EFFECTS OF NIP ROLLERS AND THREAD PATH ON TWO-DRUM WINDING

By

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TABLE OF CONTENTS

Chapter | Page

Chapter Page

LIST OF TABLES

Table Page

Table Page

LIST OF FIGURES

Figure Page

NOMENCLATURE

hp	horsepower
in	inches
in-lbs	inch-pounds
lbs	pounds
Nip Load	force applied to the winding roll
NIT	nip-induced-tension
Torque 1	torque applied to drum 1 by motor 1
Torque 2	torque applied to drum 2 by motor 2
Unwind Tension	tension of the web coming off of the unwinder
WOT	wound-on-tension
WOT 1	wound-on-tension recorded by the first force gage
WOT 2	wound-on-tension recorded by the second force gage
WOT PT	wound-on-tension recorded by pull-tabs

CHAPTER 1

INTRODUCTION

Over 100,000 winders are in use in the U.S. alone. These range from 40 to 400 inches in width and 24 to 84 inches on a finished roll diameter. Winders roll various materials including textiles, rubbers, steel, paper, nonwovens, film/foil laminates, countertops, wallpapers, and carpets[1]. These are continuous winders. Every time the winder is down due to maintenance, changeovers, or repairs, profits are lost.

Another item that causes a loss in profits is roll quality. If the wound roll is no good, it either has to be re-wound or scrapped. Many "bad" rolls can cause a substantial loss in profits. Also, it may be necessary to dispose of certain types of materials according to EPA regulations, which adds even more cost.

For a wound roll to be considered having high quality, it needs to have good edge quality (no ripped edges), adequate internal pressure to prevent internal slippage, tight starts, proper roundness (to avoid vibrations), absence of web defects, good web quality and good core quality. The internal pressures that are developed in winding rolls are influenced largely by the level of wound-on-tension (WOT) in the outer layer of a winding roll. For the purpose of this research, only the stress condition will be examined as determined by WOT.

The basic controllable mechanics of winding are the drives, brakes, drums, rollers, and tension controls that produce tension, nip, and torque. For good roll quality, these parameters can be adjusted until the desired quality is obtained.

Much research has been done to obtain the effects of altering these parameters, but they are not the same for each method of winding. The four main methods of winding are center winding, center winding with a nip, surface winding, and two-drum winding, all shown in Figure 1.

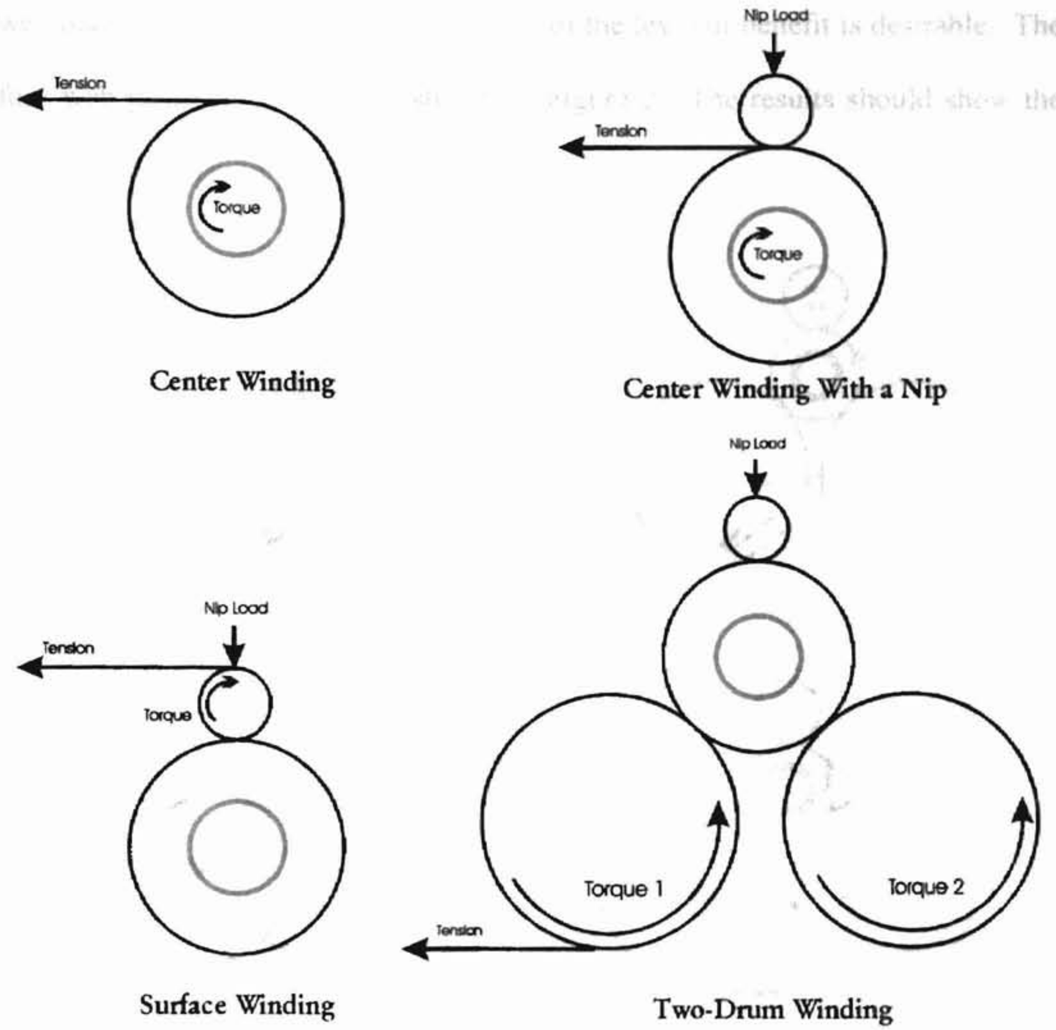

Figure 1—Different Types of Web Winding

In the two-drum winding specifically, the controllable parameters are web line tension, nip load, drum diameter, nip roller diameter, and the torque applied to each drum. Varying these parameters affects the WOT in the wound roll.

This research focuses on two different topics. The first is altering the web path, for it has been found in the field that certain web paths in the winder produce better quality rolls. Often it is difficult and/or expensive to modify the web path in a winder and thus knowledge of the level of benefit is desirable. The four web paths being used are shown in Figure 2. The results should show the effects each different path has on WOT.

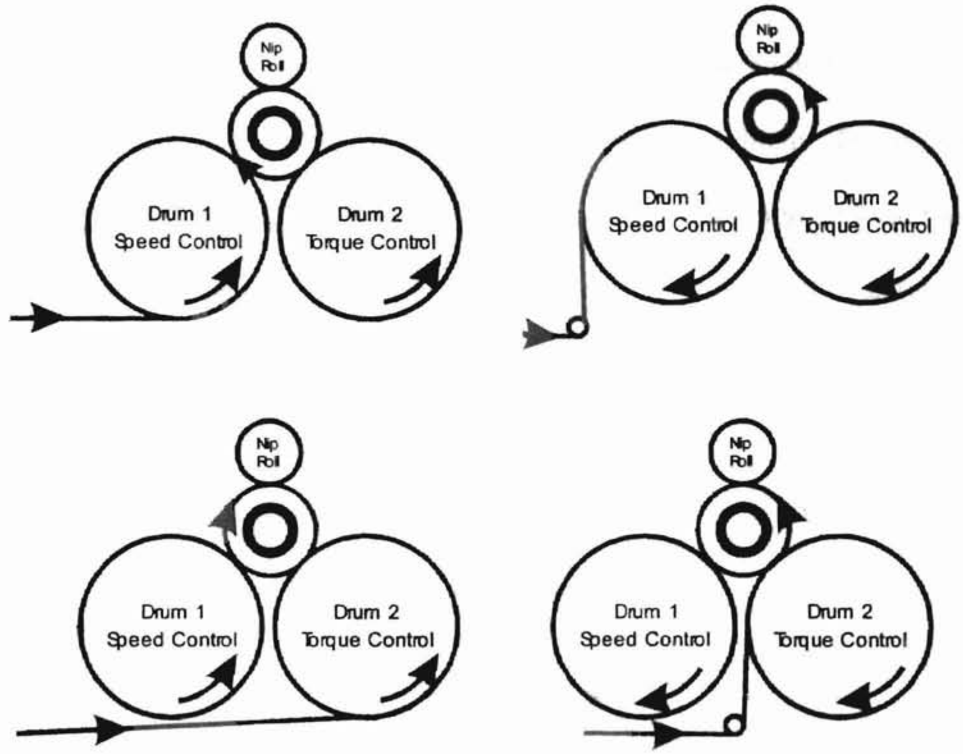

Figure 2—Four Different Web Paths

The second is to remove the nip roller. Results from previous research show that the WOT is greatly increased after passing under the nip roller. Almost all two-drum winders engage the nip roller to begin the winding process. At the start of winding, the wound roll weight is minimal and limits the WOT due to the inability to transfer the drum torque to increased tension in the web. When the wound roll nears its final diameter the roll weight has become near maximum and problems with web breaks become more frequent. Since the nip roller tends to tighten the web to yet higher tensions the load on the nip roller is diminished throughout the wind. In some winders the nip roller is retracted away from the roll surface, however in many cases it is left in position at a reduced load level to prevent the wound roll from escaping the winder as a safety precaution. In the WHRC winding laboratory the two-drum winder is not large enough to wind rolls large and heavy enough that web breaks might become a problem. To investigate how the WOT is affected when wound roll weights become high and the nip roll load is reduced, weights were added within the core and the nip roll was removed, as shown in Figure 3. The results should reveal a better understanding of each winding parameter's influence on the WOT in the absence of a nip roller. For this part of the research, the parameters to be varied are wound roll weight, input torques to the drums, and web line tension.

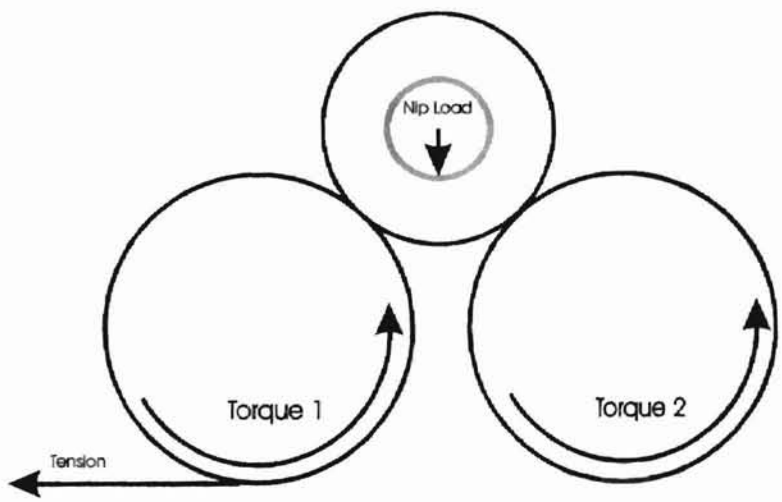

Figure 3—Setup After Removing Nip Roller

CHAPTER 2

LITERATURE REVIEW

Much work has been done on the analysis of web winding; however, very little is specifically dedicated to two-drum web winding.

The most accurate method in measuring wound roll internal pressures is through the use of pull-tabs. Monk, Lautner, and McMullen [2] first employed this method to measure radial pressures in rolls of cellophane. They placed nylon tabs in the rolls as they were being wound. After wound, the tabs were dislodged with a force gage. With a known coefficient of friction the radial pressures could be determined, inputting the force required to dislodge the gage.

Hakiel [3] developed the first orthotropic model with state dependent moduli for determining center-wound roll stress, which is based on a roll being considered as many concentric hoops rather than a spiral. Hakiel's model cannot account for nip-induced tensions that occur in winders that impinge rollers into the outer surfaces of the winding roll, such as a two-drum winder. It can however be used to infer the WOT produced in these winders if pressures are measured and the winding tension is varied in the model until the theoretical pressures agree with the measured. The winding tension is then assumed to have been the wound-on-tension.

Pfeiffer [4] established a method that will be used in both types of experiments performed in this research (changing the web path and removing the nip roller). It involves pulling the outermost layer of paper away from the roll, around a load cell roller to take tension measurements, and returning the web to the winding roll. This is a good method for getting a large amount of data, therefore small differences are very easy to determine. One disadvantage with this method, discovered by Good, Hartwig, and Markum [5], is that pulling the outermost layer away from the roll affects the wound-on-tension. They discovered this by comparing wound-on-tensions inferred from pressure measurements using Hakiel's model (as previously discussed) to those directly measured using Pfeiffer's method. However, they did find that in some cases the load cell data could be adjusted to match the pull-tab data.

Rand and Eriksson [6] researched the effects of a nip roller on a wound roll. They discovered maximum stress conditions occur beneath the rider roll or one of the drums, by gluing strain gages to the web and recording WOT as the roll was produced. Figures 4 and 5 show the results. In both of these figures, it is shown that the rider roll and drum 2 supply most of the WOT.

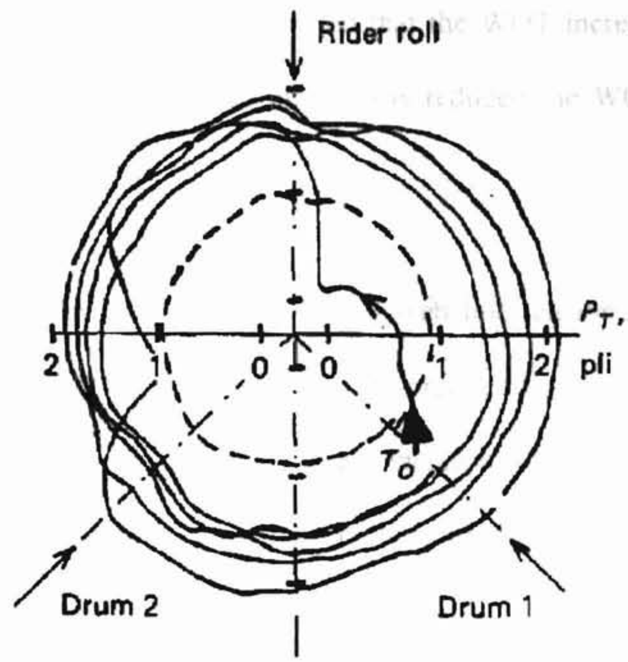

Figure 4—Rand and Eriksson; 4-in dia. Paper Roll WOT from Two-Drum Winder

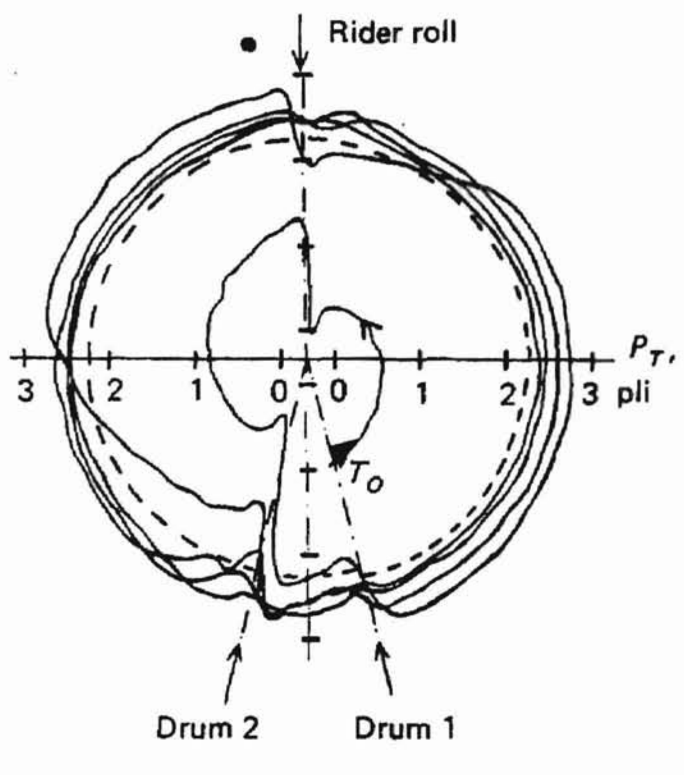

Figure 5— Rand and Eriksson; 31-in dia. Paper Roll WOT from Two-Drum Winder

Rand and Eriksson also discovered that the WOT increases as the radius grows with a constant nip. If the nip load is reduced the WOT could be kept constant.

Dolezal [7] researched the effects of web line tension, drum torque, nip load, and nip diameter on the WOT of rolls produced on a standard two-drum winder. He discovered that the WOT greatly increased after passing under the nip roller. The results from removing the nip roller in this research will be directly compared with Dolezal's results.

Objectives

There are two objectives of this research:

The first is to study the effects of changing the web path. Pfeiffer's method of pulling away the outermost layer of paper is used to find WOT's, for two different web types. The results will show if there are any significant changes in WOT due to changing the web path.

The second part is to investigate the effects of retracting the nip roller. Pfeiffer's method along with the use of pull-tabs and Hakiel's model are used to determine WOT. These results will show how to what extent the WOT is induced by the nip roller, and what levels of WOT can be expected after the nip roller is retracted.

CHAPTER 3

EXPERIMENTAL SETUP

A two-drum web-winder has been altered slightly for this research. There are two 24" drums setting 5/8" apart. The drums are attached to two 5-hp electric motors. One is in speed control, and the other in torque control. Therefore, drum 1 has a constant speed input while drum 2 has a constant torque input. This is similar to industry except for the fact that in industry, the relative velocity between the drums is limited to prevent drum 2 from runaway at low nip loads.

On the two drums rests the winding core. The core has a 6-9/16" outside diameter and is made from aluminum. For this research, the final wound roll diameter will not be greater than 11". On the core a nip force is applied in two different methods, and the setup is different for the two cases. The nip force loads and the two different cases will be discussed later in this chapter. The generic setup can be seen in Figure 6.

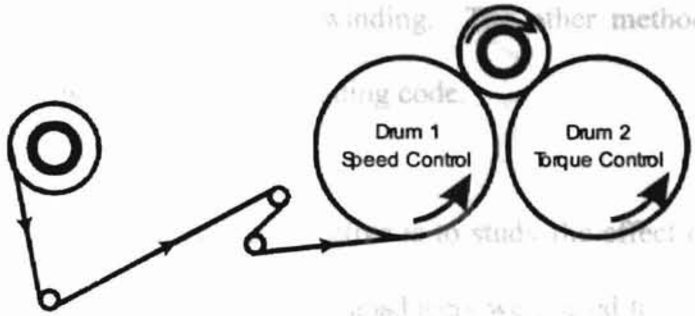

Figure 6—General Setup

The Unwind Station

To control the tension, the unwind stand uses a magnetic brake through a closed loop controller. The feedback signal is obtained through the web passing over a roller that is mounted upon force transducers. Tensions used in each experiment are given in Table 2 later in this chapter.

The unwind stand is on guide rods allowing for lateral movement. To wind good rolls active web guiding must be employed. The web passes through a pneumatic edge position sensor. The pressure difference is used as a feedback signal to a pneumo-hydraulic controller, and it adjusts the lateral position of the unwind stand with a hydraulic cylinder.

Measuring Wound-on-Tension (WOT)

Two different methods of determining WOT were used for this research. The first method was that of Pfeiffer which uses force transducers that actively measure the WOT while the roll is winding. The other method infers WOT through the use of pull-tabs and the winding code.

In the first case where the objective is to study the effect on WOT when changing the web path, only the force transducers were used to measure tension. In the second case where the objective was to study WOT when the nip roller was retracted, both methods were used. The pull-tab measurements yield more accurate results but cannot actively measure the tension during winding.

Force Transducers for Measuring WOT

On both sides of the winding roll are rollers on force transducers used to measure the WOT. They are located on each side of the nip roller so tension can be measured before and after the web passes under the nip roller. There are other rollers (seen in Figure 7) that are used to keep the angle of the web about the load cell rollers constant, as the wound roll grows larger.

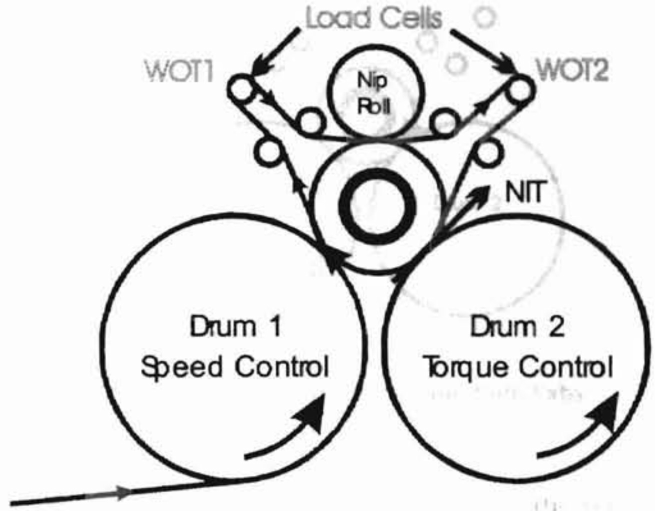

Figure 7—Setup of Force Transducers

Pull-Tabs

As discussed in Chapter 2, one method of finding pressure in a wound roll is through the use of pull-tabs. The pressures measured can be input into Hakiel's model to infer WOT.

The tabs are placed on the roll perpendicular to the direction of the travelling web. The web is then wound with the pull-tabs in it. While winding, the web path bypasses the WOT 1 and WOT 2 rollers so no web is pulled away from the roll, as shown in Figure 8.

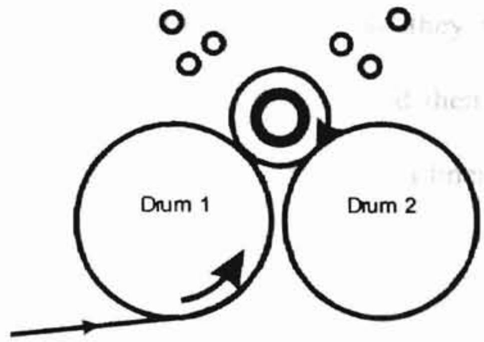

Figure 8—Web Path When Using Pull-Tabs

Once wound, a force gage is used to determine the pull force required to dislodge the tab. A calibration curve is then used to relate pull force to wound roll pressure at this radius where the tab was inserted.

A pull-tab consists of a steel shim (12" long, ¾" wide, .001" thick) enclosed in a brass folder. The brass folder is attached to the web and the steel shim is placed in between the fold, as seen in Figure 9. The pull-tab is then placed on the web itself, perpendicular to web direction.

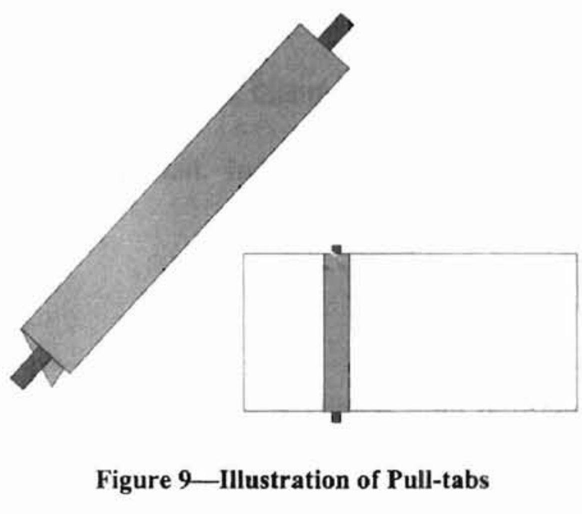

Figure 9—Illustration of Pull-tabs

Before attaching the pull-tabs to the web, they have to be calibrated. Many known pressures were applied to the tab, and then the force required for dislodgment is recorded. This data is used to make a linear calibration curve for each individual pull-tab.

To be comparable to Dolezal's data, these were placed every ½ inch along the radius of the roll. In order to save time, two sets of pull-tabs were used so data could be obtained every time the roll is wound rather than every alternate time.

A roll in the process of winding can be very dangerous. Therefore, when applying the pull-tabs, the winder is stopped, the tab applied, and the machine is then restarted. This is done for every tab and then the roll is rewound. Starting and stopping the machine may cause inconsistencies so no data is taken while applying the pull-tabs.

A disadvantage of pull-tabs is that the force may be too great to pull by the average human or the tab may fail. In this case, no data can be recorded.

Winding Code

Once the pressure distribution is known from pull-tabs, the WOT of the roll can be inferred using winding code based on Hakiel's model. It requires input of several parameters including wound roll dimensions, web and stack material properties, core properties, and an initial estimate for WOT. For this research, the winding code was only used on newsprint, and all the required parameters for newsprint are given in Table 1.

Winding Code Input Parameters	
Web Properties:	
Web Caliper (in)	0.003
Web Width (in)	9.625
Web-to-Web Kinetic Coef. of Friction	0.26
In-Plane Modulus: Et	7.78E+05
Stack Modulus Er: K1	2.9
Stack Modulus Er: K2	23.9
Poisson's Ratio of Web	0.01
Core Properties:	
Core ID (in)	6.07
Core OD (in)	6.6
Roll OD (in)	13.1
Core Material Modulus (psi)	1.00E+07
Poisson's Ratio of Core	0.33
Core Stiffness (psi)	2.76E+06

Table 1—List of Input Parameters for the Winding Code

Torque Measurements

Each drum has a 5 hp motor attached to it. To measure torque, a load cell is attached to the bottom of each motor and measures how much force is required to restrain it. This can be seen in Figure 10.

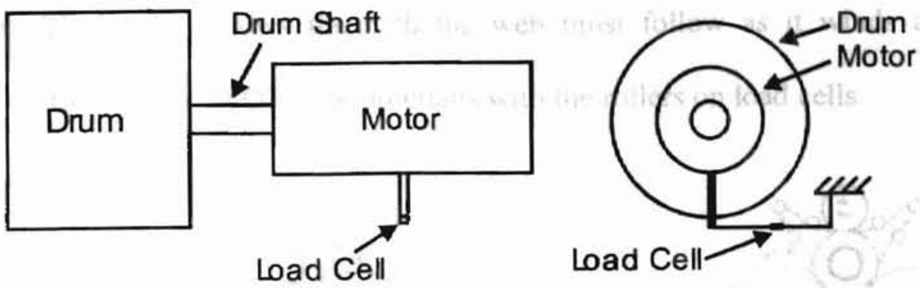

Figure 10—Measuring Torque

Motor 1, the motor in speed control, is operated at 10, 30, and 50 rpm. The variation in speed is because at higher speeds, the pull-tabs tend to break while passing through the alignment guide. Motor 2, the motor in torque control, was set to 50, 100, 150, and 200 in-lbs.

Winder Setup

The two-drum web winder was set up differently for each experiment. The first case is setup exactly the same as in Dolezal's research, only the web path has been altered. The second is different in that the nip roller has been removed and the nip force is applied from inside the winding roll.

Case 1—Changing the Web Path

All previous research has only been for one particular web path, but it has been discovered that other paths are being used. For this reason, part of this research focuses on how WOT is effected by altering the web path. The four different paths are shown again in Figure 11, with NIT representing nip-induced-tension. This figure shows the path the web must follow as it winds and is extracted to make the WOT measurements with the rollers on load cells.

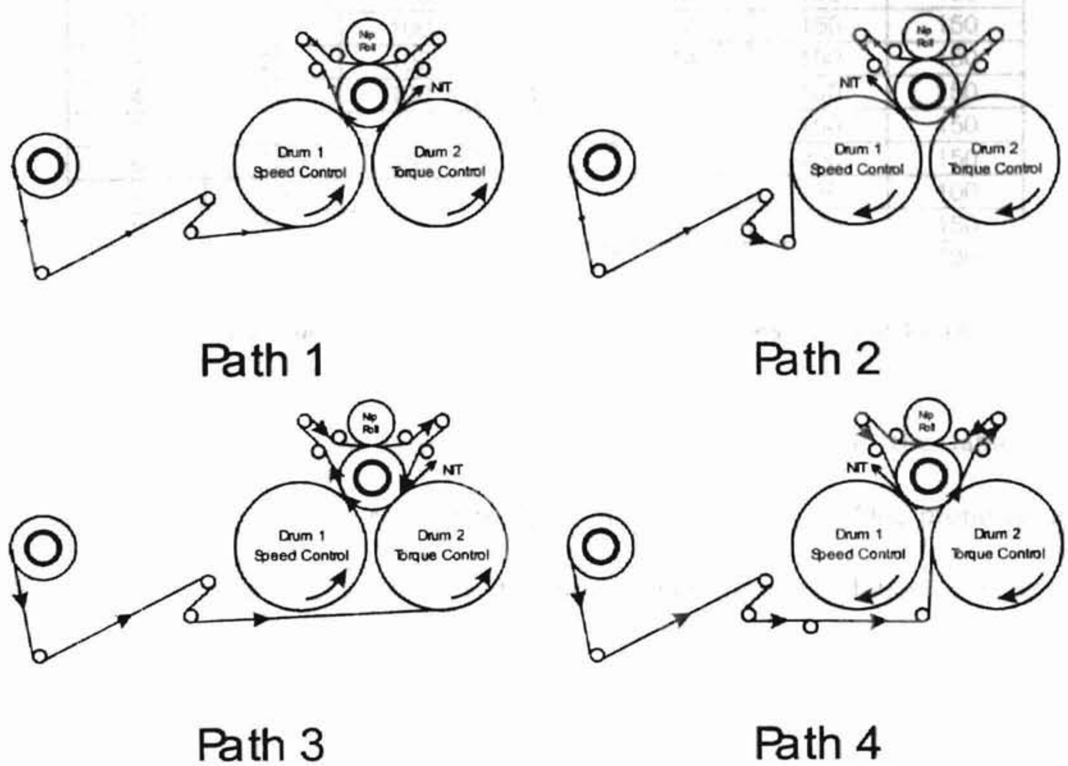

Figure 11—Four Different Web Paths

As in Dolezal's research, the nip force is applied with pneumatic cylinders, and is measured with load cells whose input is used for feedback in a closed loop control system. In Dolezal's case, he used 3 different sizes of nip rollers, a 2", a 6½" and a 10" diameter roller. For this research, only the 6½" diameter roller is used. Newsprint and Tyvek® were both used as the winding films, so data could be taken on two different materials and show the same results. Nine different parameters were used in winding each roll, and they are listed in Table 2. Due to slippage the test conditions were modified for the Tyvek®.

Test Conditions Used						
	Newsprint			Tyvek		
Test No.	Tension (lbs.)	Nip (lbs.)	Torque 2 (in-lbs.)	Tension (lbs.)	Nip (lbs.)	Torque 2 (in-lbs.)
1	12	100	100	6	150	150
2	16	100	100	10	150	150
3	20	100	100	14	150	150
4	12	100	100	10	100	150
5	12	50	100	10	150	150
6	12	150	100	10	200	150
7	12	100	100	10	150	100
8	12	100	50	10	150	150
9	12	100	150	10	150	200

Table 2—The Nine Different Testing Parameters for Newsprint and Tyvek®

The properties for newsprint were given in Table 1, the table that describes all properties to be inserted into the winding code. One property not listed is the web-to-steel kinetic coefficient of friction that was found to be about .28.

Tyvek® is a spun-bond non-woven polyethylene web produced by DuPont. It's largest commercial applications are express mail packages and for vapor barriers for buildings and homes. Its properties are shown in Table 3.

Tyvek® Paper Type	Nominal Thickness (in)	Measured Thickness (in)	E_t (psi)	K_1 (psi)	K_2
OSU3	0.0069	0.006	81,000	0.99	34.61
OSU1	0.005	0.006	64,500	1.92	30.91

Table 3—Properties for Tyvek®

The radial modulus is of the form $E_r = K_2 K_1 + P$, with P being the pressure exerted on the stack in units of psi. The width of the Tyvek® is 12-1/4" wide.

Case 2—Removing the Nip Roller

In Dolezal's research, he discovered that most of his wound-on-tension developed after the paper passed under the nip roller. For this reason, the second part of this research is to find the effect of removing the nip roller; however, a nip force must still be present to keep the roll from slipping, as seen in Figure 12.

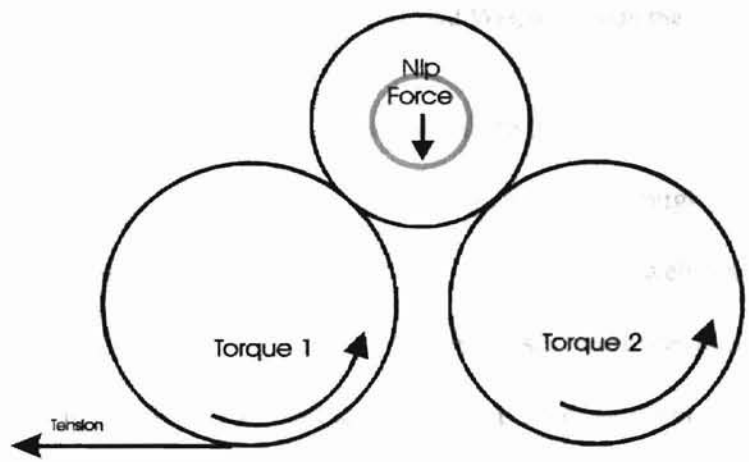

Figure 12—Setup After Removing Nip Roller

Therefore, many circular disks were made from lead that will just fit inside of the winding core, as shown in Figure 13.

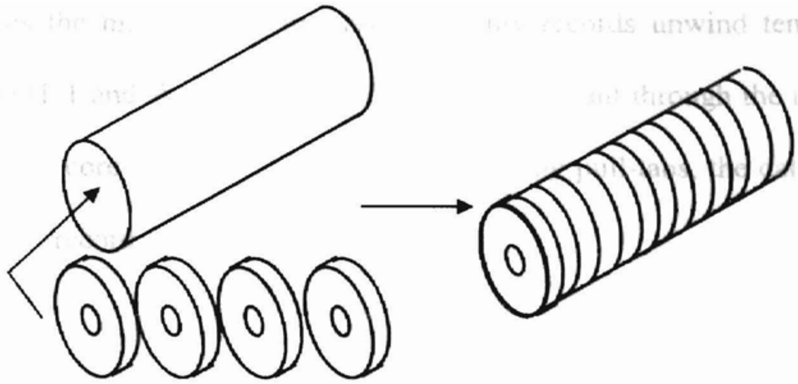

Figure 13—Nip Load Made From Lead Weights Inside the Core

To be comparable with Dolezal's data, two sets of rolls were wound. With one set of windings, wound-on-tension was inferred through the use of pull-tabs and a winding model. In the second set of windings the web was routed over the WOT measurement rollers. Seven winding cases were developed in which web tension, the torque to the second drum, and nip load were varied per Table 4.

Test Parameters			
Test No.	Tension (lbs)	Torque 2 (in-lbs)	Nip Load (lbs)
1	12	100	100
2	16	100	100
3	20	100	100
4	12	50	100
5	12	150	100
6	12	100	50
7	12	100	150

Table 4—The Seven Test Conditions for Newsprint

Data Acquisition

For Case 1, changing the webpath, a program written in Labview records unwind tension, torque to drum 1, torque to drum 2, WOT 1, WOT 2, nip load, and controls the nip load. In Case 2, it only records unwind tension, both torques, WOT 1 and WOT 2, for the nip load is constant through the use of lead weights in the core. In Case 2, when winding using pull-tabs, the data from the tabs is simply recorded by hand.

CHAPTER 4

EXPERIMENTAL RESULTS

The experimental results are divided into two different sections. The first presents data obtained in case 1, changing the web path, and the second is case 2, removing the nip roller.

Case 1—Changing the Web Path

In this case, only the load cells were used to find WOT. No pull-tab data was necessary, for in each case only a comparison between the different paths was required.

Listed in Table 5 is a partial example of the output file that is taken in real time while a test is being run using the load cells. Not all are listed for in a single run, over 1000 rows of data are obtained. Labview records incoming web tension, torques to drums, nip load, WOT 1, and WOT 2.

Tension	Torque2	Torque1	Nip	WOT2	WOT1
11.758	100.64	68.377	97.711	23.091	7.039
11.68	102.985	79.73	98.644	22.891	8.69
12.138	102.164	95.009	95.091	23.206	6.351
11.925	101.598	100.554	99.889	22.182	7.516
11.713	101.478	93.532	103.606	23.982	6.938
11.492	102.454	83.379	97.433	22.407	6.915
11.567	101.486	83.105	99.251	22.972	6.287

Table 5—Sample Output of Data from Labview

Three different parameters were changed during each run, giving nine different test cases. Those were listed in Table 2 of Chapter 3. Each case was held for approximately 3 minutes before advancing to the next test case. For newsprint, each thread path was run twice to ensure repeatability, with those results shown in Table 6.

Newsprint									
TEST	WEB TENSION(LB)	NIP LOAD (LB)	TORQ#2 (IN-LB)	TP1, T1**	TP1, T2	% Diff.	TP2, T1	TP2, T2	% Diff.
1	12	100	100	23.1	22.6	1.05	22.1	23.0	-2.15
2	16	100	100	24.2	23.6	1.24	22.5	23.4	-1.95
3	20	100	100	24.9	24.1	1.63	23.5	24.9	-2.83
4	12	50	100	18.0	17.6	1.06	13.4	15.1	-6.10
5	12	100	100	24.3	23.4	1.90	22.8	23.3	-1.13
6	12	150	100	27.1	26.4	1.32	27.3	28.0	-1.24
7	12	100	50	20.4	19.6	1.85	22.5	23.8	-2.85
8	12	100	100	24.2	24.1	0.18	22.8	23.7	-1.86
9	12	100	150	27.4	27.3	0.17	22.5	23.7	-2.38
TEST	WEB TENSION(LB)	NIP LOAD (LB)	TORQ#2 (IN-LB)	TP3, T1	TP3, T2	% Diff.	TP4, T1	TP4, T2	% Diff.
1	12	100	100	21.7	22.1	-0.79	25.2	25.0	0.23
2	16	100	100	21.7	22.6	-2.21	30.6	30.3	0.58
3	20	100	100	22.2	23.4	-2.57	34.3	34.1	0.29
4	12	50	100	12.8	13.8	-3.62	19.2	18.8	1.02
5	12	100	100	21.9	22.2	-0.72	25.8	25.8	-0.12
6	12	150	100	26.7	27.3	-1.02	29.2	29.6	-0.69
7	12	100	50	21.4	22.2	-1.85	29.1	29.0	0.20
8	12	100	100	21.9	22.6	-1.61	26.0	26.0	0.16
9	12	100	150	22.3	22.6	-0.77	22.0	21.8	0.32

**TP1=Thread Path 1 T1=Test 1

Table 6—Averages for Two Different Windings on Newsprint

The values shown are an average of all values. Each test was also performed on two different materials, newsprint and Tyvek®. There are two different types of Tyvek®, OSU1 and OSU3, with the difference being that OSU1 has a surface treatment to reduce static. Table 7 lists average values for the Tyvek® paper. It is evident from the lower WOT values that adding the surface treatment lowers the coefficient of friction on OSU1.

OSU3							
TEST	WEB TENSION(LB)	NIP LOAD (LB)	TORQ#2 (IN-LB)	WOT2 T1	WOT1 T2	WOT2 T3	WOT1 T4
1	6	150	150	17.0	15.3	12.5	13.4
2	10	150	150	18.7	16.1	14.4	18.5
3	14	150	150	20.5	18.1	17.0	24.5
4	10	100	150	17.4	13.6	11.9	16.0
5	10	150	150	18.1	16.8	13.4	18.9
6	10	200	150	18.8	17.7	15.3	21.0
7	10	150	100	15.9	15.8	13.8	21.6
8	10	150	150	18.7	16.0	14.4	18.7
9	10	150	200	22.0	16.4	14.1	16.1
OSU1							
TEST	WEB TENSION(LB)	NIP LOAD (LB)	TORQ#2 (IN-LB)	WOT2 T1	WOT1 T2	WOT2 T3	WOT1 T4
1	6	150	150	14.4	13.4	10.8	10.0
2	10	150	150	16.4	14.9	13.1	14.5
3	14	150	150	18.3	16.4	15.7	18.6
4	10	100	150	15.9	11.7	10.9	11.3
5	10	150	150	17.0	14.3	12.7	13.9
6	10	200	150	16.9	15.2	13.9	15.7
7	10	150	100	14.4	13.1	13.4	16.1
8	10	150	150	16.6	13.1	12.1	13.8
9	10	150	200	19.2	14.6	11.4	11.3

Table 7—Average WOT's for Tyvek®: OSU1 and OSU3

Figures 14 and 15 show the interdependence of each parameter. In the first 3 tests, tension is increased; therefore torque 1 increases to maintain constant velocity. In the second 3 tests, nip load is increased which also causes an increase in torque 1. In the last 3 tests, torque 2 is increased, causing a decrease in torque 1, for it has to work less to maintain constant speed.

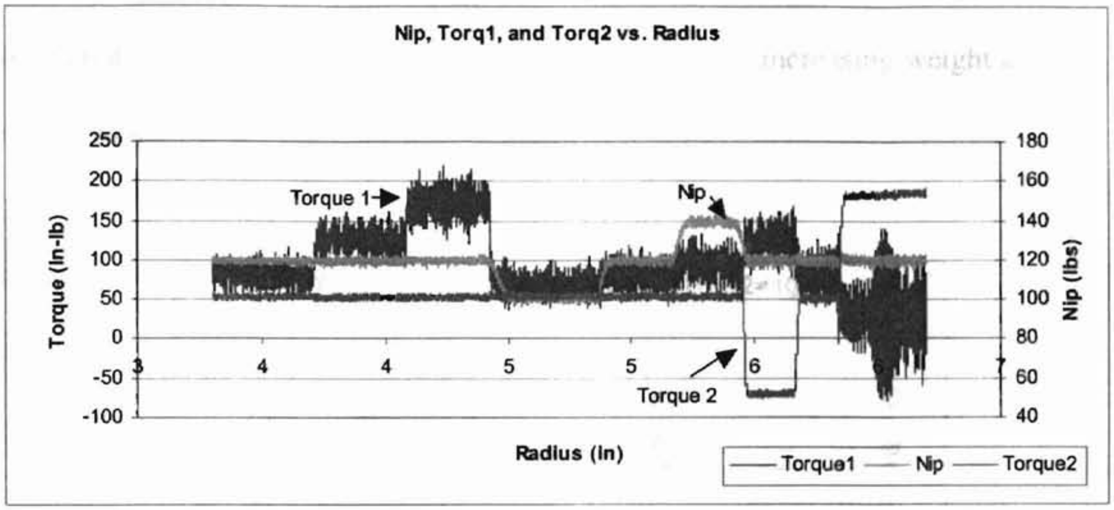

Figure 14—Nip Force, Torque 1 and Torque 2 vs. Radius

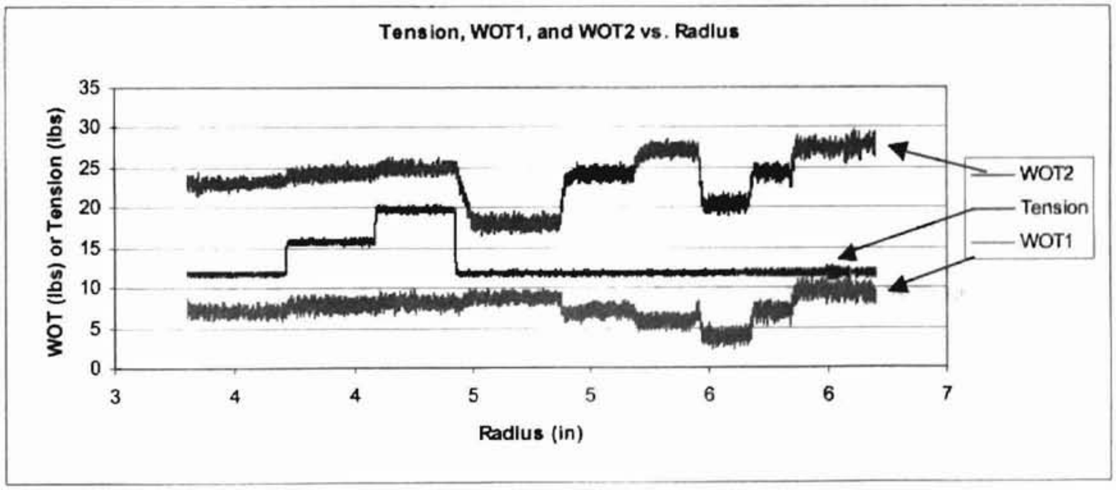

Figure 15—Tension, WOT 1 and WOT 2 vs. Radius

The nine different test cases seem to be a good method in gathering large amounts of data quickly. Figures 16-18 show WOT outputs as a function of radius. In the case of testing newsprint, tests 1,5, and 8 are repeatable test values. In testing Tyvek®, tests 2,5, and 8 are the repeatable values. It is evident that there is not a significant change in WOT as the roll grows, increasing weight and angle of wrap.

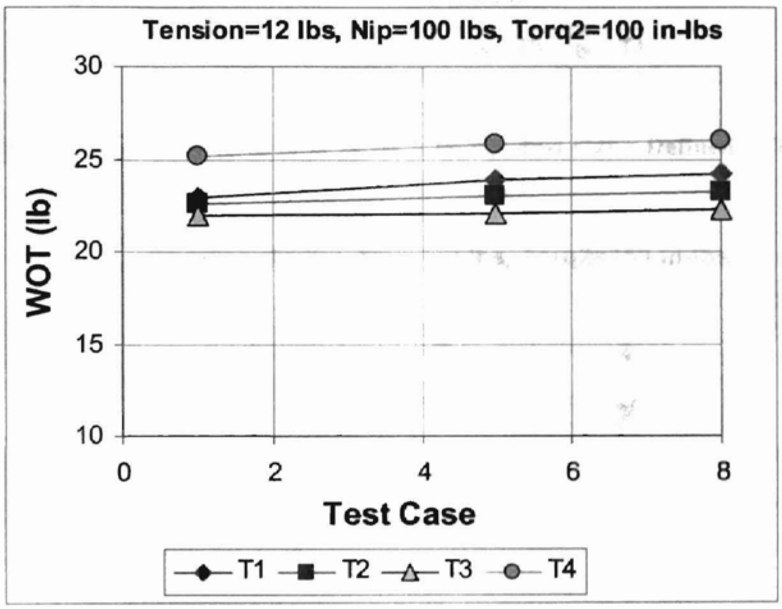

Figure 16—Repeatable Points for Newsprint, Test Cases Defined in Table 2

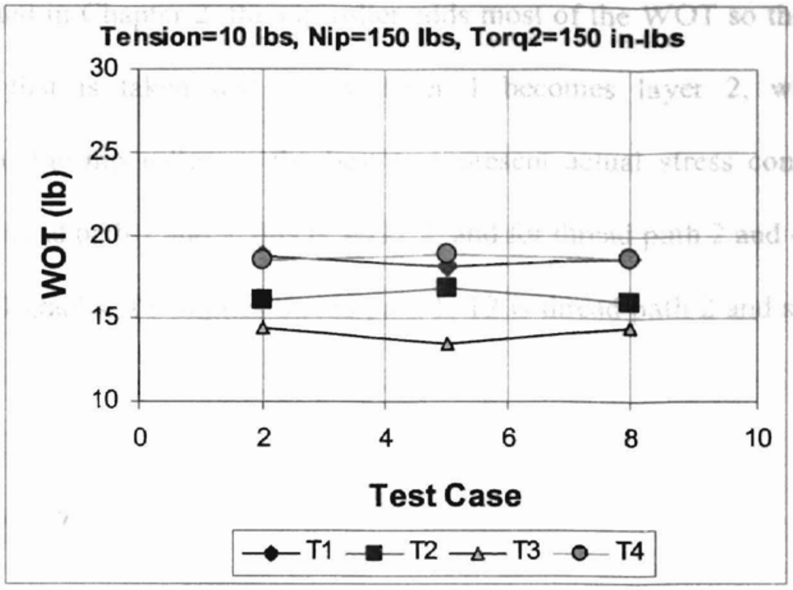

Figure 17—Repeatable Points for Tyvek®: OSU3, Test Cases Defined in Table 2

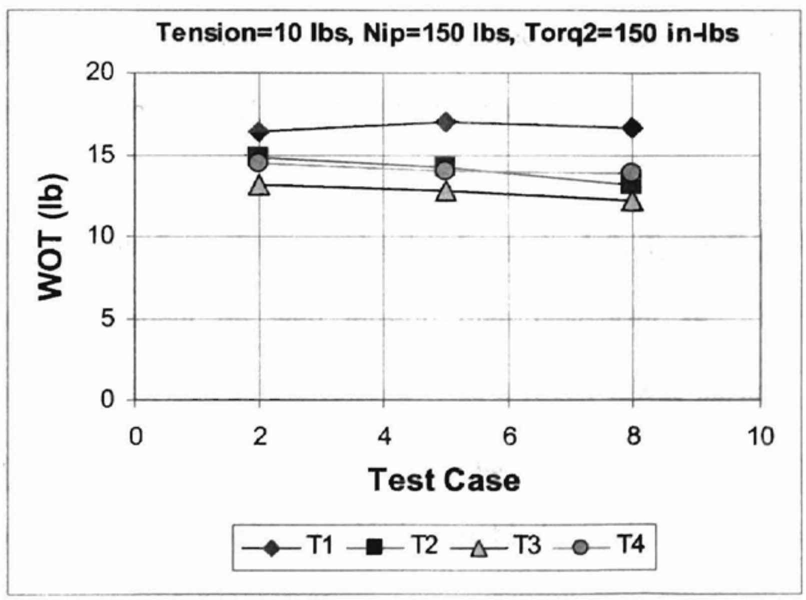

Figure 18—Repeatable Points for Tyvek®: OSU1, Test Cases Defined in Table 2

As stated in Chapter 2, the nip roller adds most of the WOT so the WOT measurement that is taken just before layer 1 becomes layer 2, which is downstream of the nip roller, is the best to represent actual stress conditions. Therefore in thread path 1 and 3, this is WOT 2, and for thread path 2 and 4 this is WOT 1. In all graphs, T1 implies thread path 1, T2 is thread path 2 and so forth, per Figure 11.

Variable Unwind Tension

Figures 19, 20, and 21 show graphs of each thread path in a plot of WOT vs. web tension, for each different material. As seen from the graphs, only path 4 is significantly affected by tension. In this case, when web tension is increased, torque to drum 1 must increase also to maintain constant speed.

It is also obvious from these graphs that for paths 1-3, Tyvek® (OSU1 and OSU3) is more dependent on web tension than newsprint is. The major component for this difference is that Tyvek® has a much lower surface friction than Newsprint, and it also has a different modulus. Another factor could be the unwind tension values used; for Newsprint it was 12, 16, and 20 lbs, whereas for Tyvek® it was 6, 10, and 14 lbs.

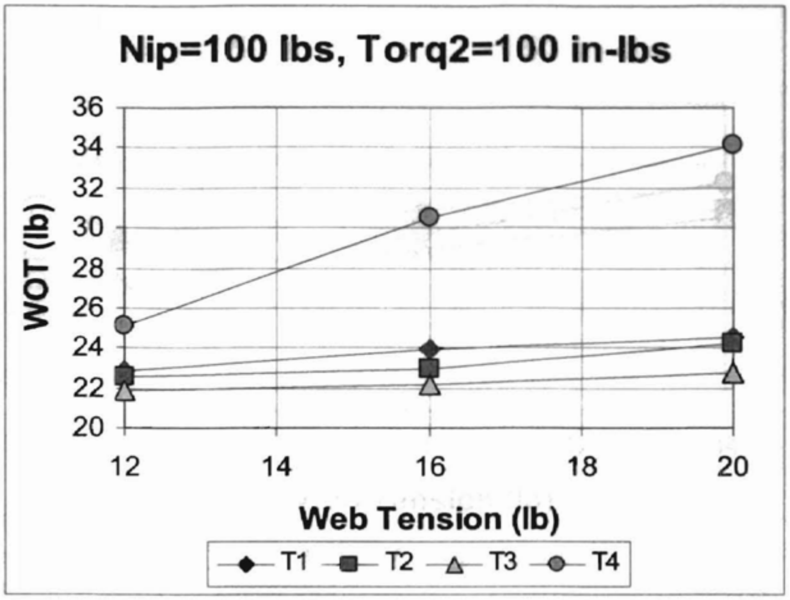

Figure 19—Results When Varying Unwind Tension on Newsprint

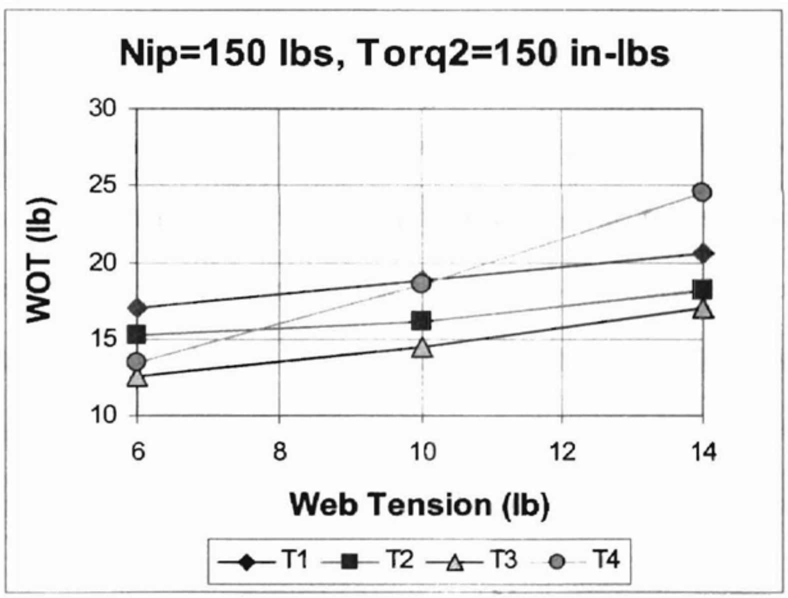

Figure 20—Results When Varying Unwind Tension on OSU3

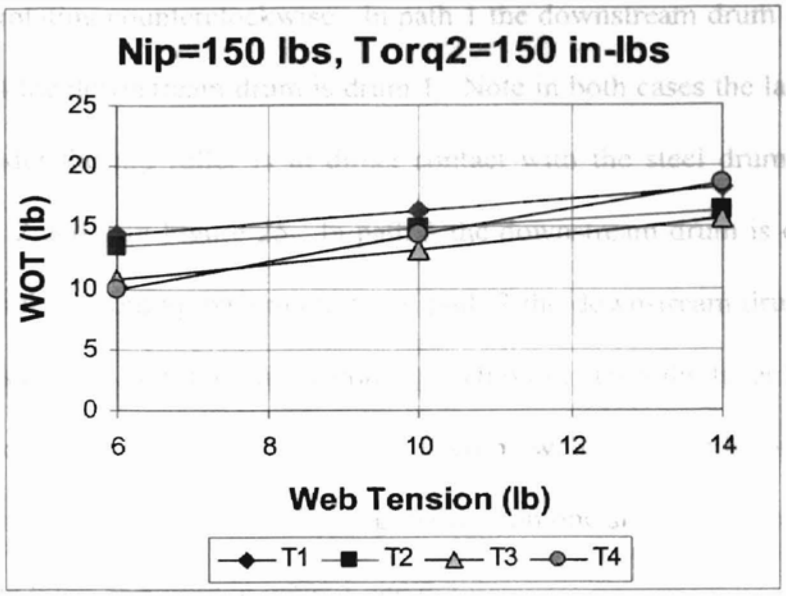

Figure 21—Results When Varying Unwind Tension on OSU1

Variable Nip Load

As shown in Figures 22 - 24, most thread paths increase in WOT when the nip load is increased. It Figure 22, the graph for newsprint, paths 1 and 4 and paths 2 and 3 show similar behavior. There has been much work done in single drum center and surface winding which shows that the nip induces slippage between the first and second layers [5]. This results in a tightening of the first layer that serves to increase the WOT. Multiple drum winding is more complex.

The web downstream of the nip roller may increase in tension as in single drum winding, but when that web passes the drum downstream from the nip roller the friction conditions may be quite different due to web path. Compare paths 1 and 4 in Figure 25 and note that in path 1 the wound roll is rotating clockwise and in path 4 it is rotating counterclockwise. In path 1 the downstream drum is drum 2 and in path 4 the downstream drum is drum 1. Note in both cases the layer that just passed under the nip roller is in direct contact with the steel drum. Now compare paths 2 and 3 in Figure 25. In path 3 the downstream drum is drum 2, which also has the incoming web upon it. In path 2 the downstream drum from the nip roller is drum 1 and it too has incoming web on it. Thus the layer that has just been slipped by the nip roller is now restrained by web layers on both sides, a friction condition very different than having the web on one side and a steel drum contact with the other as before in paths 1 and 4.

Note, particularly on the Tyvek®, that in web path 1 the WOT appears almost independent of the nip load.

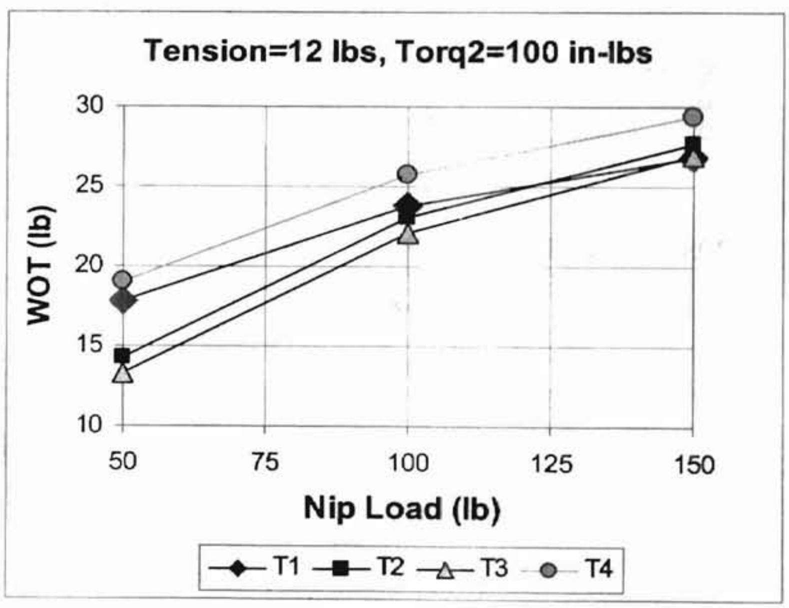

Figure 22—Results When Varying Nip Load on Newsprint

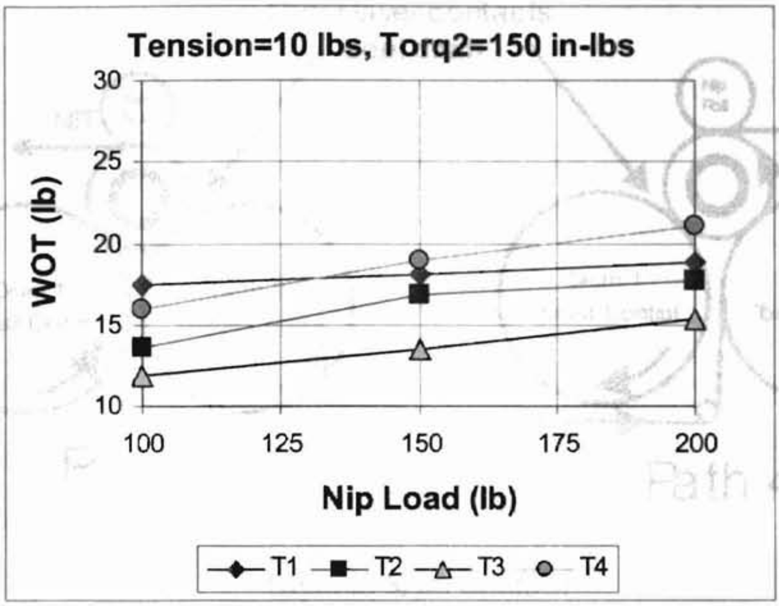

Figure 23—Results When Varying Nip Load on OSU3

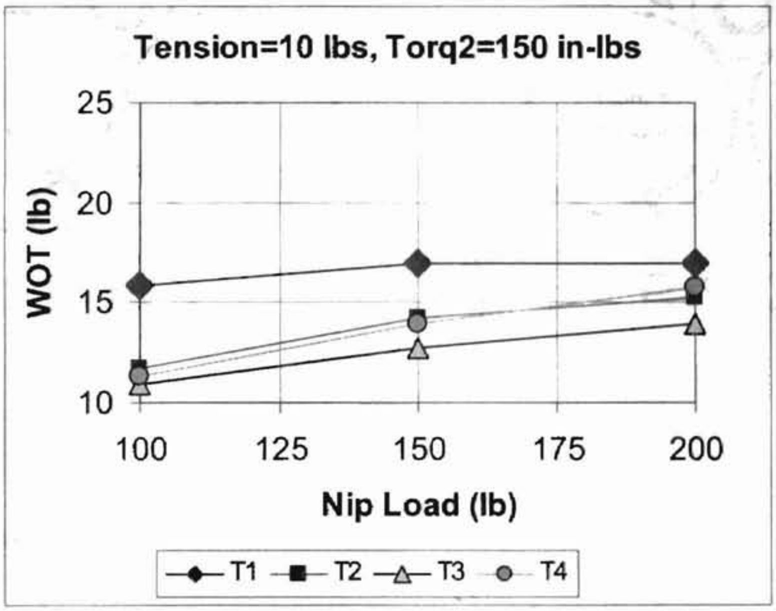

Figure 24—Results When Varying Nip Load on OSU1

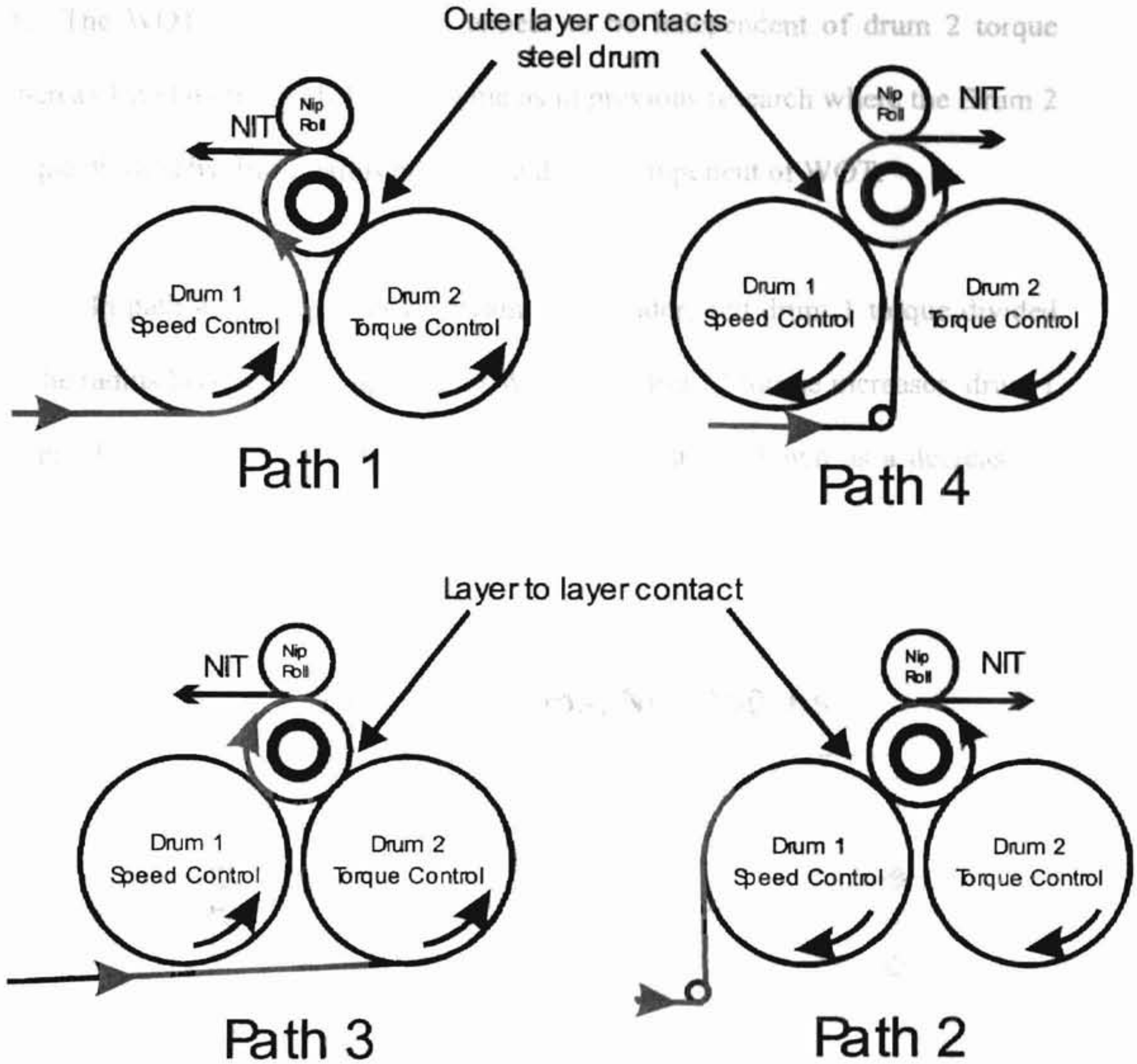

Figure 25—Different Conditions of Friction and Slippage

Variable Torque

From varying nip load, it was evident that paths 1 and 4 differed from paths 2 and 3 based on if the drum force passes through incoming web before affecting WOT. This might suggest that paths 1 and 4 will be very different from paths 2 and 3 when varying drum 2 torque, which is clearly evident in Figures 26-

28. The WOT for paths 2 and 3 appear to be independent of drum 2 torque whereas 1 and 4 are. Path 1 is the same as in previous research where the Drum 2 torque divided by drum radius becomes a direct component of WOT.

In path 4, drum 1 is downstream of the rider, and drum 1 torque divided by the radius becomes a component of WOT. As drum 2 torque increases, drum 1 torque decreases in order to maintain velocity. This is shown as a decrease in WOT as Drum 2 torque is increased.

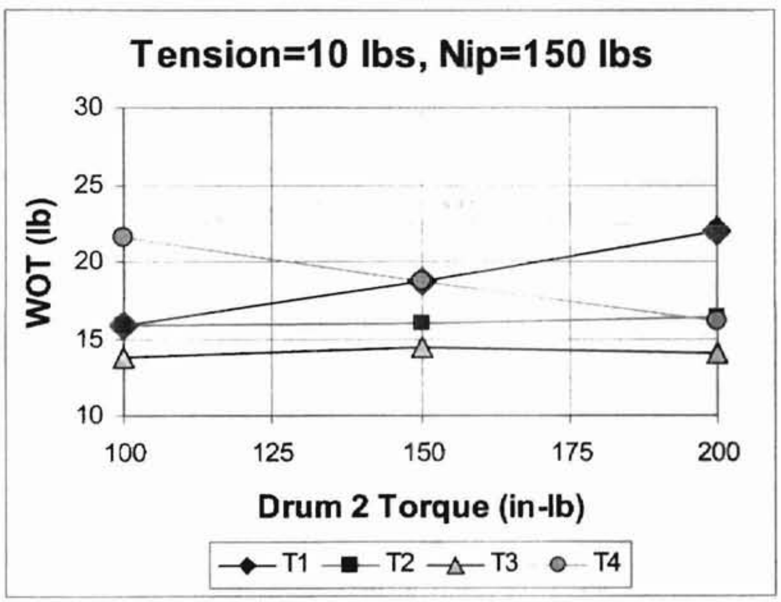

Figure 26—Results When Varying Drum 2 Torque on Newsprint

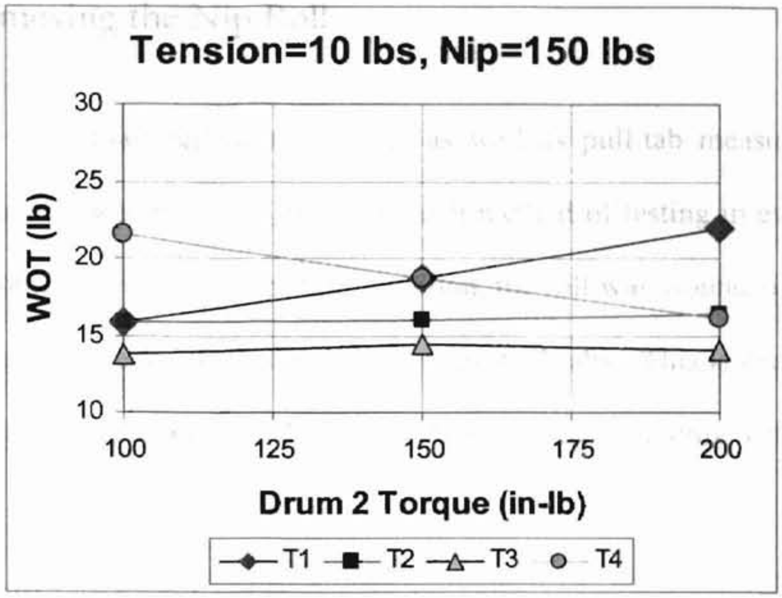

Figure 27—Results When Varying Drum 2 Torque on OSU3

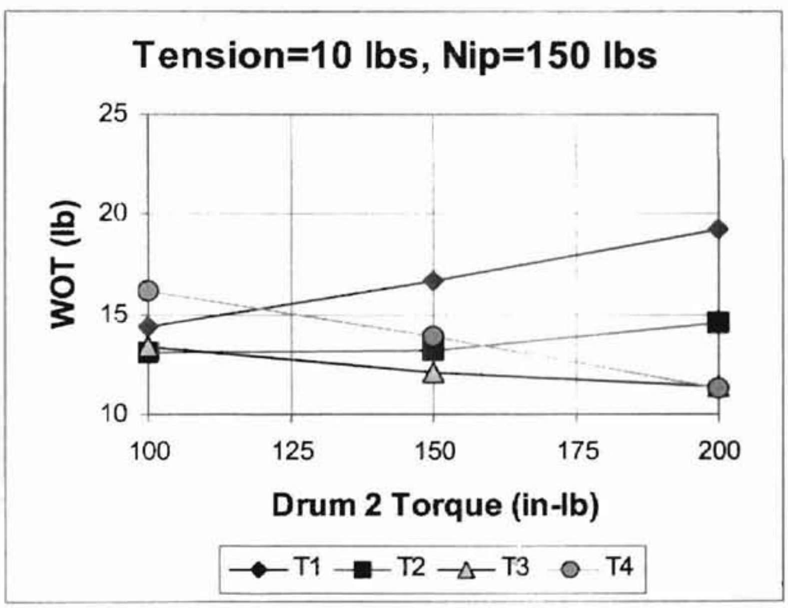

Figure 28—Results When Varying Drum 2 Torque on OSU1

Case 2—Removing the Nip Roller

In this case, load cell measurements as well as pull-tab measurements were used. The roll was wound 3 times for each method of testing in every test condition. In other words, for every test condition, the roll was wound six times, three using load cell measurements and three using pull-tabs. This is exactly the same manner in which Dolezal's data was obtained when winding with a nip roller.

Load Cell Measurements

For each run, the load cell test output was averaged leaving three values for every test condition, and these values were averaged to find one final value, which will be compared to pull-tab data as well as Dolezal's data. The results along with the statistics are shown in Table 8.

Test 1		Tension 12 lb	Torque2 100 in-lb	Torque1	Nip Load 100 lb	WOT2	WOT1
	Run 1	11.72	100.01	122.21	100	8.91	8.48
	Run 2	11.72	102.37	124.02	100	9.66	9.24
	Run 3	11.73	103.09	125.84	100	8.51	8.08
	Average	11.72	101.83	124.02	100	9.03	8.60
	Std. Dev.	0.00	1.31	1.48	0.00	0.48	0.48
	95% CI	0.01	1.49	1.68	0.00	0.54	0.54
Test 2		**Tension 16 lb**	**Torque2 100 in-lb**	**Torque1**	**Nip Load 100 lb**	**WOT2**	**WOT1**
	Run 1	15.67	101.44	163.29	100	11.54	11.12
	Run 2	15.67	103.25	167.05	100	10.32	9.90
	Run 3	15.64	103.30	171.03	100	10.25	9.83
	Average	15.66	102.66	167.12	100	10.70	10.28
	Std. Dev.	0.01	0.87	3.16	0.00	0.59	0.60
	95% CI	0.02	0.98	3.58	0.00	0.67	0.67
Test 3		**Tension 20 lb**	**Torque2 100 in-lb**	**Torque1**	**Nip Load 100 lb**	**WOT2**	**WOT1**
	Run 1	19.55	101.11	213.23	100	11.04	10.64
	Run 2	19.59	101.27	212.26	100	11.12	10.73
	Run 3	19.57	103.43	204.83	100	11.49	11.10
	Average	19.57	101.93	210.11	100	11.21	10.82
	Std. Dev.	0.02	1.06	3.75	0.00	0.20	0.20
	95% CI	0.02	1.20	4.25	0.00	0.22	0.23
Test 4		**Tension 12 lb**	**Torque2 50 in-lb**	**Torque1**	**Nip Load 100 lb**	**WOT2**	**WOT1**
	Run 1	11.71	51.37	164.65	100	5.25	4.77
	Run 2	11.73	52.90	161.60	100	5.56	5.07
	Run 3	11.74	55.42	160.72	100	4.84	4.35
	Average	11.72	53.23	162.32	100	5.21	4.73
	Std. Dev.	0.01	1.67	1.68	0.00	0.29	0.30
	95% CI	0.01	1.89	1.90	0.00	0.33	0.34
Test 5		**Tension 12 lb**	**Torque2 150 in-lb**	**Torque1**	**Nip Load 100 lb**	**WOT2**	**WOT1**
	Run 1	11.72	155.49	68.07	100	13.69	13.35
	Run 2	11.71	155.10	68.05	100	13.03	12.68
	Run 3	11.71	155.10	68.27	100	13.47	13.14
	Average	11.72	155.23	68.13	100	13.40	13.06
	Std. Dev.	0.00	0.19	0.10	0.00	0.28	0.28
	95% CI	0.01	0.21	0.12	0.00	0.31	0.32
Test 6		**Tension 12 lb**	**Torque2 100 in-lb**	**Torque1**	**Nip Load 50 lb**	**WOT2**	**WOT1**
	Run 1	11.72	103.37	110.67	50	8.57	8.10
	Run 2	11.71	100.98	109.03	50	8.75	8.29
	Run 3	11.71	103.46	102.18	50	9.66	9.23
	Average	11.72	102.60	107.29	50	8.99	8.54
	Std. Dev.	0.01	1.15	3.67	0.00	0.48	0.49
	95% CI	0.01	1.30	4.16	0.00	0.54	0.56
Test 7		**Tension 12 lb**	**Torque2 100 in-lb**	**Torque1**	**Nip Load 150 lb**	**WOT2**	**WOT1**
	Run 1	11.73	102.84	122.49	150	9.44	9.01
	Run 2	11.73	103.94	126.03	150	10.34	9.94
	Run 3	11.72	101.81	123.96	150	10.06	9.65
	Average	11.73	102.86	124.16	150	9.95	9.53
	Std. Dev	0.01	0.87	1.45	0.00	0.38	0.39
	95% CI	0.01	0.98	1.65	0.00	0.43	0.44

Table 8—Results for Each Test Condition When Removing the Nip Roller

There should not be a difference in WOT1 and WOT2 because the web does not pass through anything but extra rollers between the force gages where the WOT is measured. Therefore the differences come from the friction in the bearings on the rollers the web passes through between the force gages. WOT2 is used in all graphs because it is the slightly larger value and the WOT2 load cell was closer to the point at which layer 1 became layer 2.

Recall that the nip roller was not used; rather lead weights were placed inside the roll core. This explains why the nip force is exactly 50, 100, or 150 pounds throughout the tests and there is no error (disregarding dynamic effects).

Pull-Tab Measurements

Obtaining WOT from pull-tabs required many steps, the first being to obtain the pull-force required to dislodge each tab after the roll was wound. Three different pull-forces were recorded and then averaged for each tab. After obtaining the average pull-force, it was converted to a radial pressure using the calibration curves discussed earlier in Chapter 3.

The stress value at each tab location (every ½" along the radius) could then be input into the winding code (also discussed in Chapter 3) to infer WOT values. The pull-tab method was run three times for each test condition, and a sample of one test condition is shown in Table 9. It also includes the standard deviation and 95% confidence interval. Table 10 lists all values inferred from pull-tabs for every test condition, along with the statistics.

Pull Tab Test Data

Condition Number	1
Tension (lbs)	12
Torque 2 (in-lb)	100
Nip Load (lbs)	100

Run 1	Tab	G	H	F	J	E	K	D	C	L	B	A
	Location	0.5	1	1.563	2	2.188	2.5	2.625	3	3	3.375	3.688
	Pull 1	43.6	50.1	37.2	34.4	41.8	35.9	39.0	42.5	36.6	33.5	24.8
	Pull 2	44.4	52.7	37.9	33.5	43.2	36.7	38.9	44.7	36.5	31.9	24.2
	Pull 3	44.3	52.7	38.3	33.4	43.2	36.2	38.2	44.8	35	31.3	25.3
	Average	44.10	51.83	37.80	33.77	42.73	36.27	38.70	44.00	36.03	32.23	24.77
	Pressure	15.35	16.76	15.21	16.64	15.38	16.33	16.49	16.04	15.24	15.06	11.77

Run 2	Tab	A	B	L	C	D	K	E	J	F	H	G
	Location	0.5	1	1	1.5	2	2.188	2.5	2.625	3	3.375	3.75
	Pull 1	26.0	33.5	38.7	43.6	39.0	37.3	43.0	33.1	39.1	>55	38.7
	Pull 2	25.6	32.7	37.5	43.4	41.0	37.8	43.2	31.5	38.3	>55	38.3
	Pull 3	25.7	32.2	37.8	44.2	40.5	38.4	43.8	33.2	39.0	>55	39.7
	Average	25.77	32.80	38.00	43.73	40.17	37.83	43.33	32.60	38.80	>55	38.90
	Pressure	12.23	15.37	16.14	15.93	17.14	17.10	15.64	15.92	15.63	>19.2	13.47

Run 3	Tab	G	H	F	J	E	D	L	C	B	A
	Location	0.5	1	1.563	2	2.188	2.625	3	3	3.375	3.688
	Pull 1	44.2	47.1	39.9	34.6	47.0	36.9	36	44.9	33.4	26.2
	Pull 2	45.3	49.8	39.0	34.3	45.2	35.6	35.6	44.7	33.1	27.1
	Pull 3	45.1	51.3	39.9	33.6	46.5	36.4	36.1	44.2	33.1	25.3
	Average	44.87	49.40	39.60	34.17	46.23	36.30	35.90	44.60	33.20	26.20
	Pressure	15.63	15.92	15.96	16.89	16.86	15.44	15.18	16.28	15.59	12.43

Summary of Results	
Run 1: WOT Inferred Using Winding Code (lbs)	23.421
Run 2: WOT Inferred Using Winding Code (lbs)	22.842
Run 3: WOT Inferred Using Winding Code (lbs)	23.015
Average WOT Inferred (lbs)	23.092
Standard Deviation (lbs)	0.243
95% Confidence Interval (lbs)	0.275

Table 9—Pull-Tab Data Record for Condition 1

Summary of Pull-Tab Results						
Test No.	Tension (lbs)	Torque 2 (in-lbs)	Nip Load (lbs)	WOT (lbs)	Std. Dev.	95% CI
1	12	100	100	23.09	0.24	0.27
2	16	100	100	23.88	0.31	0.35
3	20	100	100	25.19	0.12	0.13
4	12	50	100	19.11	0.47	0.53
5	12	150	100	27.12	1.42	1.61
6	12	100	50	17.37	0.95	1.07
7	12	100	150	30.40	1.18	1.34

Table 10—Results From Pull-Tabs

Recall that pull-tabs were placed every ½" in both web directions. This is why there was occasionally more than one data point for the same location. Data was recorded on all tabs regardless of which direction the web was winding. Some tests also had less data points because the tabs would break and become useless. In this case, if another tab was close enough to the same location a new tab was unnecessary, otherwise a new tab was made and inserted into the roll.

Explanation Of Results

In the following sections, it is shown what results when varying tension, nip load, and the torque to the second drum. Also in a separate section is a comparison with Dolezal's results. On the graphs that follow each data point was going to have the 95% confidence interval error bar on it for both the pull-tab data and the force gage data, but the error bar was so small it was covered completely by the icon.

Variable Unwind Tension

Figure 29 and Table 11 show results when incoming line tension is varied at 12, 16, and 20 lbs, nip load is 100 lbs, and torque 2 is 100 in-lbs. From the graph it seems that unwind tension has a small but linear effect on WOT. As seen from the table, comparatively the differences are about the same even though the absolute values are very different. It is unclear why so little tension gets into WOT or WOT PT but it is suspected this has something to do with the capstan effect of the incoming web from the web line wrapping drum 1 and the nip mechanics between drum 1 and the wound roll which controls the rate of slippage between drum 1 and the web in the nip contact zone.

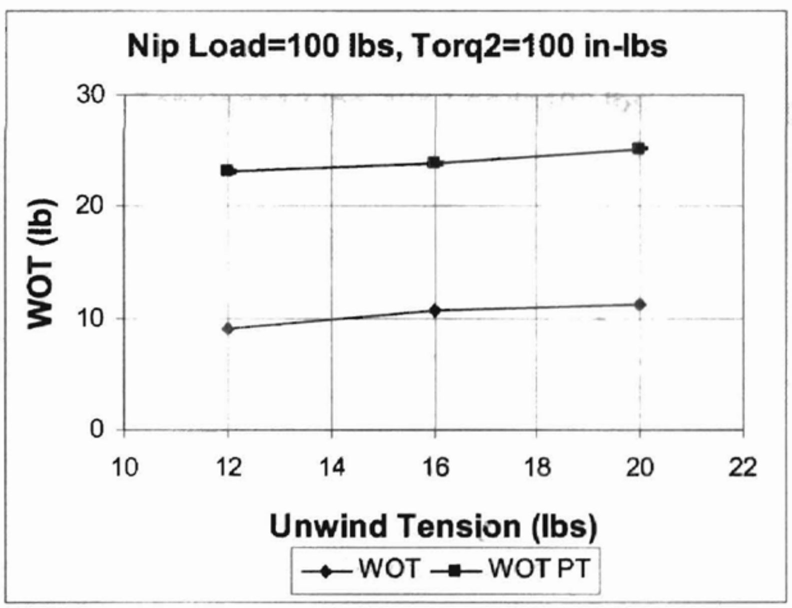

Figure 29—Results When Varying Unwind Tension

Web Tension (lbs)	WOT (lbs)	WOTPT (lbs)	WOT-9.03	WOT PT-23.09
12	9.03	23.09	0.00	0.00
16	10.70	23.88	1.68	0.79
20	11.21	25.19	2.19	2.09

Table 11—Comparison in Varying Tension with Nip Load = 100 lbs and Torque 2= 100 in-lbs

Variable Drum 2 Torque

Figure 30 and Table 12 show results when varying torque to the second drum at 50, 100, and 150 in-lbs, with nip load at 100 lbs, and incoming web tension at 12 lbs. It is clear that this torque has a large influence on WOT and WOT PT, with the relationship nearly linear in both cases. It appears that if Torque 2 is divided by the drum radius, all of the force enters WOT and WOT PT.

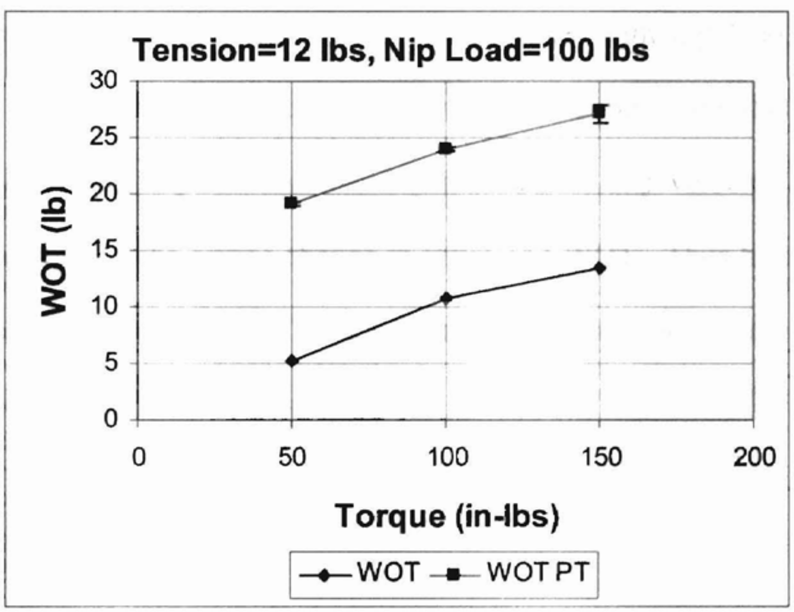

Figure 30—Results When Varying Drum 2 Torque

Torque 2 (in-lbs)	Torque 2/Radius**	WOT (lbs)	WOT PT (lbs)	Torq2/Rad-4.2	WOT-5.21	WOT PT - 19.11
50	4.2	5.21	19.1	0	0	0
100	8.3	9.0	23.09	4.1	3.82	3.99
150	12.5	13.4	27.12	8.3	8.19	8.02
**This is the force on the web due to Torque 2, =Torq2/Drum Radius (12")						

Table 12—Comparison in Varying Torque 2 with Nip Load=100 lbs, and Tension = 12 lbs

Variable Nip Load

Figure 31 and Table 13 show values when varying nip load with tension at 12 lbs, and torque 2 at 100 in-lbs. WOT appears to be nearly independent of the nip load whereas WOT PT is affected by nip load. This suggests that drums 1 and 2 must be inducing the same relative slip velocity between layers 1 and 2 in the wound roll. As long as the difference in slip velocity are the same, WOT is expected to be constant. A large percentage of WOT is due to Torque 2 which in these cases is 100/12, or 8.33 lbs. WOT PT increases with nip load, which suggests that the slip velocity increases with nip load but with this is the assumption by the time layer 1 becomes layer 2 that the slip velocity is zero. Change in velocity in webs causes change in strain and WOT. Thus had it been physically possible to locate a WOT load cell roller between drums 1 and 2 there would have been measured increases in WOT.

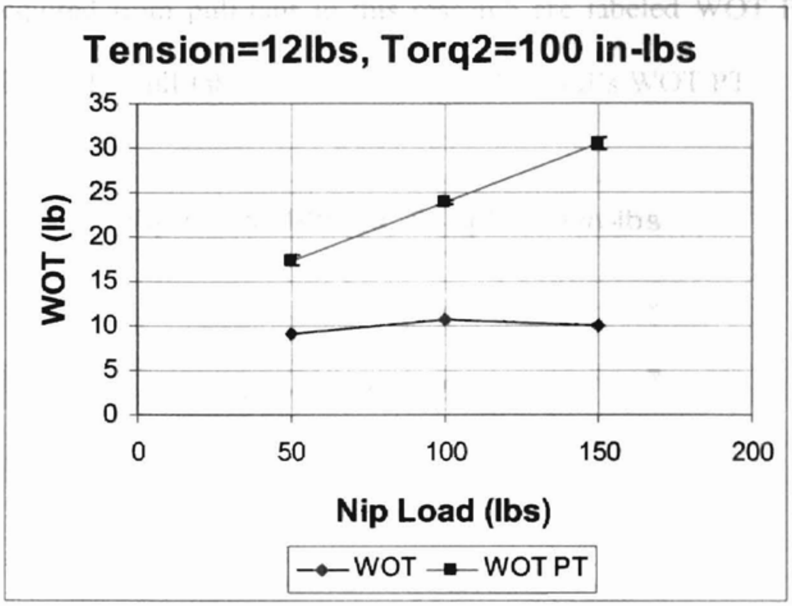

Figure 31—Results When Varying Nip Load

Nip Load (lbs)	WOT (lbs)	WOT PT (lbs)
50	8.99	17.37
100	9.03	23.09
150	9.55	30.4

Table 13—Comparison in Varying Nip Load with Torque 2=100 lbs, and Tension = 12 lbs

Comparison With Dolezal's Data

The graphs that follow (Figures 32, 33, and 34) show comparisons between Dolezal's data and the data found in this research, and Table 14 lists actual data values. The only difference between Dolezal's setup and this research is the nip roller. In his research, he used three different sizes of nip rollers (2", 6½", and 10" diameter); whereas in this research, recall there is no nip roller. For comparison purposes, only his 6½" data will be used.

Data acquired from pull-tabs in this research are labeled WOT PT, and data obtained Dolezal's pull-tab results are labeled "Dolezal's WOT PT.

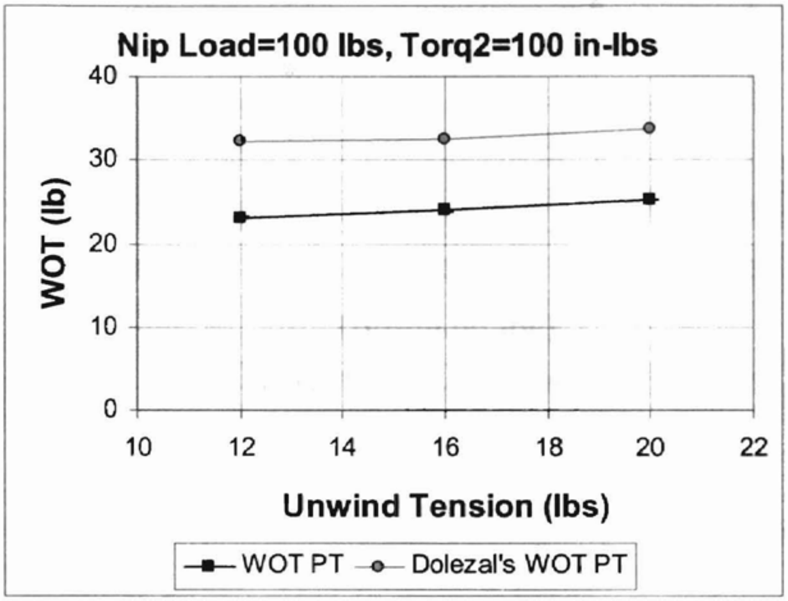

Figure 32—Comparison with Dolezal's Data for Variable Tension

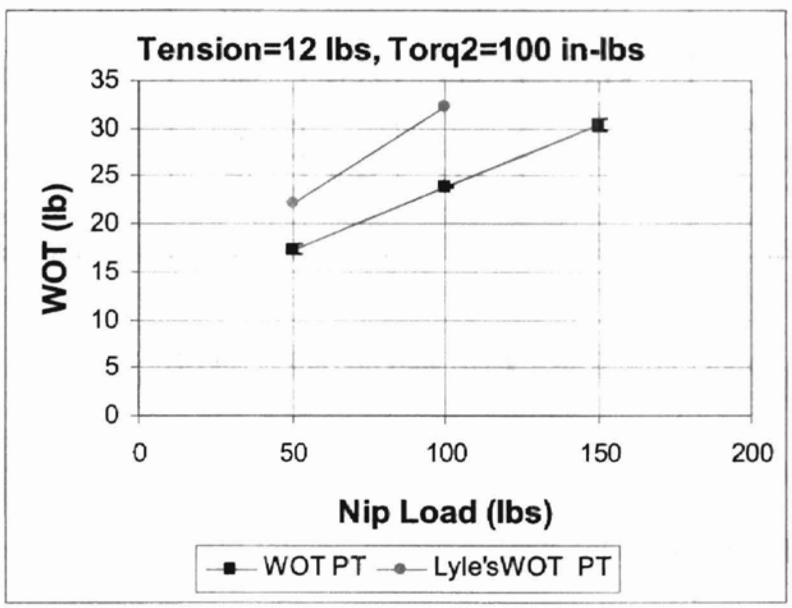

Figure 33—Comparison with Dolezal's Data for Variable Nip Load

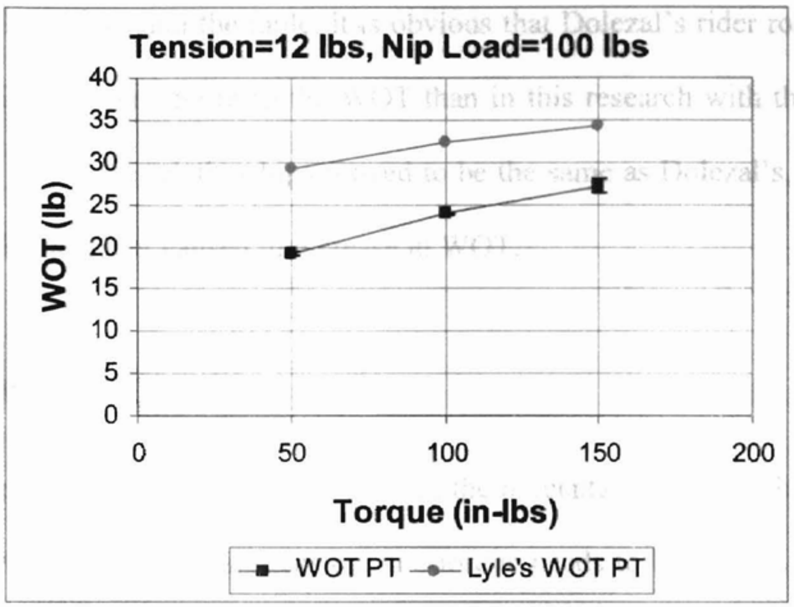

Figure 34—Comparison with Dolezal's Data for Variable Torque 2

Test No.	Tension (lbs)	Torque 2 (in-lbs)	Nip Load (lbs)	WOT (lbs)	WOT PT (lbs)	Dolezal's WOT (lbs)	Dolezal's WOT PT (lbs)
1	12	100	100	9.03	23.1	22.7	32.3
2	16	100	100	10.70	23.9	23.4	32.5
3	20	100	100	11.21	25.2	23.9	33.7
4	12	50	100	5.21	19.1	18.5	29.3
5	12	150	100	13.40	27.1	26.8	34.4
6	12	100	50	8.99	17.4	17.0	22.2
7	12	100	150	9.95	30.4	N/A	N/A
	12	100	200	N/A	N/A	28.40	No Data

Table 14—Results of Current Data Along With Dolezal's Data

Notice in his tests the maximum nip load is 200 lbs. This could not be repeated in this research for only 150 lbs. of lead weights could fit inside the core. Also, on this specific test number where he used 200 lbs. nip, the force necessary to dislodge his pull-tabs was too great to pull by hand and therefore he has no data.

From the figures and the table, it is obvious that Dolezal's rider roll (nip) in place contributed much more to the WOT than in this research with the rider roll retracted. All of the relationships proved to be the same as Dolezal's, in that increasing each parameter caused in increase in WOT.

An Empirical Model

In order to develop an empirical model, the percentage of force that goes directly into WOT from nip load, tension, and torque needs to be known. In the plot of WOT PT vs. varying unwind tension the slope is about 0.26. The slope of WOT PT with respect to nip load is about 0.12. It was assumed that nearly all of torque 2 becomes WOT PT if divided by drum radius therefore the following equation can be obtained:

$$WOT\ PT_{MODEL} = \frac{Torque2}{12} + .12 * Nip\ Load + .26 * Tension$$

and Table 14 shows the results when using this equation. It is apparent that each variable input parameter: torque2, nip load, and tension all impact the WOT in two-drum winding with the rider roll retracted.

Tension (lbs)	Torque 2 (in-lbs)	Nip Load (lbs)	WOT PT $_{actual}$ (lbs)	WOT PT $_{model}$ (lbs)	% Error
12	100	100	23.1	23.45	-1.55
16	100	100	23.9	24.49	-2.52
20	100	100	25.2	25.53	-1.37
12	50	100	19.1	19.29	-0.94
12	150	100	27.1	27.62	-1.84
12	100	50	17.4	17.45	-0.48
12	100	150	30.4	29.45	3.16

Table 15—Comparison in WOT PT Between Actual Results and Results From the Model

Summary of Results from Altering the Web Path

- Winding the nine test cases in one wound roll while collecting WOT data proved to be a good method for gathering data quickly.

- Increasing unwind tension has a large effect on WOT in path 4 for both newsprint and Tyvek®, causing a linear increase in tension. Paths 1-3 show only slight increases in WOT for Tyvek® and on newsprint the increase is small at best.

- Increasing the nip load causes an increase in WOT for all paths on both newsprint and Tyvek®.

- Increasing the torque to drum 2 causes almost no change in WOT for paths 2 and 3. Path 1 shows a linear increase in tension for both newsprint and Tyvek®, and Path 4 shows a linear decrease in tension for both materials also.

Summary of Results from Removing the Nip Roller

- Increasing unwind tension showed a small and equal increase in WOT and WOT PT.

- Increasing Drum 2 Torque increased WOT and WOT PT linearly.

- Increasing Nip Load increased WOT PT linearly, but had no effect on WOT.

- The nip-induced-tension from Dolezal's rider (nip) rollers contributed much more to the WOT than the nip-induced-tensions which resulted from the 24" OD drums by themselves.

- An empirical model with linear dependencies on web tension and nip load and directly dependent on drum 2 torque divided by drum radius yielded % errors of 3% and less for all winding cases.

CHAPTER 5

CONCLUSION

There were two main goals in this research. The first was to study the effects of altering the web path, and the second to discover what results when the nip roller is retracted on a two-drum winder.

Altering the Web Path

Experiments were run on the two-drum web winder with different input parameters for four different web paths (Figure 11), and two different web materials, newsprint and Tyvek®. Drum 1 was in speed control and drum 2 was in torque control. The results show that:

- Increasing Unwind Tension causes a small increase in paths 1,2, and 3 for Tyvek®, and a smaller increase in Newsprint for the same paths. Path 4 however is very dependent on unwind tension for both newsprint and Tyvek®.

- Increasing Nip Load causes increases in WOT for all web paths on both newsprint and Tyvek®. On newsprint, paths 1 and 4 and paths 2 and 3 show very similar behavior.

- Increasing Drum 2 Torque has no effect on paths 2 and 3 for both newsprint and Tyvek®. Path 1 shows a linear increase in WOT as drum 2 torque increases. However, path 4 showed a linear decrease in WOT as torque 2 increased.

- The paths with the most controllable parameters for WOT are paths 1 and 4 for they have three different input parameters that can be altered to make adjustments in the final tension: nip load, incoming web tension, and torque to the motors.

Retracting the Nip Roller

The second goal of this research was to find the outcome of removing the nip roller. These experiments involved measuring tension through the use of pull-tabs along with force gages. These results were compared with the previous research which included the presence of a nip roller.

- Increasing unwind tension showed a small increase in WOT.

- Increasing Drum 2 Torque increased WOT linearly.

- Increasing Nip Load increased WOT linearly.

- Nip-induced-tensions were much higher in Dolezal's results, coming from the nip roller, of smaller diameter than the drums. With the nip roller extracted, the nip-induced-tensions came from the drums alone.

- An empirical model was found with dependencies on web tension, nip force, and torque to the second drum. WOT is linearly dependent on web tension and nip force, and directly dependent on torque 2.

Future Work

The results of this research showed that changing the web path does have an effect on the WOT. After discovering this, the next step would be to develop a model that could predict the tension depending on the input variables: nip load, torque, and perhaps even incoming web tension for it did show small changes in the final wound-on-tension.

This appears possible based upon the empirical model developed herein for path 1. It would be preferable to develop a theory however, which would predict the proportional constants.

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APPENDIX

PULL-TAB EXPERIMENT RESULTS

Tables 16-21 show results from each pull-tab experiment. The force required to dislodge the tab is listed as well as the pressure inferred from the winding code. Also shown are the standard deviation and the 95% confidence interval.

Pull Tab Test Data

Condition Number	2
Tension (lbs)	16
Torque 2 (in-lb)	100
Nip Load (lbs)	100

Run 1	Tab	G	M	F	J	E	D	C	L	B	A
	Location	0.5	1	1.5625	2	2.1875	2.625	3	3	3.375	3.6875
	Pull 1	46.4	29.6	40.7	35.9	47.4	37.4	46.9	38	33.1	28.9
	Pull 2	47.2	29	39.6	36.5	48.2	38.8	42.1	39.2	33.0	27.1
	Pull 3	47.3	28.9	39.5	36.9	47.6	40.3	42.6	38.8	32.1	27.6
	Average	46.97	29.17	39.93	36.43	47.73	38.83	43.87	38.67	32.73	27.87
	Pressure	16.38	15.93	16.10	18.30	17.49	16.55	15.99	16.45	15.34	13.20

Run 2	Tab	O	M	F	J	D	L	N	B	A
	Location	0.5	1	1.5625	2	2.625	3	3	3.375	3.6875
	Pull 1	37.5	33.8	39.7	33.8	40.4	39.7	35.4	36.3	27.2
	Pull 2	35.1	33.9	40.9	35.7	40.3	39	33.6	35.7	27.8
	Pull 3	35.1	33.8	40.4	35.9	40.8	39.6	33.5	36.0	27.8
	Average	35.90	33.83	40.33	35.13	40.50	39.43	34.17	36.00	27.60
	Pressure	16.47	18.52	16.27	17.49	17.29	16.80	18.04	17.12	13.08

Run 3	Tab	A	B	L	N	D	J	F	M	O
	Location	0.5	1	1	1.5	2	2.625	3	3.375	3.6875
	Pull 1	30.1	34.4	39.6	34.3	38.4	34.2	40.2	34.7	29.8
	Pull 2	29.7	31.9	40.5	33.6	39.7	34.9	41.8	34	28.8
	Pull 3	30.7	33.7	40.9	33.1	39.8	34.6	42.4	35	28.9
	Average	30.17	33.33	40.33	33.67	39.30	34.57	41.47	34.57	29.17
	Pressure	14.27	15.66	17.21	17.76	16.76	17.14	16.75	18.92	9.96

Summary of Results	
Run 1: WOT Inferred Using Winding Code (lbs)	23.45
Run 2: WOT Inferred Using Winding Code (lbs)	24.17
Run 3: WOT Inferred Using Winding Code (lbs)	24.03
Average WOT Inferred (lbs)	23.88
Standard Deviation (lbs)	0.31
95% Confidence Interval (lbs)	0.35

Table 16—Pull-Tab Record for Test Condition 2: 16 lbs Tension, 100 in-lbs Torque 2, 100 lbs Nip Load

Pull Tab Test Data

Condition Number	3
Tension (lbs)	20
Torque 2 (in-lb)	100
Nip Load (lbs)	100

Run 1	Tab	O	M	F	J	D	L	N	B	A
	Location	**0.5**	**1**	**1.5625**	**2**	**2.625**	**3**	**3**	**3.375**	**3.6875**
	Pull 1	37	33.8	40.2	37	42.4	44.3	36.3	37.9	29.6
	Pull 2	39.1	33.1	40.9	36.8	42.5	43.1	36.2	38.0	30.4
	Pull 3	37.7	33.1	42.2	37.4	43.1	44	35.8	38.1	29.9
	Average	37.93	33.33	41.10	37.07	42.67	43.80	36.10	38.00	29.97
	Pressure	17.6014	18.2383	16.5923	18.69813	18.24443	18.80124	19.09786	18.2103	14.17387

Run 2	Tab	O	M	F	J	Q	P	R	B	A
	Location	**0.5**	**1**	**1.5625**	**2**	**2.625**	**3**	**3**	**3.375**	**3.6875**
	Pull 1	38.8	34.5	41.6	37.9	36.2	33	34.9	38.9	29.4
	Pull 2	38.7	32.8	42.2	37.1	36.4	33.7	34.7	36.6	28.2
	Pull 3	39.8	34.5	42.9	38.7	37.5	31.1	35.5	36.7	29.7
	Average	39.10	33.93	42.23	37.90	36.70	32.60	35.03	37.40	29.10
	Pressure	18.2489	18.57112	17.0683	19.2173	19.46919	18.95878	16.44388	17.88288	13.77278

Run 3	Tab	O	M	F	J	T	P	S	B	A
	Location	**0.5**	**1**	**1.5625**	**2**	**2.625**	**3**	**3**	**3.375**	**3.6875**
	Pull 1	37.9	35.9	41.8	38.2	38.7	35.4	36	40.2	28.7
	Pull 2	38.4	36.2	42.7	37.3	38	35.5	34.7	38.0	31.6
	Pull 3	38.3	35	42.8	38.2	37.5	36	35.1	38.0	30.8
	Average	38.20	35.70	42.43	37.90	38.07	35.63	35.27	38.73	30.37
	Pressure	17.7494	19.55109	17.1523	19.2173	18.23067	20.87827	17.25016	18.61048	14.35899

Summary of Results	
Run 1: WOT Inferred Using Winding Code (lbs)	25.04175
Run 2: WOT Inferred Using Winding Code (lbs)	25.33125
Run 3: WOT Inferred Using Winding Code (lbs)	25.1865
Average WOT Inferred (lbs)	25.1865
Standard Deviation (lbs)	0.118188
95% Confidence Interval (lbs)	0.13374

Table 17—Pull-Tab Record for Test Condition 3: 20 lbs Tension, 100 in-lbs Torque 2, 100 lbs Nip Load

Pull Tab Test Data

Condition Number	4
Tension (lbs)	12
Torque 2 (in-lb)	50
Nip Load (lbs)	100

Run 1	Tab	A	B	S	T	J	F	P	M	O*
	Location	**0.5**	**1**	**1.5**	**2**	**2.625**	**3**	**3**	**3.375**	**3.6875**
	Pull 1	26.2	26.7	28.7	27.7	25.7	28.1	24.8	24.8	19.6
	Pull 2	25.5	25.4	27.9	26.5	24	27.9	24.7	23.5	19.6
	Pull 3	24.9	25.8	25.6	26.2	24.7	27.9	24.1	25.4	19.7
	Average	25.53	25.97	27.40	26.80	24.80	27.97	24.53	24.57	19.63
	Pressure	12.12213	11.64371	12.46644	11.9495	11.056	11.0763	13.85419	13.37543	7.4449

Run 2	Tab	A	V	S	T	J	W	P	M	U
	Location	**0.5**	**1**	**1.5**	**2**	**2.625**	**3**	**3**	**3.375**	**3.6875**
	Pull 1	24.6	24.5	27.2	25.6	24.2	23.3	23.8	25	17.8
	Pull 2	24.4	25.0	27.4	25.3	24.2	23.6	23.8	24.7	20.3
	Pull 3	25	25.2	25.8	25	24.3	23.8	24.2	24	20.4
	Average	24.67	24.90	26.80	25.30	24.23	23.57	23.93	24.57	19.50
	Pressure	11.72103	10.38126	12.10158	11.11325	10.70297	9.985307	13.47451	13.37543	8.62615

Run 3	Tab	U	M	W	J	T	P	S	V	A
	Location	**0.5**	**1**	**1.5625**	**2**	**2.625**	**3**	**3**	**3.375**	**3.6875**
	Pull 1	26.9	26.8	23.5	25.5	26.3	25.1	23.8	24.1	21.6
	Pull 2	26.5	28.3	22.7	23.9	25.2	24.3	23.6	23.2	20.5
	Pull 3	26.3	27.5	22.7	24.4	25.2	25.4	23.1	22.9	20.6
	Average	26.57	27.53	22.97	24.60	25.57	24.93	23.50	23.40	20.90
	Pressure	12.24923	15.02104	9.640547	10.9314	11.26192	14.10731	10.09485	9.61416	9.97782

Summary of Results	
Run 1: WOT Inferred Using Winding Code (lbs)	19.686
Run 2: WOT Inferred Using Winding Code (lbs)	19.107
Run 3: WOT Inferred Using Winding Code (lbs)	18.528
Average WOT Inferred (lbs)	19.107
Standard Deviation (lbs)	0.472752
95% Confidence Interval (lbs)	0.534958

Table 18—Pull-Tab Record for Test Condition 4: 12 lbs Tension, 50 in-lbs Torque 2, 100 lbs Nip Load

Pull Tab Test Data

Condition Number	5
Tension (lbs)	12
Torque 2 (in-lb)	150
Nip Load (lbs)	100

Run 1	Tab	A	V	P	S	T	J	W	M	U
	Location	0.5	1	1.5	1.5	2	2.625	3	3.375	3.3875
	Pull 1	38.1	36.4	41.2	39.5	42.4	42.7	40.5	37.2	31.8
	Pull 2	40	40.6	43.6	43.9	46.6	43.2	39.5	40.2	32
	Pull 3	41.7	40.6	42.7	40.6	45.9	41.8	40.5	38.1	31.5
	Average	39.93	39.20	42.50	41.33	44.97	42.57	40.17	38.50	31.77
	Pressure	18.78645	17.69428	25.2235	20.9393	22.07742	22.12463	19.52367	21.10425	14.91527

Run 2	Tab	V	P	S	X	J	W	M	U
	Location	1	1.5	1.5	2	2.625	3	3.375	3.6875
	Pull 1	34.2	39.8	39.1	33.3	37.8	37.2	33.2	28.1
	Pull 2	33.4	37.1	38.3	36.1	36.3	36.9	33.6	27.7
	Pull 3	33.4	35.4	37.8	33.2	35	36.4	34.3	26.4
	Average	33.67	37.43	38.40	34.20	36.37	36.83	33.70	27.40
	Pressure	14.86453	22.01731	19.15554	18.11024	18.26203	17.60833	18.44169	12.67648

Run 3	Tab	U	M	W	J	X	P	S	V
	Location	0.5	1	1.5625	2	2.625	3	3	3.375
	Pull 1	45.2	44.3	47.1	46.1	43.2	41.3	47.2	40.5
	Pull 2	46.9	43.8	47.3	47.2	43.3	43.4	45.4	40.0
	Pull 3	45.4	42.3	45.2	46.9	43.2	41.7	46.6	39.1
	Average	45.83	43.47	46.53	46.73	43.23	42.13	46.40	39.87
	Pressure	22.12725	23.85926	23.18195	24.72047	23.90693	24.99147	24.02034	18.03521

Summary of Results	
Run 1: WOT Inferred Using Winding Code (lbs)	26.9235
Run 2: WOT Inferred Using Winding Code (lbs)	25.476
Run 3: WOT Inferred Using Winding Code (lbs)	28.95
Average WOT Inferred (lbs)	27.1165
Standard Deviation (lbs)	1.424805
95% Confidence Interval (lbs)	1.612287

Table 19—Pull-Tab Record for Test Condition 5: 12 lbs Tension, 150 in-lbs Torque 2, 100 lbs Nip Load

Pull Tab Test Data

Condition Number	6
Tension (lbs)	12
Torque 2 (in-lb)	100
Nip Load (lbs)	50

Run 1	Tab	V	P	S	X	J	W	M	U
	Location	**1**	**1.5**	**1.5**	**2**	**2.625**	**3**	**3.375**	**3.6875**
	Pull 1	25.4	22.2	26.7	26.7	27.0	25.7	25.1	21.7
	Pull 2	23.5	22.4	24.7	24.5	25.8	25.2	23.6	20.4
	Pull 3	22.4	22.5	24.7	23.7	25.4	25.2	23.5	19.7
	Average	23.77	22.37	25.37	24.97	26.07	25.37	24.07	20.60
	Pressure	9.801673	12.48313	11.22997	12.18521	11.84513	11.01959	13.09808	9.19012

Run 2	Tab	U	M	W	J	X	P	S	V
	Location	**0.5**	**1**	**1.5625**	**2**	**2.625**	**3**	**3**	**3.375**
	Pull 1	19.2	18.2	21.4	24.2	21.9	21.3	23	18.3
	Pull 2	17.1	16.7	20.9	22.8	20.6	19.5	20.9	16.5
	Pull 3	18.2	17.9	22.4	22.1	21.5	20.9	21.4	17.2
	Average	18.17	17.60	21.57	23.03	21.33	20.57	21.77	17.33
	Pressure	7.94255	9.51102	9.955367	6.511667	9.8537	11.34409	9.04081	8.836107

Run 3	Tab	V	P	S	X	J	W	M	U
	Location	**1**	**1.5**	**1.5**	**2**	**2.625**	**3**	**3.375**	**3.6875**
	Pull 1	22.2	21.2	22.6	20.2	22.9	24.9	21.8	16.2
	Pull 2	20.0	20.2	21.5	20.1	23.1	24.6	20.2	14.8
	Pull 3	20.3	20.8	21	20.1	23.2	24.0	21.2	14.3
	Average	20.83	20.73	21.70	20.13	23.07	24.50	21.07	15.10
	Pressure	8.301567	11.44955	9.00027	9.08366	9.976133	10.5216	11.43398	6.37027

Summary of Results	
Run 1: WOT Inferred Using Winding Code (lbs)	18.528
Run 2: WOT Inferred Using Winding Code (lbs)	16.212
Run 3: WOT Inferred Using Winding Code (lbs)	17.37
Average WOT Inferred (lbs)	17.37
Standard Deviation (lbs)	0.945503
95% Confidence Interval (lbs)	1.069916

Table 20—Pull-Tab Record for Test Condition 6: 12 lbs Tension, 100 in-lbs Torque 2, 50 lbs Nip Load

Pull Tab Test Data

Condition Number	7
Tension (lbs)	12
Torque 2 (in-lb)	100
Nip Load (lbs)	150

Run 1								
	Tab	U	M	J	X	P	S	V
	Location	**0.5**	**1**	**2**	**2.625**	**3**	**3**	**3.375**
	Pull 1	45.6	42.2	43.1	42.3	40.1	40.2	32.4
	Pull 2	46.9	43.2	45.4	42.3	40.1	39.5	32.6
	Pull 3	44.3	43.9	44.8	43.4	39.9	41.4	33.1
	Average	45.60	43.10	44.43	42.67	40.03	40.37	32.70
	Pressure	22.00762	23.65587	23.28757	23.5433	23.66259	20.35147	14.37018

Run 2								
	Tab	V	P	S	X	J	M	U
	Location	**1**	**1.5**	**1.5**	**2**	**2.625**	**3.375**	**3.6875**
	Pull 1	43.3	44.2	47.3	47	45.3	41.5	35.8
	Pull 2	45.1	44.7	48	46.1	45	42.9	35.1
	Pull 3	45.2	42.5	49	46.6	45.8	41.7	34.4
	Average	44.53	43.80	48.10	46.57	45.37	42.03	35.10
	Pressure	20.42175	26.04614	25.05411	26.04593	23.86903	23.06419	16.62427

Run 3								
	Tab	U	M	J	X	P	S	V
	Location	**0.5**	**1**	**2**	**2.625**	**3**	**3**	**3.375**
	Pull 1	50.4	45.4	47.1	47.6	42.9	43.1	33.4
	Pull 2	49	45.9	47.6	46.7	43.2	42.5	32.8
	Pull 3	48.4	45.9	47.2	49.1	43.8	43.1	33.1
	Average	49.27	45.73	47.30	47.80	43.30	42.90	33.10
	Pressure	23.88752	25.11658	25.0735	26.83736	25.72974	21.89199	14.57474

Summary of Results	
Run 1: WOT Inferred Using Winding Code (lbs)	28.95
Run 2: WOT Inferred Using Winding Code (lbs)	31.845
Run 3: WOT Inferred Using Winding Code (lbs)	30.3975
Average WOT Inferred (lbs)	30.3975
Standard Deviation (lbs)	1.181879
95% Confidence Interval (lbs)	1.337395

Table 21—Pull-Tab Record for Test Condition 7: 12 lbs Tension, 100 in-lbs Torque 2, 100 lbs Nip Load

VITA

Barbara R. Cowan

Candidate for the Degree of

Master of Science

Thesis: EFFECTS OF NIP ROLLERS AND THREAD PATH ON TWO- DRUM WINDING

Major Field: Mechanical Engineering

Biographical:

Education: Graduated from Locust Grove High School, Locust Grove, Oklahoma in May 1993; received Bachelor of Science degree in Mechanical Engineering from Oklahoma State University, Stillwater, Oklahoma in May 1999. Completed the requirements for the Master of Science degree with a major in Mechanical Engineering at Oklahoma State University in August 2001.

Experience: Raised in Stinnett, Texas; worked for Lennox Industries, Dallas, Texas, and Stuttgart, Arkansas as a co-op engineer fall of 1996, summer of 1997, spring and summer of 1998. Served as a lab assistant in the Mechanical Engineering North Lab from November 1998 until January 2001. Also employed as a Research Assistant from October 1999 until January 2001.