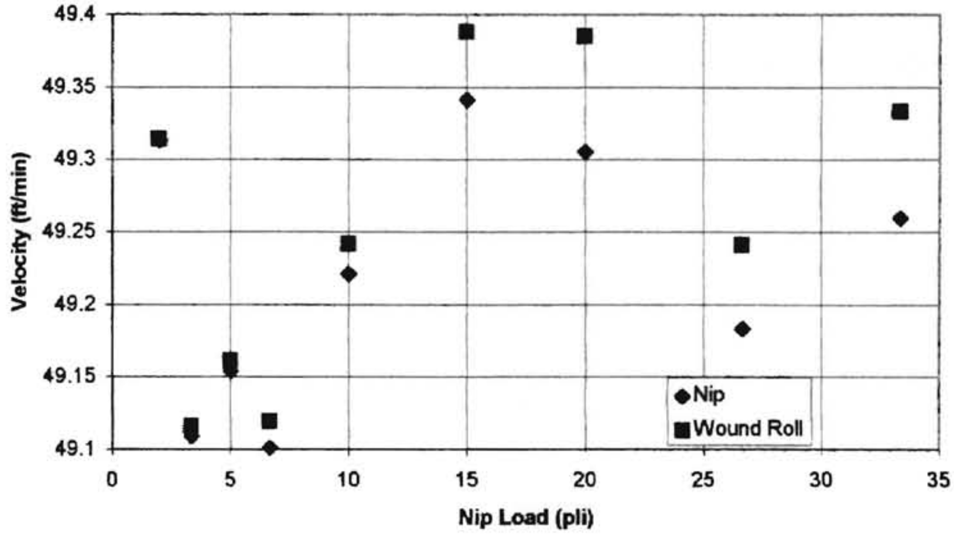

Figure 20 - Results of Velocity Tests - Encoders Swapped in Locations

Where V_R = Velocity of the rewind roll
V_N = Velocity of the nip roller
V = is the average velocity of the nip and the roller
E_t = is the Tangential modulus of elasticity

As seen in Figure 21 , the results from the two velocity experiments produced encloses the curve introduced by Pfeiffer. This may be an accurate method of predicting wound-on-tension. The tests performed were done by hand picking out 20 separate points and averaging the points. Even though the data seem accurate and repeatable this was not included in the main finding since the investigation was not taken further due to time constraints. To get an extremely accurate evaluation of the small velocity difference, a computer should be employed so a larger number of points can be evaluated. The data do seem accurate, due to the fact that even reversing the encoders the data still read in the same direction with respect to wound-on-tension. After reversing the encoders, the velocity changes are reading in the same directional range which shows the velocity difference is valid and should be investigated further. If expression {7} is valid it needs some modification for the web line tension.

$$\mathbf{WOT} = \frac{V_R - V_N}{V_N} E_t + T_w$$

$$\textbf{but if WOT} \geq \frac{\mu_k N}{h} \qquad \{8\}$$

$$\textbf{then WOT} = \frac{\mu_k N}{h}$$

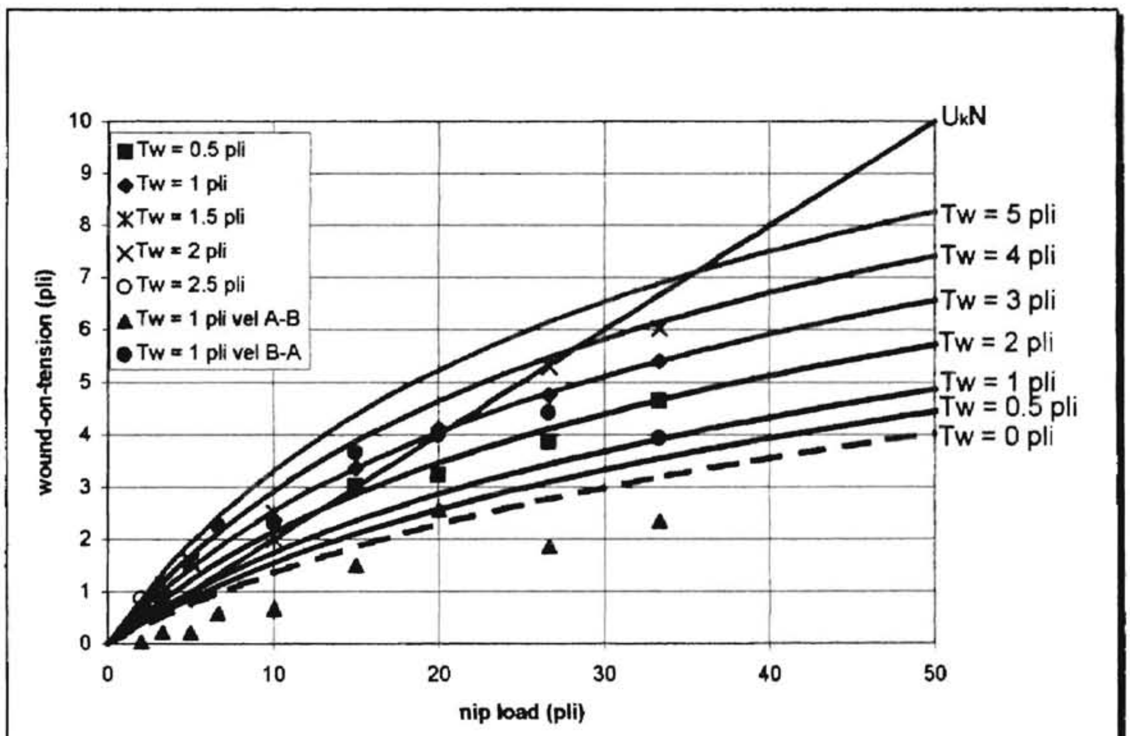

Figure 21: Wound-on-tension calculated from velocity differences.

Chapter 5

Conclusions

- It has been verified that the WOT in surface winding does, in fact, behave as previous authors have published. The WOT expression {5} reported by Vijayarangan [10] has been found to be valid at low nip loads. At high nip loading a WOT less than that given by expression {5} has been found similar to that reported by Pfeiffer [3] and shown in Figure 15.
- It has been found that the winding torque cannot be related to WOT in surface winding, as is possible when center winding without a rider roll. The torque due to web line tension and the torque due to rolling resistance are measurable using this technique.
- Measurements of interlayer slippage using two J-Line methods have shown that at low nip loads, a good deal of interlayer slippage occurs within the wound roll. At higher nip loads, above 10 pli for newsprint, the slippage ceases to occur showing that the WOT has decreased to values less than that given by expression {5}.
- Velocity measurements have shown that at higher nip loads, above 10 pli. for newsprint, the wound roll velocity becomes larger than the nip velocity. Preliminary results indicate that the differential velocity is reliable to WOT.

Future Work

The velocity difference between the web and the surface driven nip should be studied further upon to evaluate the accuracy of the velocity difference in calculating wound-on-tension. The winder should be reconfigured similar to Pfeiffer's WIT-WOT as it looks to be an accurate and expedient method for determining wound-on-tension.

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(10) Vijayarangan, T., "A Study on Nip Mechanics in Surface Winding", M. S. Thesis, Oklahoma State University, Stillwater, OK. Dec. 1996.

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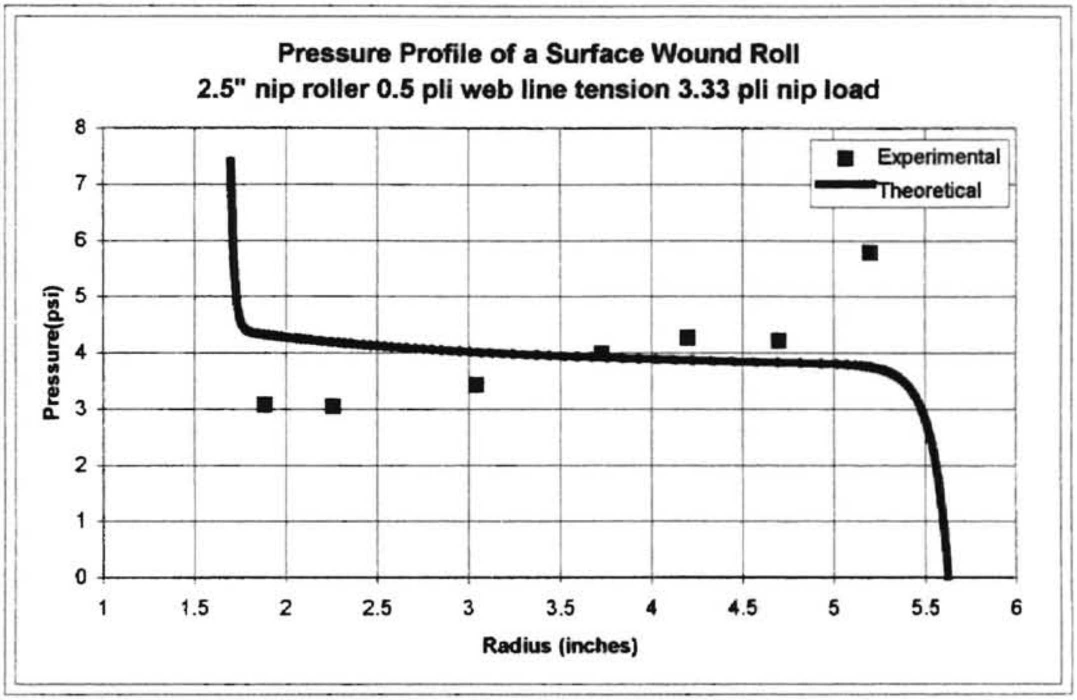
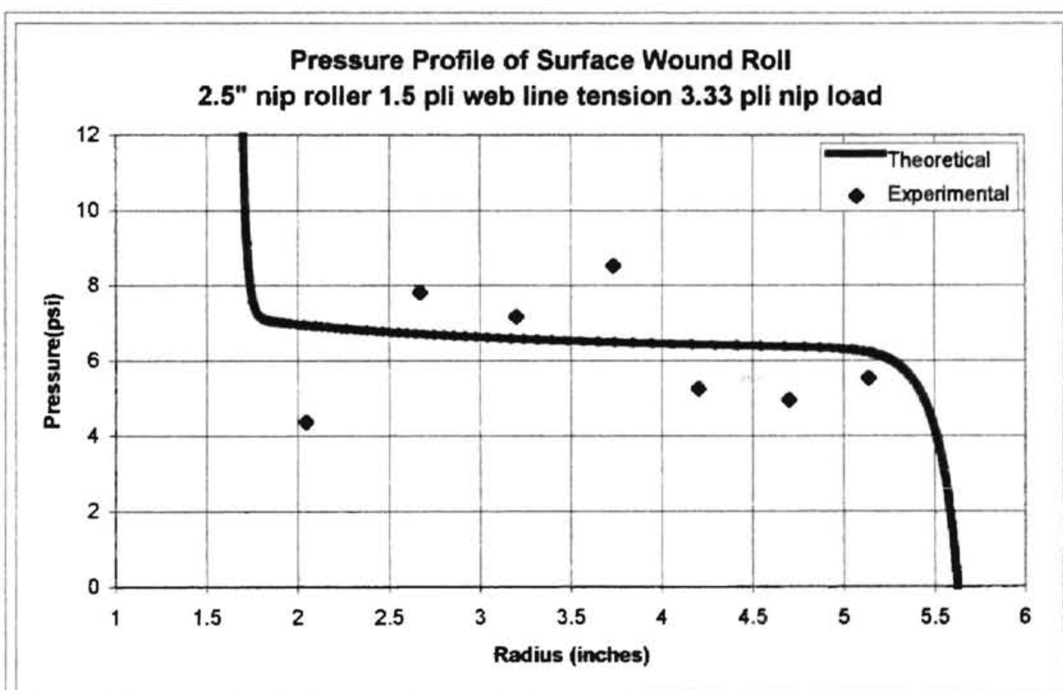
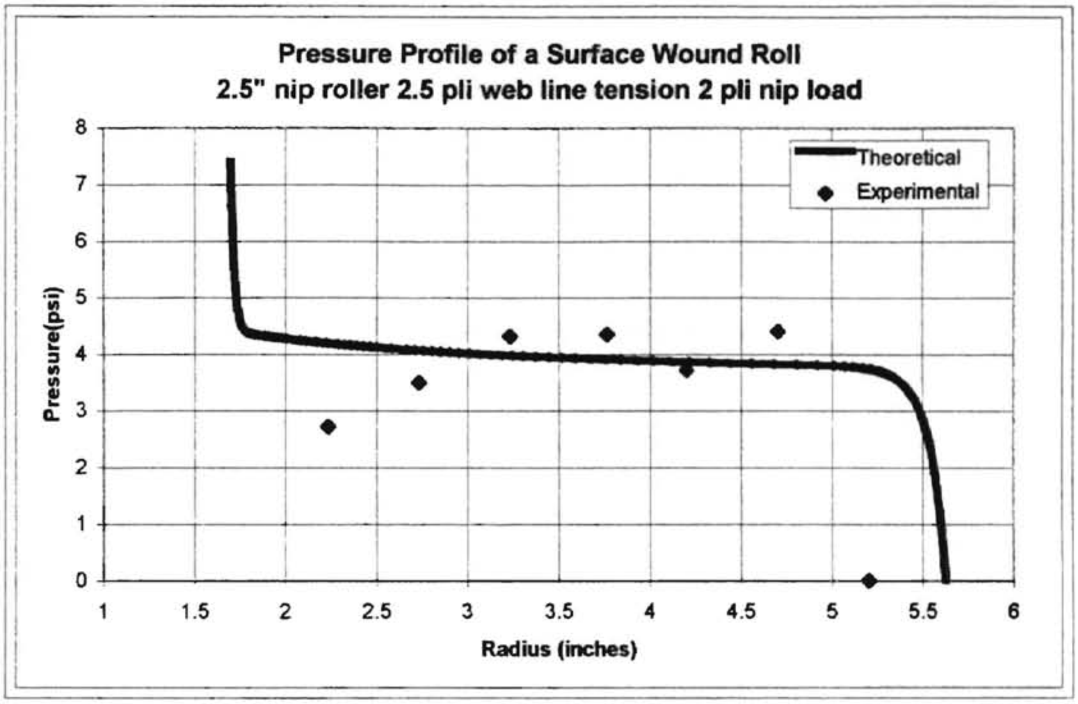
(15) Pfeiffer, J.D., "Relative Motion between Web and Winder Drum at the Nip and the Effect of Additional Torque," Advances and Trends in Winding Technology, published by the Swedish Newsprint Research Center, 1987, pp. 39-51.

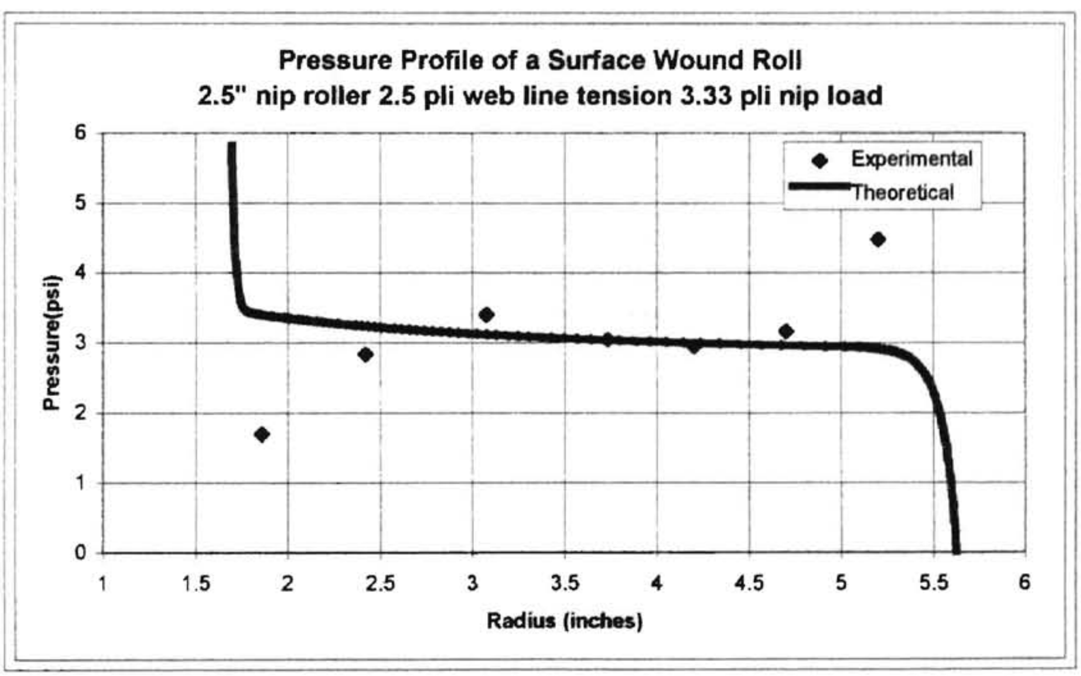
(16) Vaidyanathan, N., "A Study on Wound Roll Slippage," Ph.D. dissertation, Oklahoma State University, Stillwater, OK. June 1996.

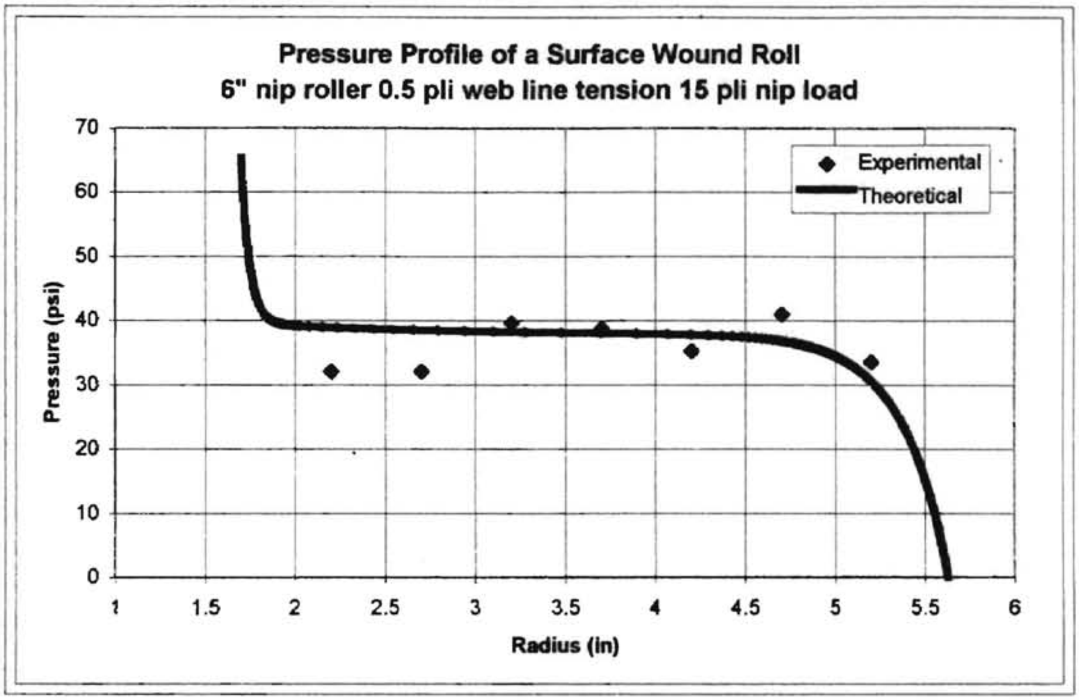
Appendix A

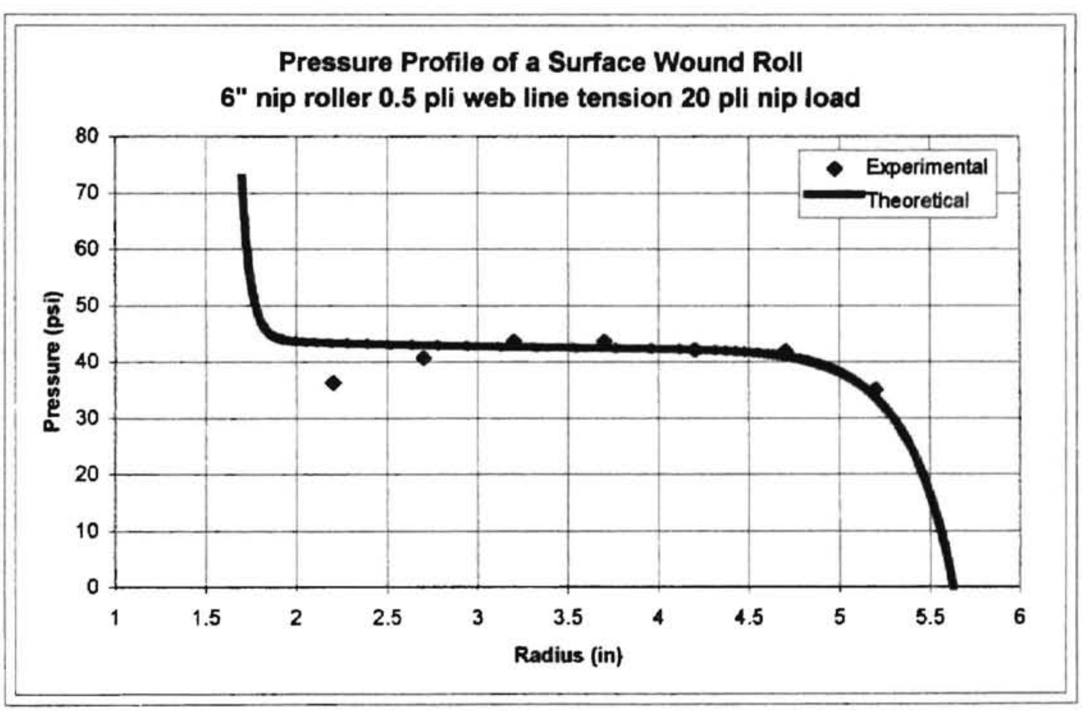

Pressure Profile of a Surface Wound Roll
2.5" nip roller 0.5 pli web line tension 3.33 pli nip load
Experimental
Theoretical
Pressure(psi)
0
1
2
3
4
5
6
7
8
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
Radius (inches)

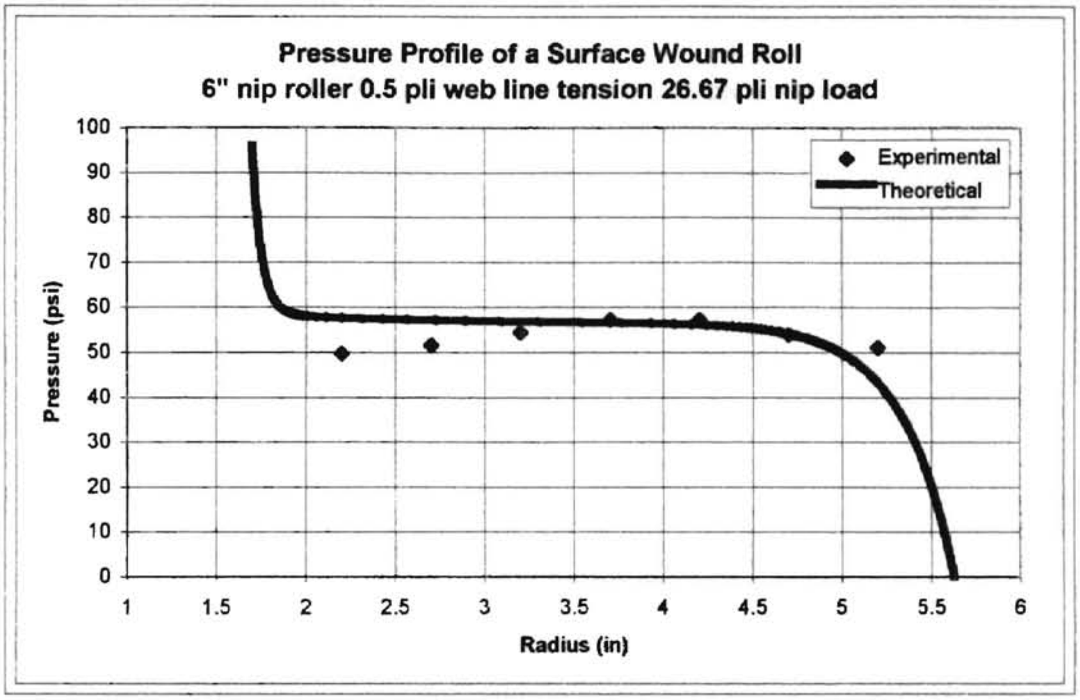

Pressure Profile of Surface Wound Roll
2.5" nip roller 1.5 pli web line tension 3.33 pli nip load
Theoretical
Experimental
Pressure(psi)
0
2
4
6
8
10
12
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
Radius (inches)


Pressure Profile of a Surface Wound Roll
2.5" nip roller 2.5 pli web line tension 2 pli nip load
Theoretical
Experimental
Pressure(psi)
Radius (inches)
0
1
2
3
4
5
6
7
8
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6


Pressure Profile of a Surface Wound Roll
2.5" nip roller 2.5 pli web line tension 3.33 pli nip load
Experimental
Theoretical
Pressure(psi)
Radius (inches)
0
1
2
3
4
5
6
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6


Pressure Profile of a Surface Wound Roll
6" nip roller 0.5 pli web line tension 15 pli nip load
Experimental
Theoretical
Pressure (psi)
Radius (in)
70
60
50
40
30
20
10
0
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6


Pressure Profile of a Surface Wound Roll
6" nip roller 0.5 pli web line tension 20 pli nip load
Experimental
Theoretical
Pressure (psi)
Radius (in)
80
70
60
50
40
30
20
10
0
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6


Pressure Profile of a Surface Wound Roll
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Experimental
Theoretical
Pressure (psi)
Radius (in)
100
90
80
70
60
50
40
30
20
10
0
1
1.5
2
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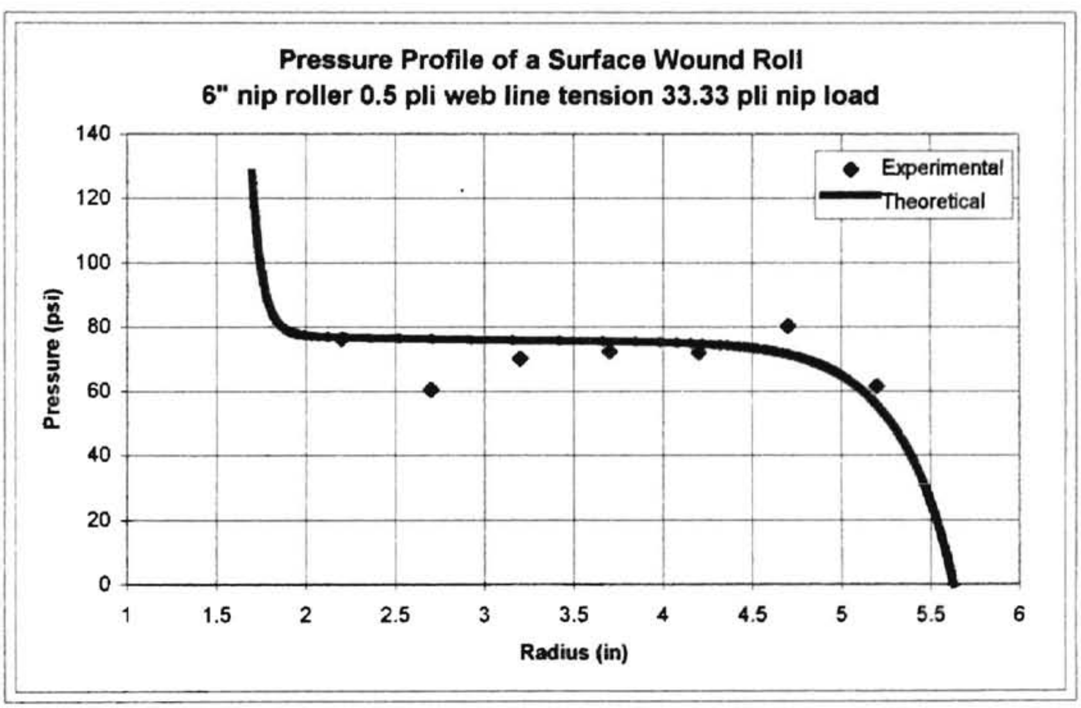
3
3.5
4
4.5
5
5.5
6


Pressure Profile of a Surface Wound Roll
6" nip roller 0.5 pli web line tension 33.33 pli nip load
Experimental
Theoretical
Pressure (psi)
Radius (in)
140
120
100
80
60
40
20
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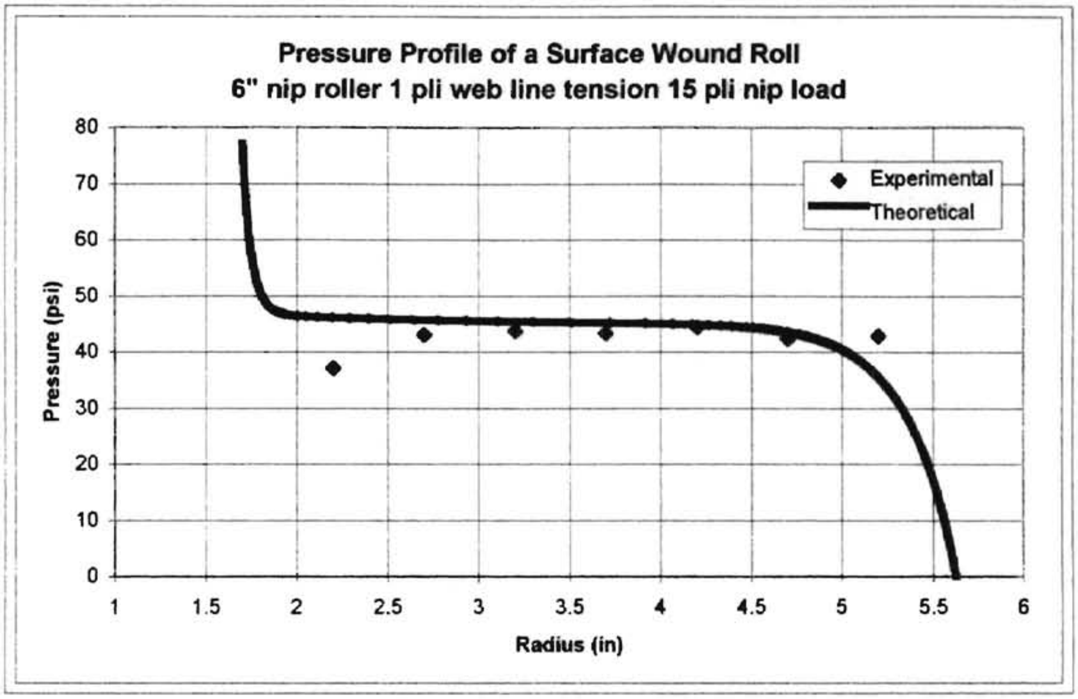
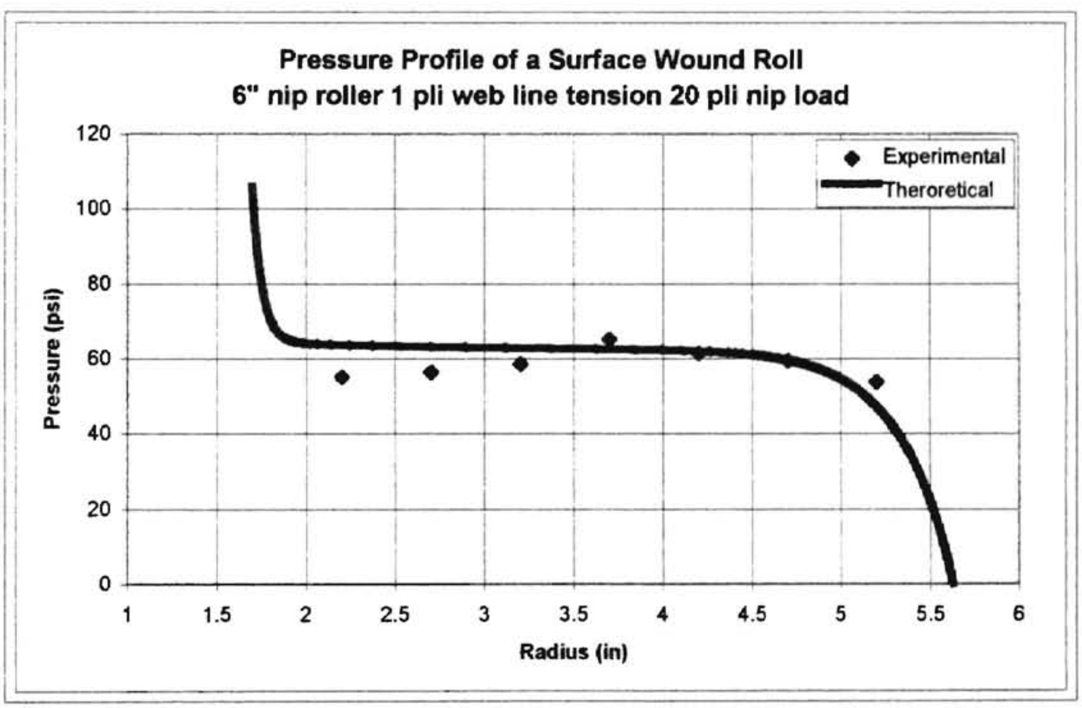
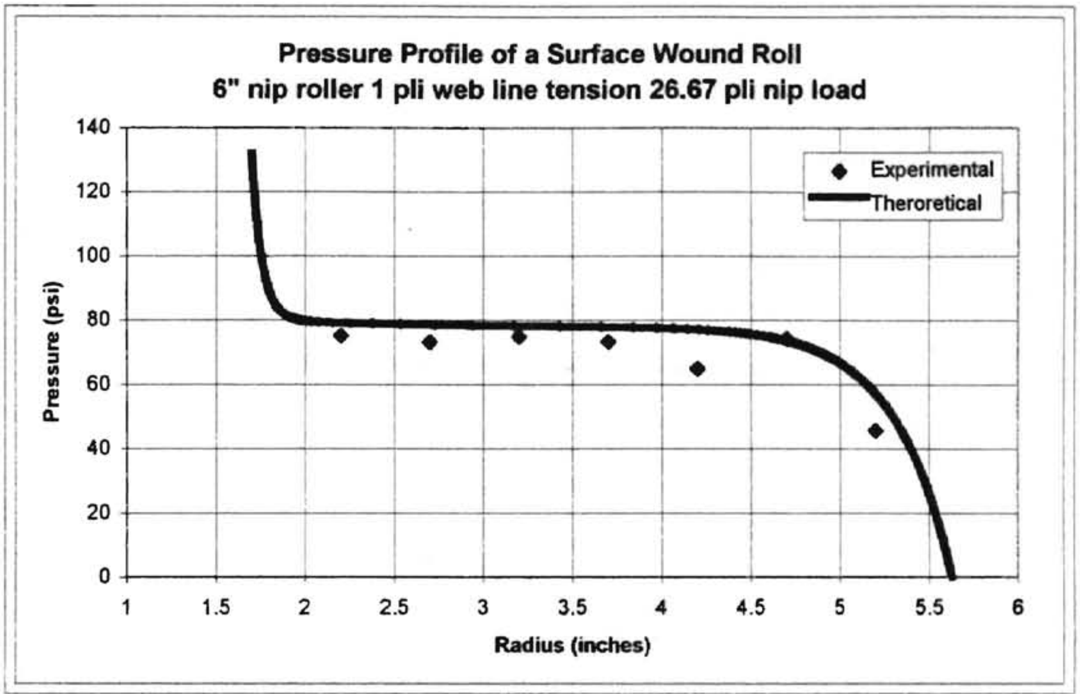
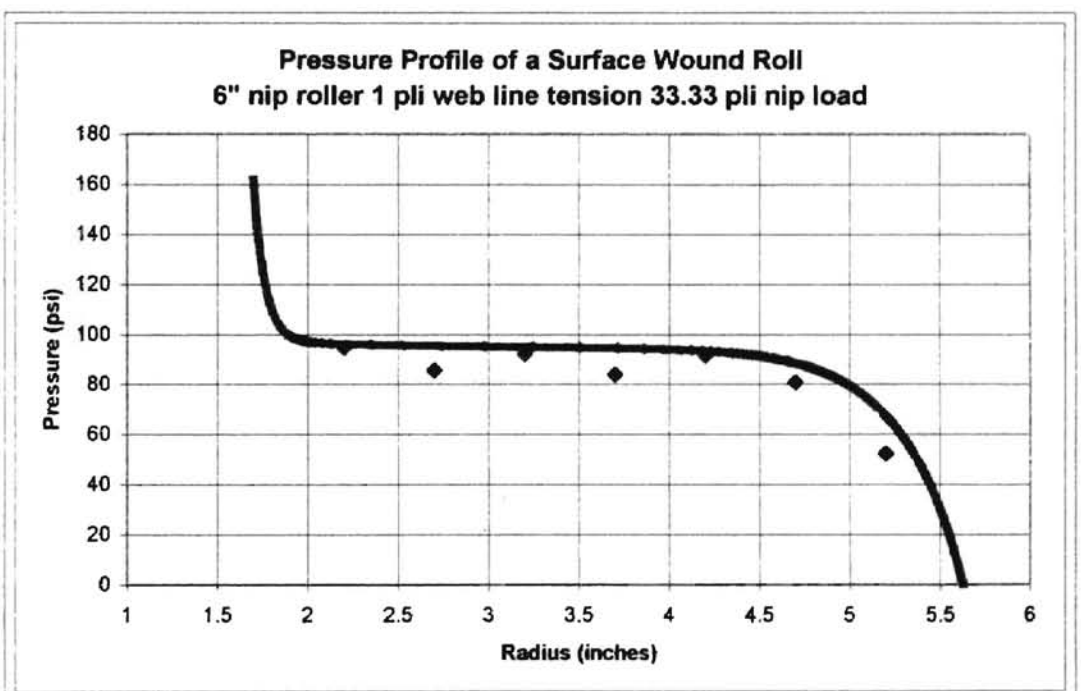
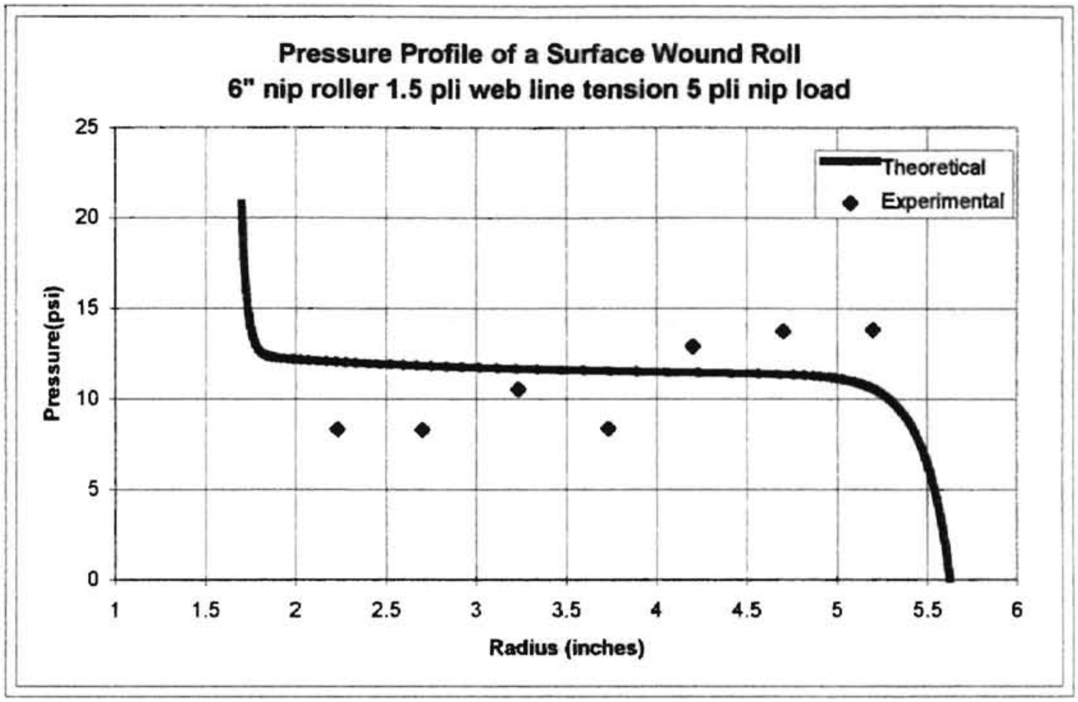
4.5
5
5.5
6

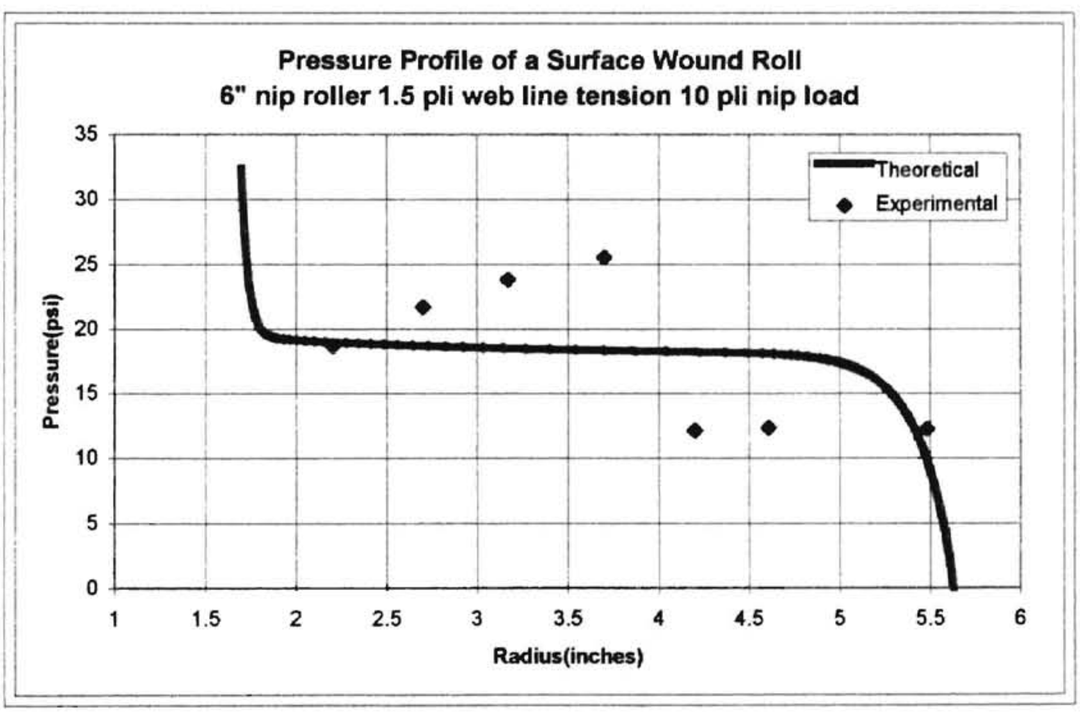

Pressure Profile of a Surface Wound Roll
6" nip roller 1 pli web line tension 15 pli nip load
Pressure (psi)
Radius (in)
Experimental
Theoretical


Pressure Profile of a Surface Wound Roll
6" nip roller 1 pli web line tension 20 pli nip load
Pressure (psi)
Radius (in)
Experimental
Theroretical


Pressure Profile of a Surface Wound Roll
6" nip roller 1 pli web line tension 26.67 pli nip load
Pressure (psi)
140
120
100
80
60
40
20
0
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
Radius (inches)
Experimental
Theroretical


Pressure Profile of a Surface Wound Roll
6" nip roller 1 pli web line tension 33.33 pli nip load
Pressure (psi)
180
160
140
120
100
80
60
40
20
0
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
Radius (inches)


Pressure Profile of a Surface Wound Roll
6" nip roller 1.5 pli web line tension 5 pli nip load
Pressure(psi)
Radius (inches)
Theoretical
Experimental
0
5
10
15
20
25
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6


Pressure Profile of a Surface Wound Roll
6" nip roller 1.5 pli web line tension 10 pli nip load
Pressure(psi)
Radius(inches)
Theoretical
Experimental
0
5
10
15
20
25
30
35
1
1.5
2
2.5
3
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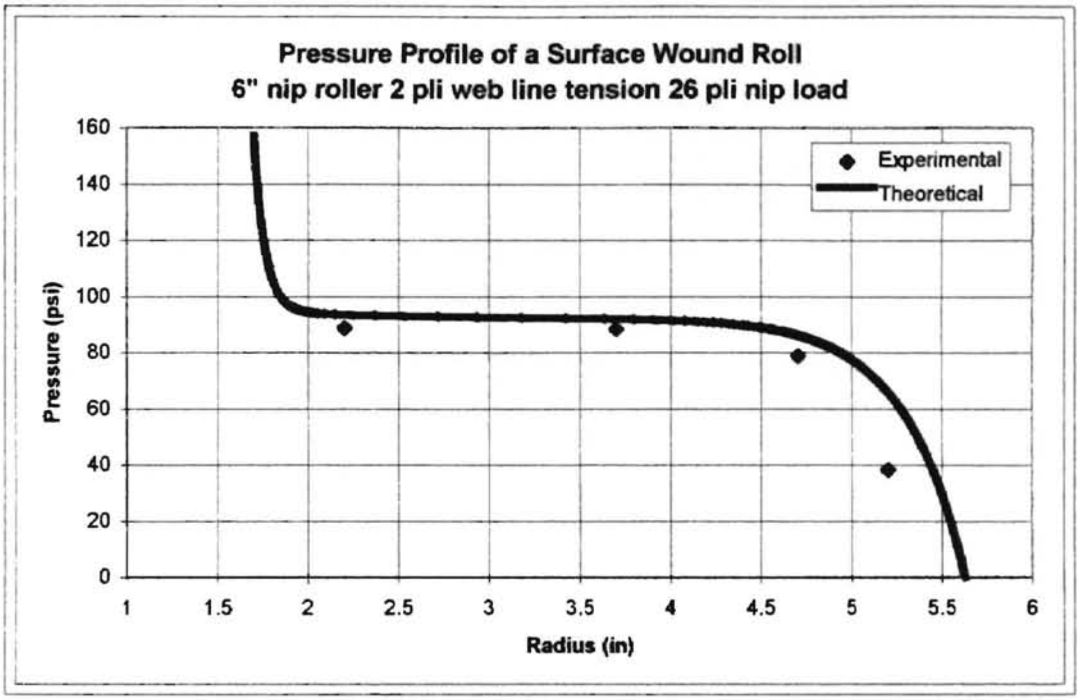
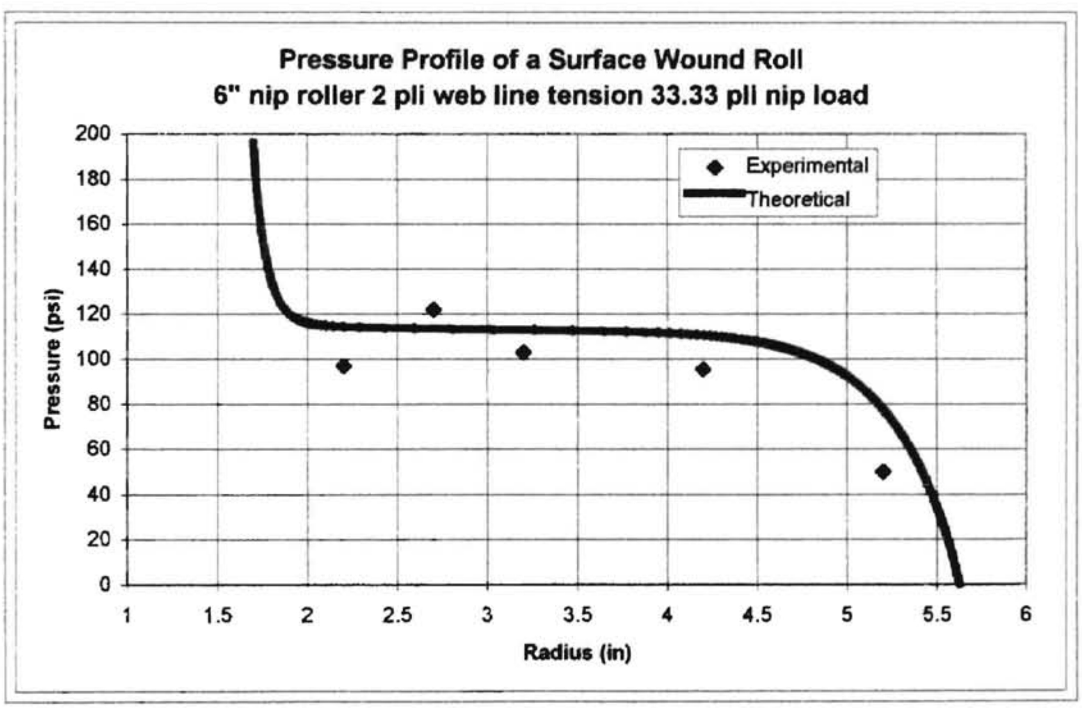
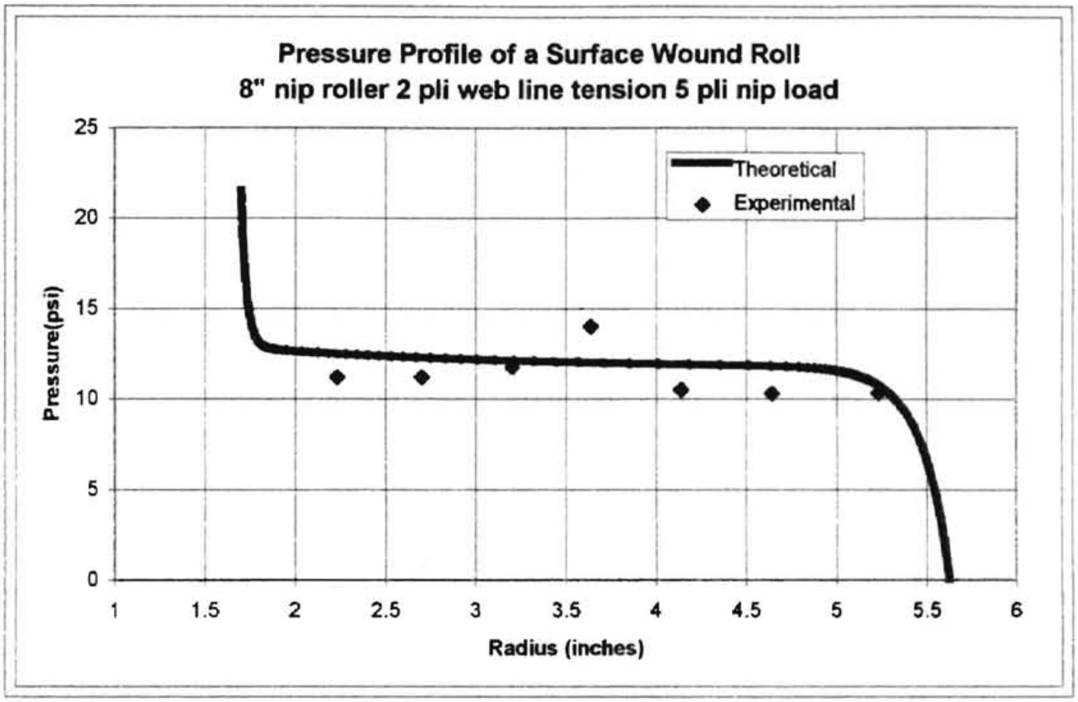
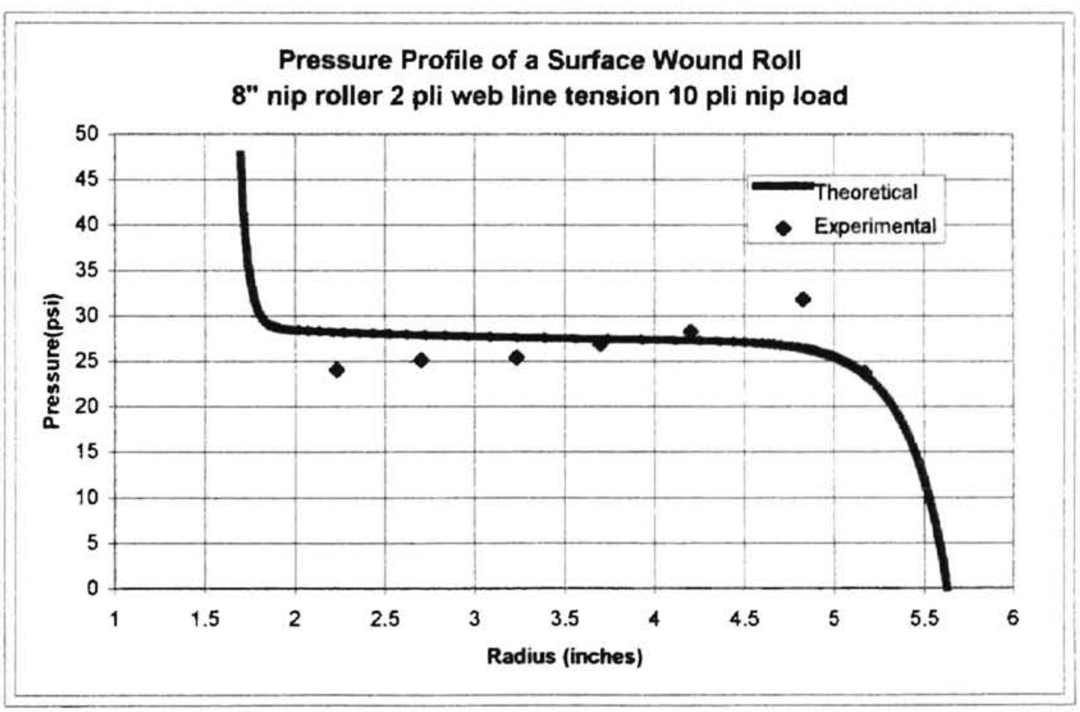
4
4.5
5
5.5
6

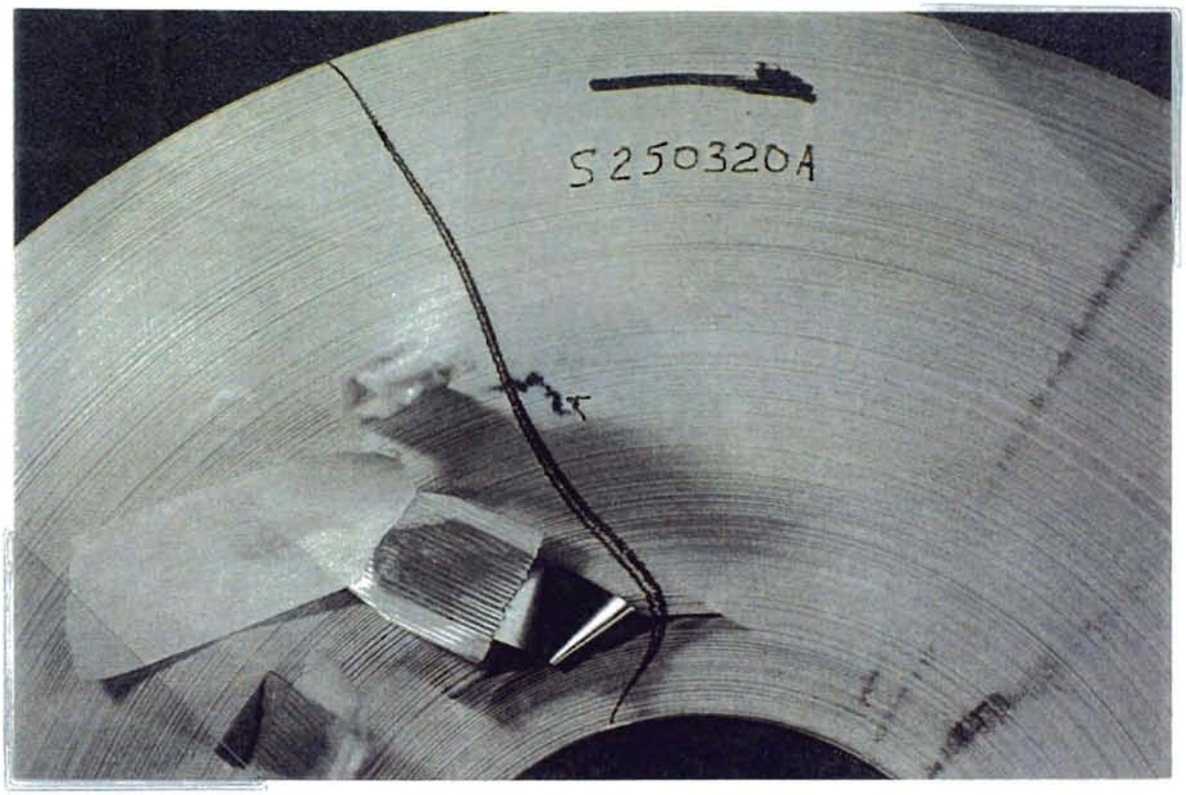

Pressure Profile of a Surface Wound Roll
6" nip roller 2 pli web line tension 26 pli nip load
Pressure (psi)
160
140
120
100
80
60
40
20
0
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
Radius (in)
Experimental
Theoretical


Pressure Profile of a Surface Wound Roll
6" nip roller 2 pli web line tension 33.33 pli nip load
Pressure (psi)
200
180
160
140
120
100
80
60
40
20
0
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
Radius (in)
Experimental
Theoretical


Pressure Profile of a Surface Wound Roll
8" nip roller 2 pli web line tension 5 pli nip load
Theoretical
Experimental
Pressure(psi)
25
20
15
10
5
0
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
Radius (inches)


Pressure Profile of a Surface Wound Roll
8" nip roller 2 pli web line tension 10 pli nip load
Theoretical
Experimental
Pressure(psi)
50
45
40
35
30
25
20
15
10
5
0
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
Radius (inches)

Appendix B



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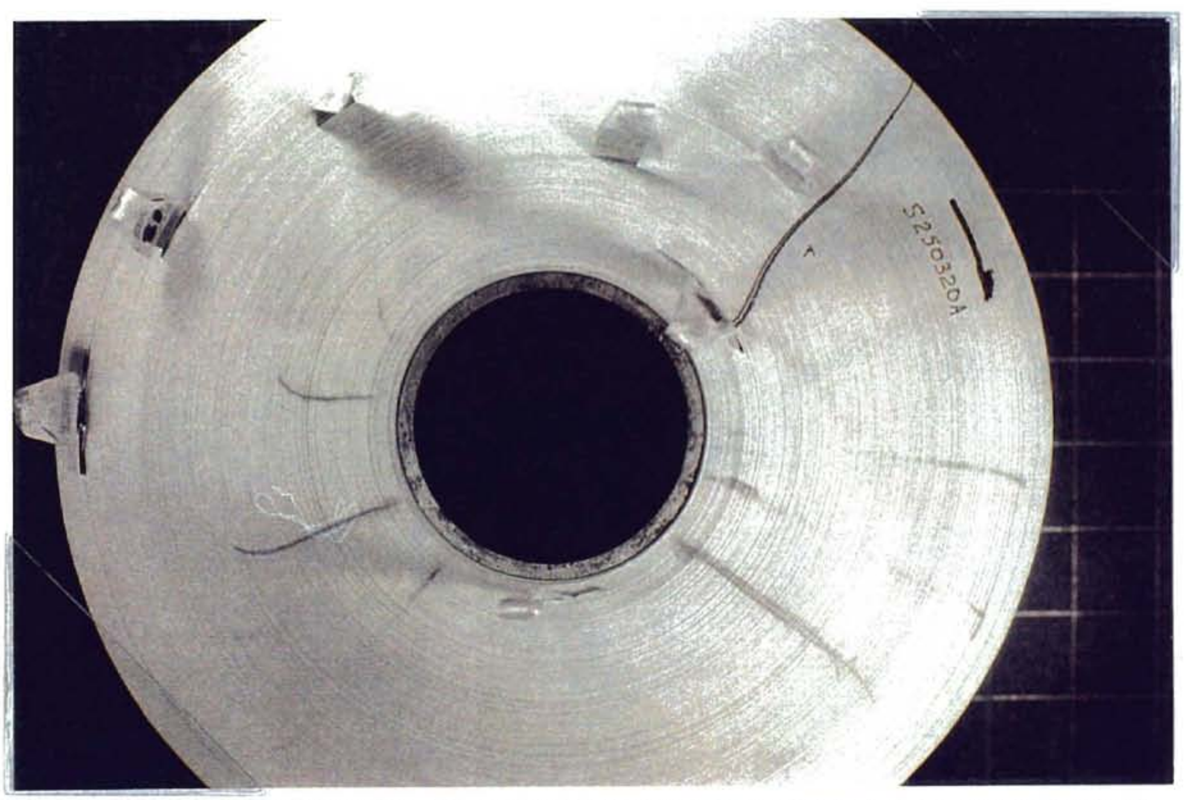

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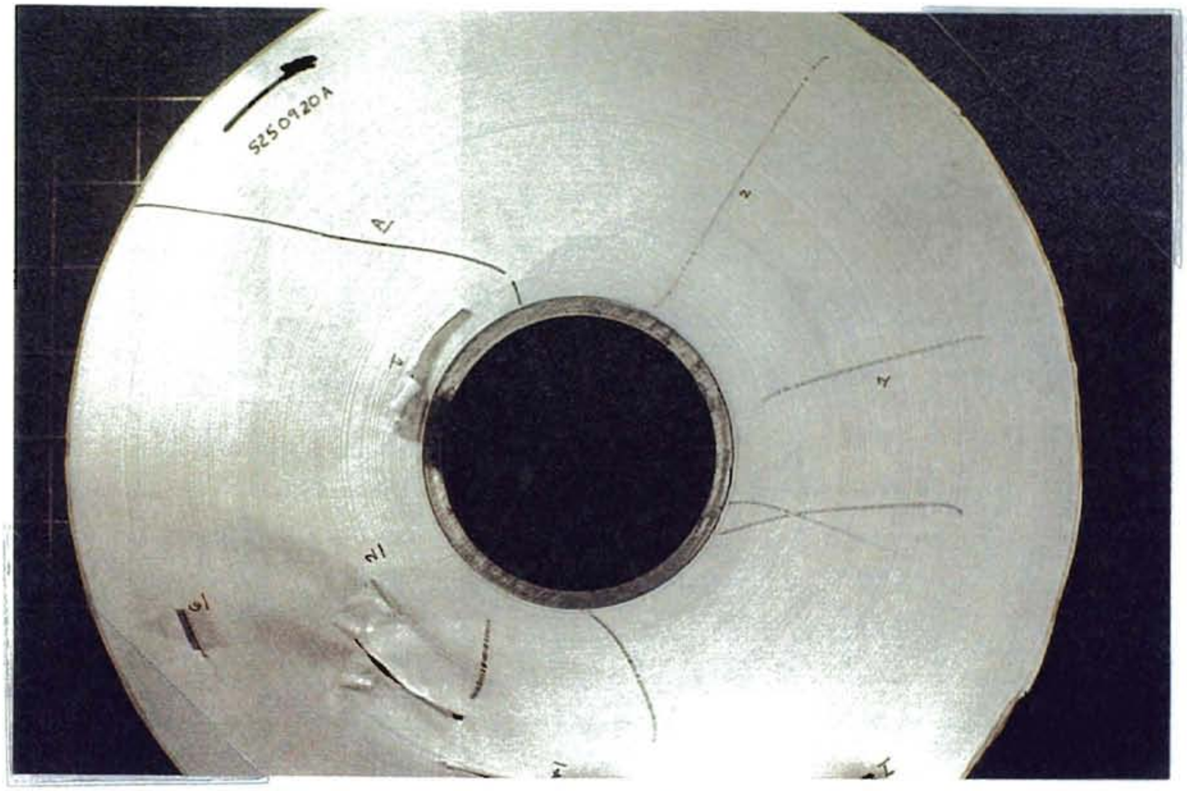
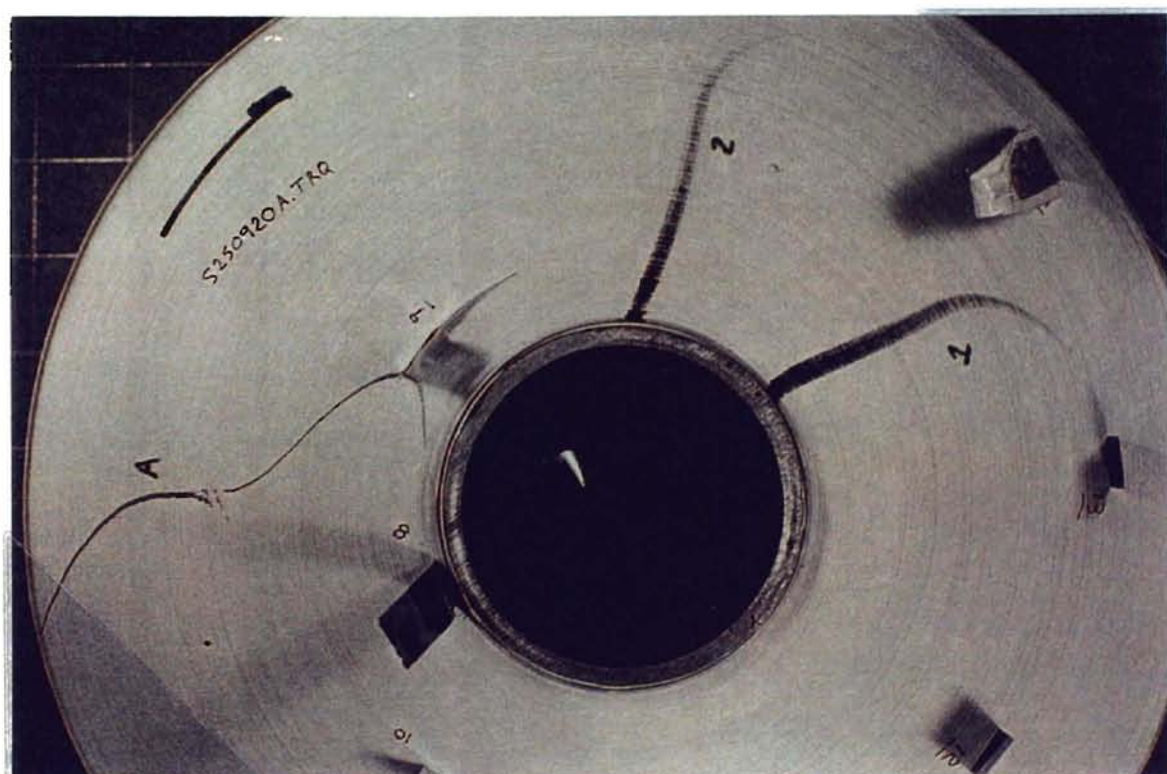
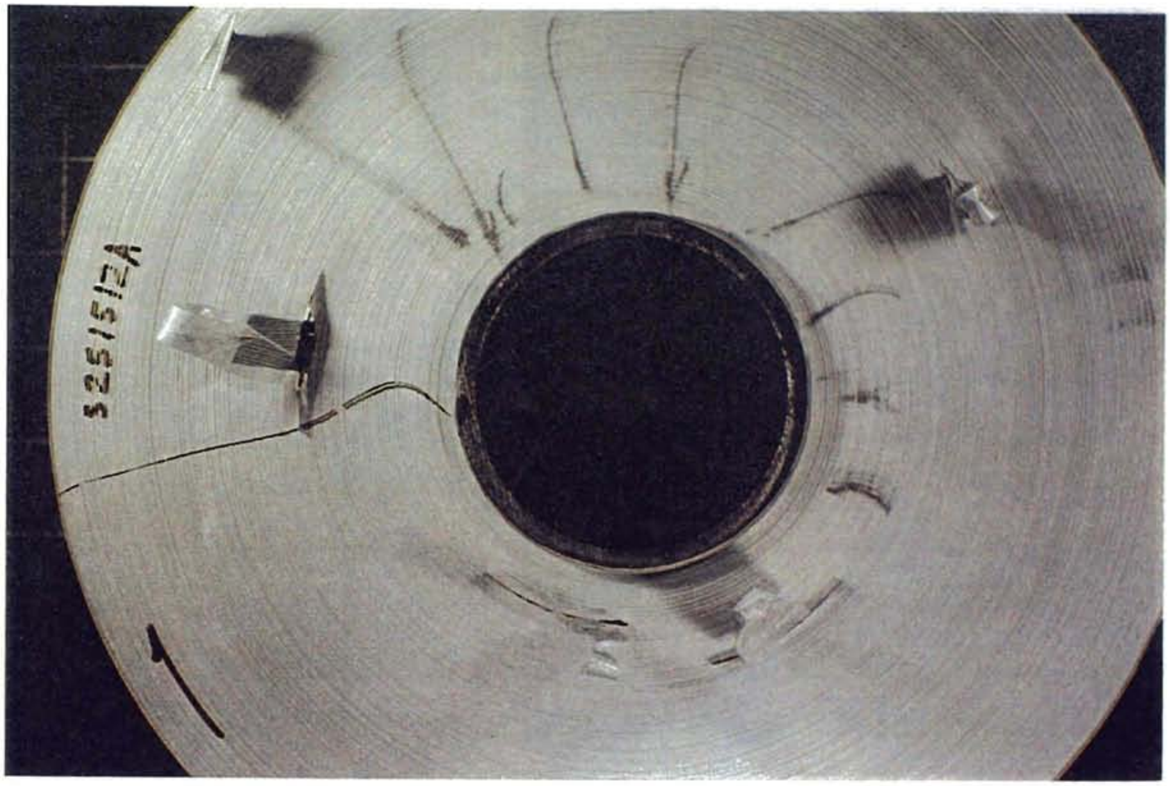


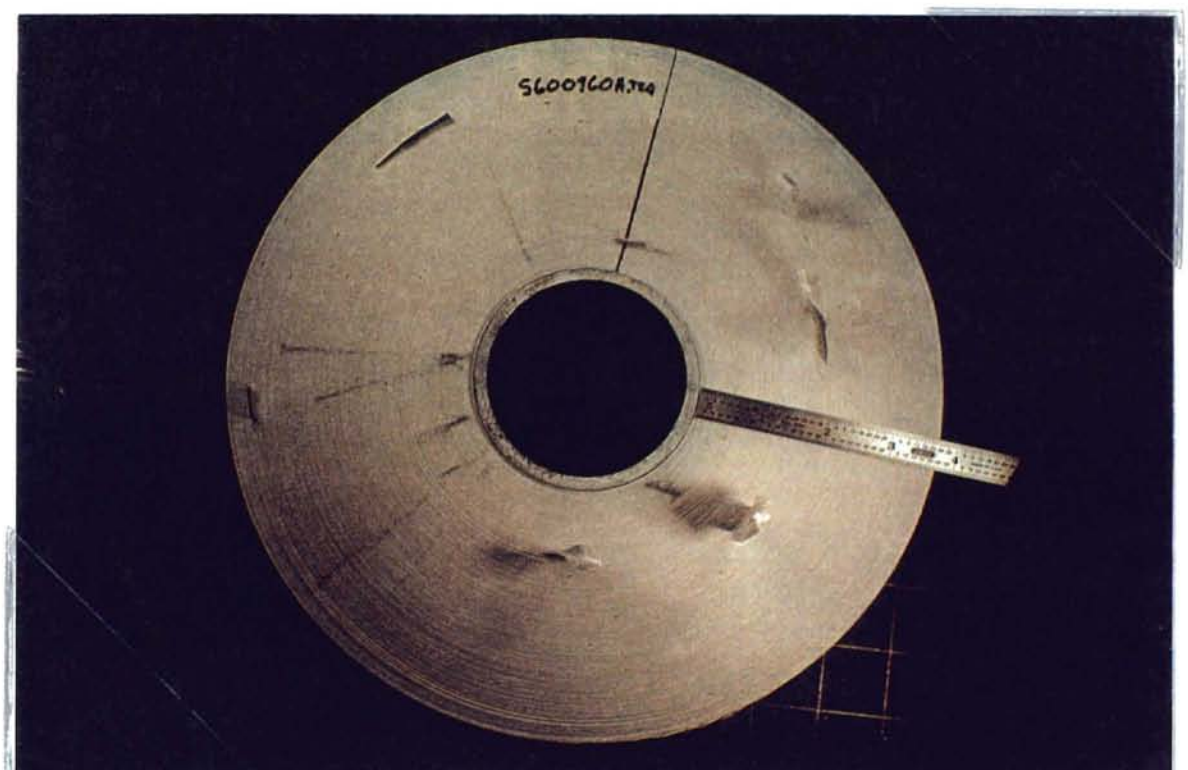
J-LINES 2.5 INCH NIP ROLLER, 1.5 PLI WEB LINE TENSION, 3.33 PLI NIP LOAD



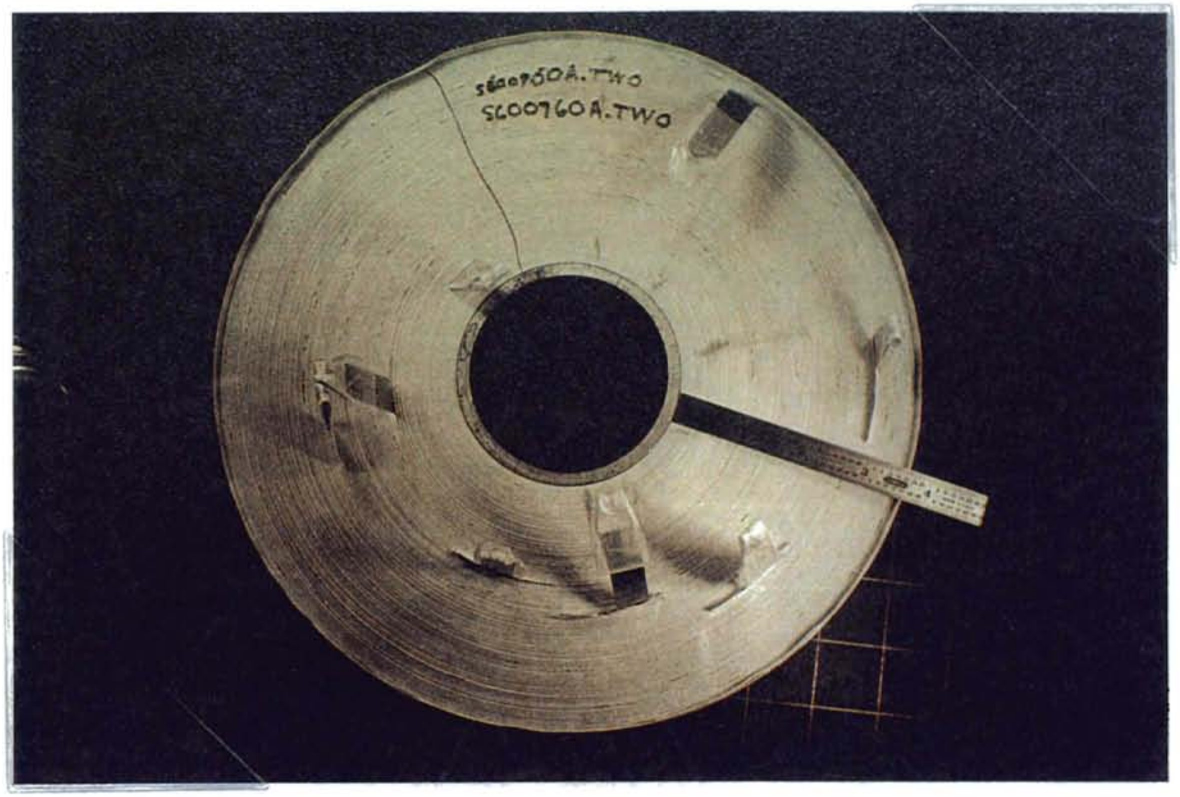
J-LINES 2.5 INCH NIP ROLLER, 1.5 PLI WEB LINE TENSION, 3.33 PLI NIP LOAD



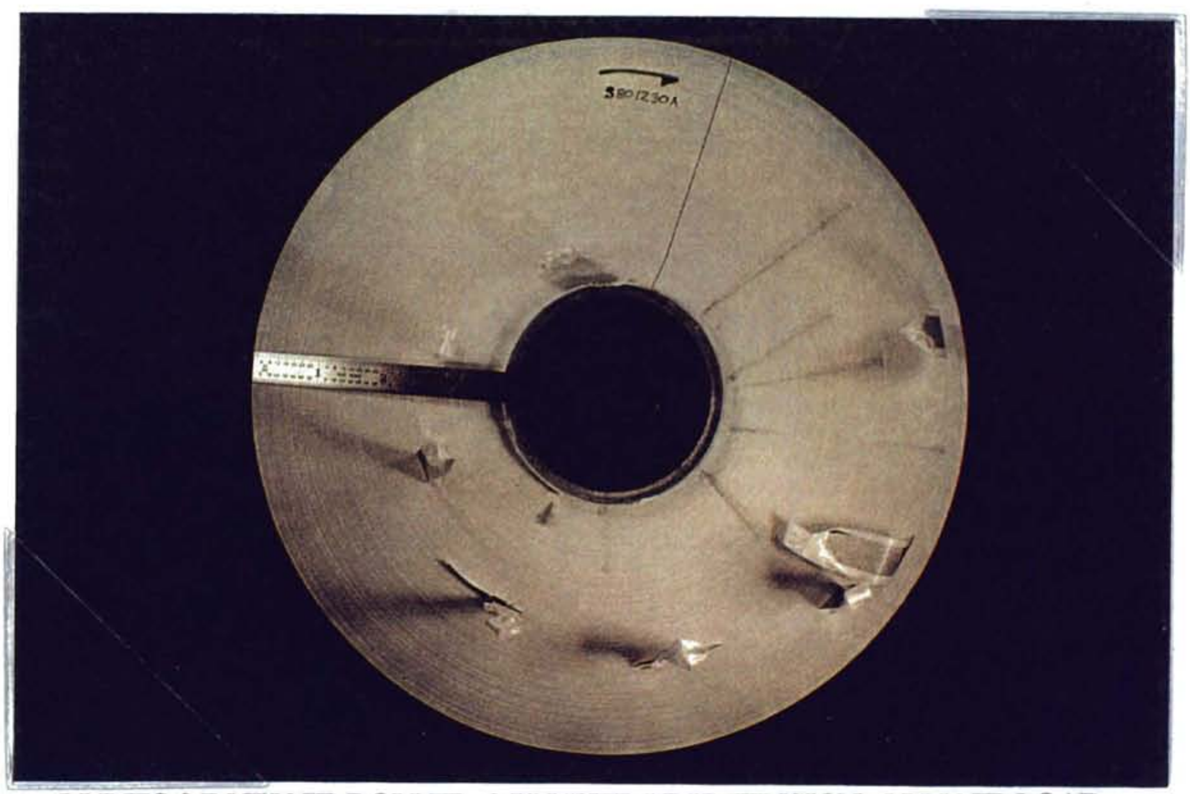
J-LINES 2.5 INCH NIP ROLLER, 2.5 PLI WEB LINE TENSION, 2 PLI NIP LOAD



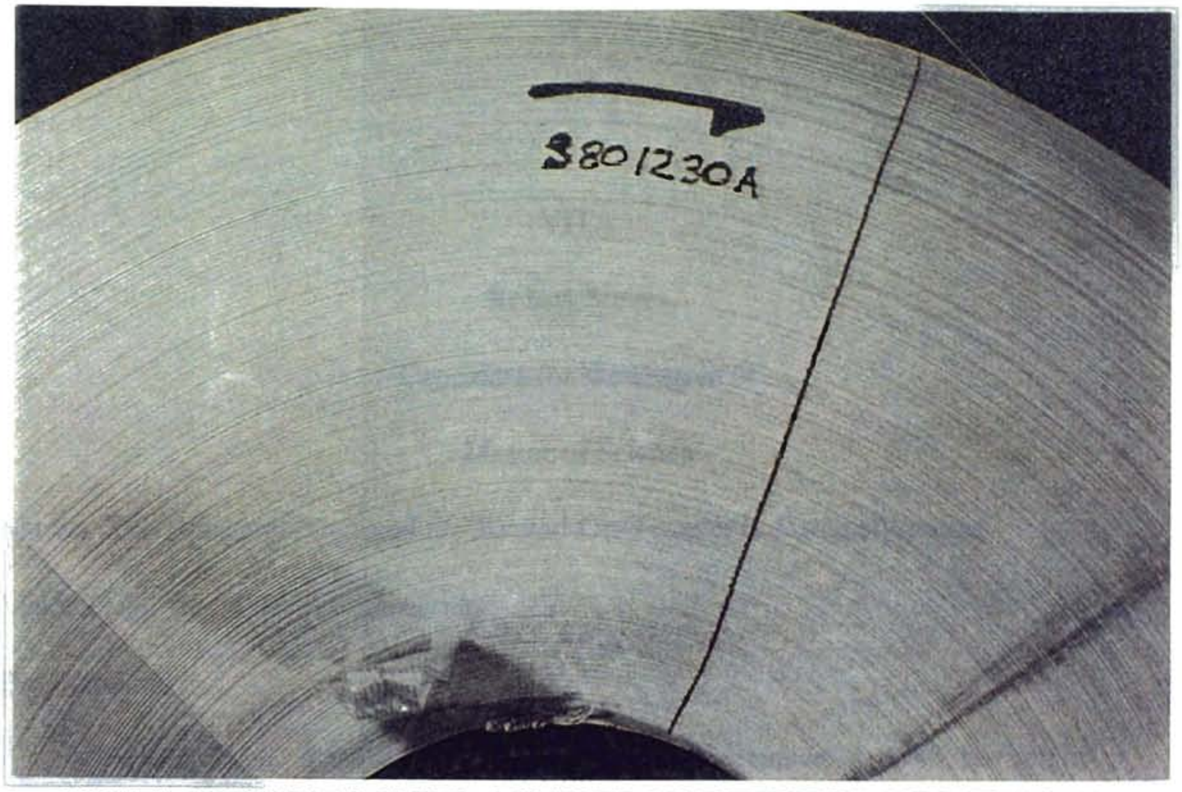
J-LINES 6 INCH NIP ROLLER, 1.5 PLI WEB LINE TENSION, 10 PLI NIP LOAD



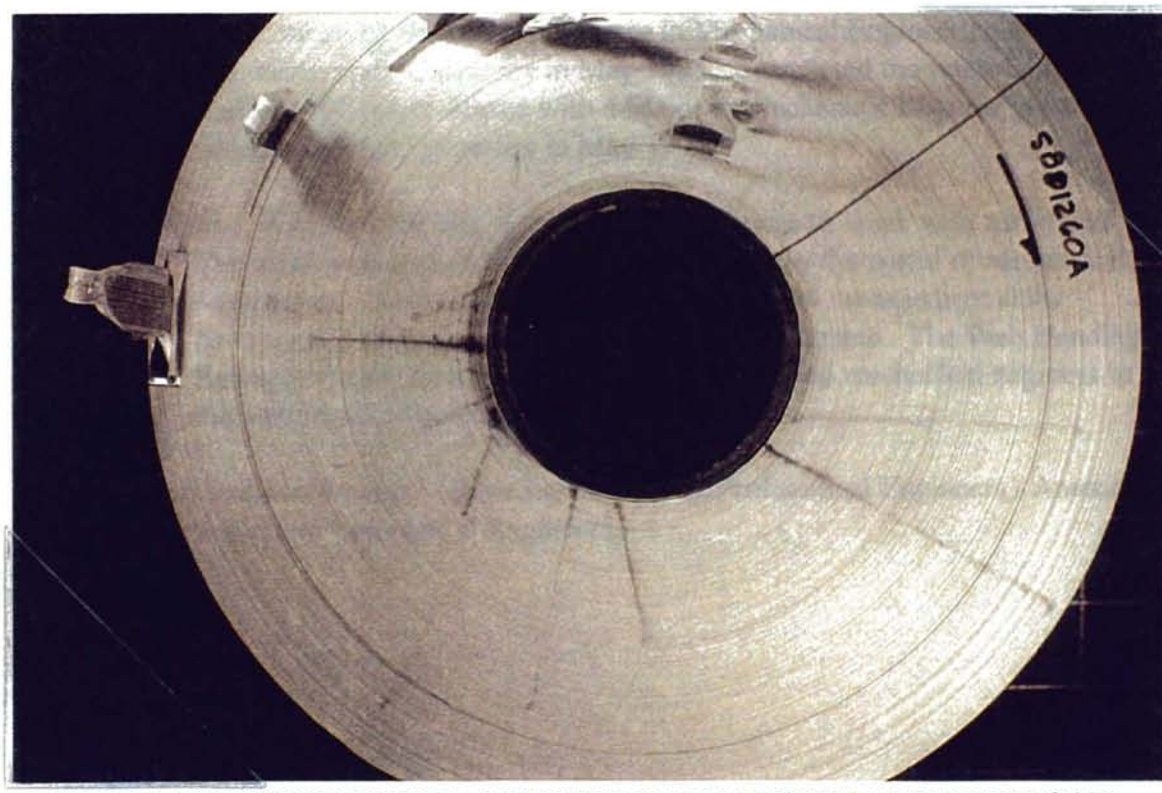
J-LINES 6 INCH NIP ROLLER, 1.5 PLI WEB LINE TENSION, 10 PLI NIP LOAD



J-LINES 8 INCH NIP ROLLER, 2 PLI WEB LINE TENSION, 5 PLI NIP LOAD



J-LINES 8 INCH NIP ROLLER, 2 PLI WEB LINE TENSION, 5 PLI NIP LOAD


J-LINES 8 INCH NIP ROLLER, 2 PLI WEB LINE TENSION, 10 PLI NIP LOAD

VITA

Robert Steves

Candidate for the Degree of

Master of Science

Thesis. The Effects of Nip Load On Wound-On-Tension In Surface Winding

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Personal Data. Born in Tulsa, Oklahoma, On September 23, 1968, the son of Heinz and Mary Steves.

Education: Graduated from Memorial High School, Tulsa, Oklahoma in May 1987; received Bachelor of Science in Mechanical Engineering from Oklahoma State University in May 1995. Completed the requirements for Masters of Science degree with a Major in Mechanical Engineering at Oklahoma State University in May 1997

Experience: Raised in the city, I had many experiences to work with automobiles. The work with automobiles gave me insight into the world of mechanical engineering. This experience was embraced with management skills developed while working in various jobs of leadership. The Web Handling Research Center molded me into the well rounded mechanical engineer in the web handling processes.

Professional Membership. American Society of Professional Engineers, American Society of Mechanical Engineers.