INSTRUMENTING ROLLING NIPS FOR VIDEO RECORDING AND STRAIN RECORDING

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ABSTRACT

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

NOMENCLATURE

T web tension in N/m (or pli)
P pressure, Pa (or psi)
dP differential pressure, Pa (or psi)
R roll radius, m (or inches)

Introduction

Investigations in the mid-1960's showed that the rolling of a winder drum or nip cylinder on the outside of the winding roll of paper would produce tensions following the nip which were higher that the incoming web tension (1,2). Less is known about the action of rolling as it affects those sheets of material that lie below the outer one. The disturbance due to the moving wave of pressure that the nip sends through the wraps already on the roll is suspected of doing great harm, the least of which is to cause a slight reduction of tension in a few of the layers. At the other end of the spectrum we have serious mechanical damage where the sheet is forced to break in the MD or CMD, sometimes with microscopic tears and sometimes with long breaks running 8 or 10 meters in the machine direction, or CMD breaks that weaken the sheet to the point of failure. And what about the mysterious formation of crepe wrinkles? At what point does the movement of the sheet start and stop, enabling tiny wrinkles to pile up in one-quarter or less of their flat-sheet length, while neighboring sheets above or below this location seem defect free? We are quite sure that the nip plays a large part in this, but it can't be the sole cause. In particular, in the production of paper, and more specifically in newsprint production where this defect frequently occurs, it is well know that paper properties have a large influence on whether the trouble persists or goes away. Some paper companies have no crepe wrinkle problems in one mill but are plagued with defects in another of their mills making what is said to be the same product and winding it on the same winding equipment.

Studies of rolling nips

In the 1968 rolling nip study (2), a flat plate was used to simulate the interior of the roll body. That did not allow any possibility for the pressure between layers to be built up on a wrap-by-wrap basis by the tension in individual sheets. (Each wrap contributes a differential pressure of **dp = T/R** Pascals (or psi) to the total pressure acting on the wrap below, and the pressure rises almost linearly for the first dozen or so wraps beneath the nip.)

Recent studies of winding have shown that friction acts to limit the development of induced tension (3), and that the travelling pressure wave created by the nip can be viewed as uniquely responsible for the development of induced tension (4). Certainly when the roll is viewed as a free body, it rests with the inter-layer friction to hold the roll in a wound condition, and the same is true as the roll winds, the friction is the safety valve against excessive tension production. These studies do not treat the mechanism which would explain straining in a direction opposite to tension production in those layers beneath the nip.

Development of experimental machinery

After many years of planning to build an instrumented nip that would be constructed on basis of the curved geometry of an actual roll, the opportunity to actually build it occurred in 1990, when Bernhard Moser was visiting from the University of Aachen, Germany. He needed a final year design project to complete his Diploma of Engineering work at the University, and spent seven very productive months in building and calibrating the apparatus shown in Figs 1 and 2.

This piece of laboratory apparatus for studying the slow speed rolling action of a nip consists of a 22" dia cylinder, 4" wide and 1.5 inches wall thickness, around which a rolling cylinder of 8" dia. by 3" width travels. A moving arm or frame pivots at the center of the apparatus and carries the roller with it, while a small pneumatic cylinder provides the adjustable level of nip force. The roller arm is neutrally counterbalanced on the frame to cancel the effect of gravity on the nip force. Each end of every strip of paper which wraps the larger steel cylinder (which represents the relatively hard roll body) is attached to a proving ring load cell which measures its tension. There are thirty of these load cells, allowing 15 strips of paper to be measured simultaneously.

To facilitate capturing the load cell readings in real time, the 30 channels of load cell readings are individually amplified and conditioned by a bank of chopper-stabilized amplifiers (Fig. 2) which eliminate zero drift, and the outputs are fed to two 16-channel PCL 812 Lab Tech Data Acquisition cards in a computer. This allows two extra channels, one of which is used to pick up the angular degree of rotation of the frame arm, through a potentiometer mounted at its center of rotation. The acquisition of data is triggered at even increments of the arm rotation which are selectable at the start of the program. As the data are captured, they are presented on the monitor screen of the computer as a separate line drawn in a curve of tension vs angle of rotation for each of the 15 sheets. Different colors are used to indicate the load cells on opposite ends of the sheets. The numerical values of every data point are written to a file in the computer memory, and this may be transferred to a floppy disk for further analysis in a spreadsheet. From this hard-copy graphs may be drawn in greater detail than the screen presentation of data.

Video monitoring of web strains

An Infinity Continuous Focus Microscope is mounted rigidly to the stationary drum at a location which allows it to zoom in on the sheets in the nip. This unusual piece of optical hardware has 14 lens elements in 8 groups, allowing it to focus from scenes in the distance (out the window, for instance) down to a working distance of 6 mm, where it can produce an optical magnification of 360 to 1 when equipped with a charge-coupled miniature television camera and suitable size high-resolution monitor. In addition, a ring of fibre optic illuminators surrounds the nose of the microscope to provide brilliant illumination in shadowed working conditions. Using this microscope it is quite easy to magnify the side view of the 15 sheets of paper that are in the nip to fill the entire frame of the television monitor. The video signal from the camera amplifier may be recorded directly on a video cassette recorder for later playback and analysis.

At an overall magnification of 150 to 1 or greater, one sees a picture that is quite different than would be expected from a rolling cylinder. The axis of rotation is so far away that only the slightly curved surface of the roller periphery is seen approaching the web, and the action of the roller surface meeting the webs is a sort of heel-and-toe motion that looks like a shoe sole walking across a soft carpet. Although the degree of straining that the eye can detect through the microscope is less than the strain gages can pick up, the basic motion that rocks a packet of the web material as the rolling contact goes by can be seen to suggest a definite thrusting of material in the reverse direction at a depth several sheets down from the surface. The reverse direction is that opposite to the tensile straining direction whereby the outer sheet was initially tightened when applied to the roll.

Experimental analysis

Fifteen strips of newsprint of 91 micron (0.0037") thickness and 90 mm width were attached to the load cells and pre-tensioned to two tension levels, 200 N/m and 400 N/m. Three magnitudes of nip force were used as shown in the table below.

Table I

Run identification for nip and tension	Tension 200 N/m	Tension 400 N/m
Nip force 700 N/m	N1T1	N1T2
Nip force 1400 N/m	N2T1	N2T2
Nip force 2100 N/m	N3T1	N3T2

Although each web experienced its own curve of tension versus angle of nip roller displacement, the most significant fact emerged from a comparison of the beginning and final web tensions for each of the sheets. This allowed a significant reduction in the quantity of data to be presented. (Over 1500 real numbers of data were produced for each traverse of the nip roller.) As seen in Fig. 3 through Fig. 8, the left load cell of the top one or two sheets in each run experienced a large increase of tension, which is normal when nip-induced tension is produced. The right load cells of the same webs experienced a corresponding loss of tension, which approached 100% for the higher nip runs. But the layers beneath the top ones experienced opposite directions of tensile straining. Righthand load cells of the third, fourth, and fifth webs below the top showed increased tension, indicating straining in a direction opposite to the direction of motion of the nip. The lefthand load cells of the same webs indicated corresponding losses of tension. The shape of the curves in Figs. 3 to 8 argue for the type of moment generation of tension as would be expected from rotation about an instant center (2).

CONCLUSIONS

In summary, with this new apparatus we are able to study the differential straining created by the motion of one web over another. For the first time, numerical values of straining have been documented which show that the direction of web motion in underlying layers is opposite to that of tensile straining. The data acquisition system allows capture of these numerical values, and the CFM microscope permits visualization of the manner in which these deformations occur. When more compressible materials or backup layers are added, these motions should become even more visible.

ACKNOWLEDGMENTS

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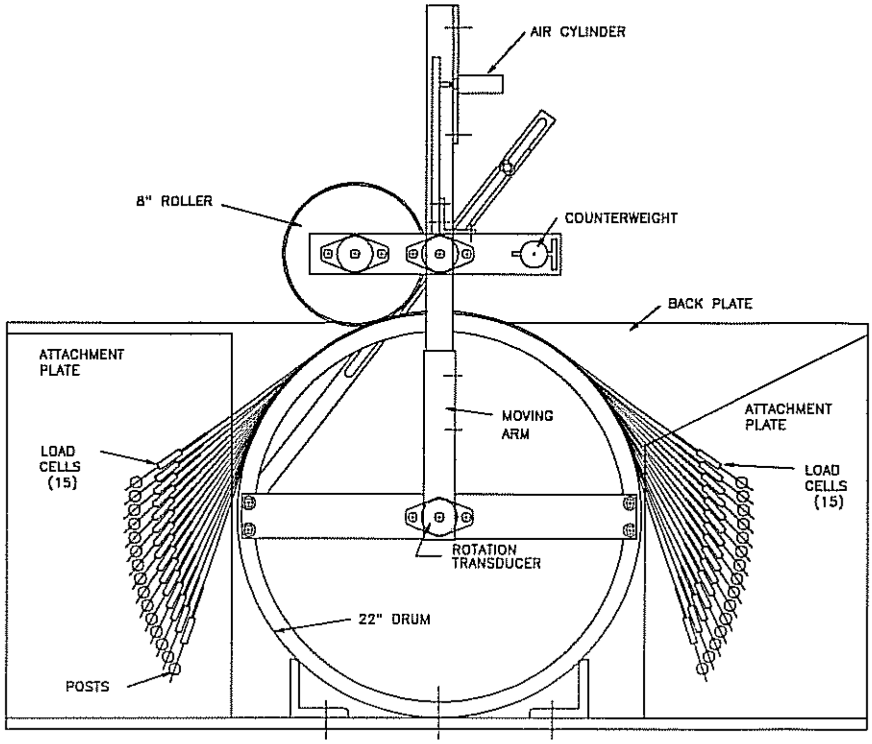


Fig.1 Rolling nip strain measuring apparatus

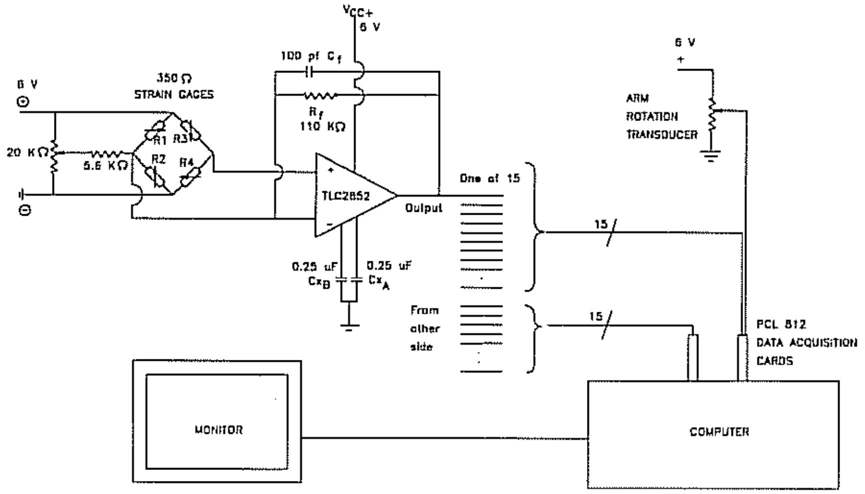
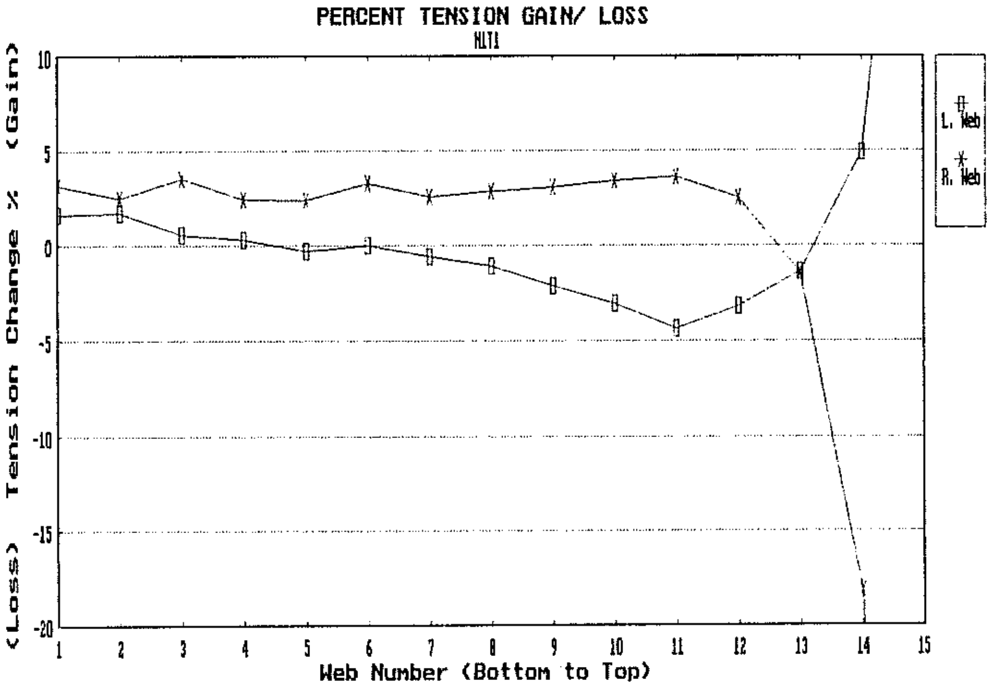
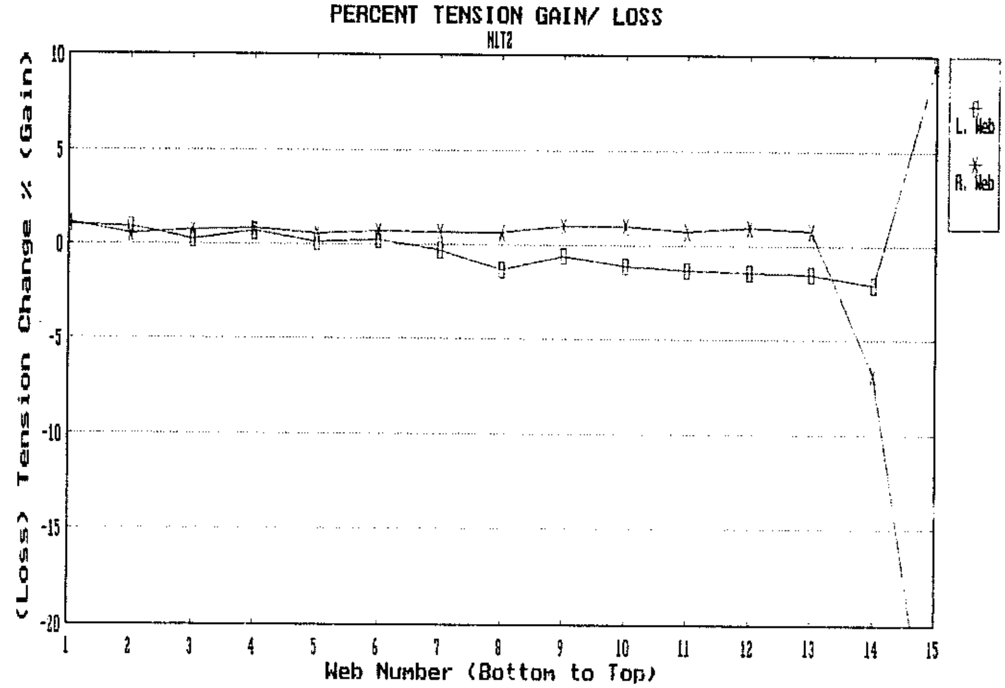


Fig.2 Data acquisition and amplifiers



Web	L. ~T.	L. %T.	Web	R. ~T.	R. %T.
1	0.235	1.636	1	0.422	3.139
2	0.198	1.679	2	0.306	2.448
3	0.075	0.546	3	0.497	3.502
4	0.038	0.289	4	0.335	2.418
5	-0.038	-0.274	5	0.348	2.374
6	0.000	0.000	6	0.426	3.256
7	-0.078	-0.583	7	0.347	2.545
8	-0.144	-1.077	8	0.388	2.828
9	-0.297	-2.115	9	0.384	3.039
10	-0.421	-3.054	10	0.423	3.385
11	-0.604	-4.352	11	0.472	3.580
12	-0.485	-3.207	12	0.318	2.517
13	-0.193	-1.362	13	-0.194	-1.421
14	0.694	4.883	14	-2.078	-18.184
15	5.381	35.681	15	-10.092	-75.722

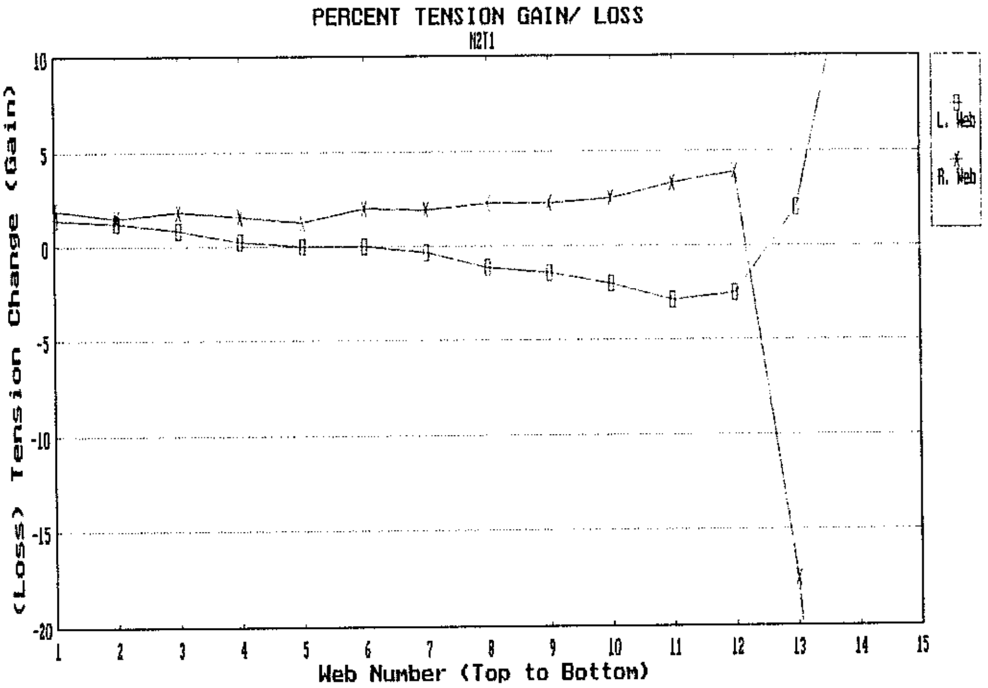
Fig.3 Run N1T1, 700 pli nip, 200 pli tension



Web	L. ~T.	L. %T.
1	0.275	1.044
2	0.237	0.901
3	0.075	0.259
4	0.189	0.678
5	0.038	0.137
6	0.075	0.265
7	-0.078	-0.292
8	-0.322	-1.328
9	-0.148	-0.581
10	-0.307	-1.104
11	-0.377	-1.314
12	-0.373	-1.470
13	-0.425	-1.536
14	-0.539	-2.101
15	2.501	9.692

Web	R. ~T.	R. %T.
1	0.307	1.132
2	0.153	0.527
3	0.191	0.713
4	0.223	0.795
5	0.155	0.547
6	0.194	0.667
7	0.193	0.649
8	0.195	0.639
9	0.269	0.986
10	0.269	0.962
11	0.218	0.726
12	0.278	0.942
13	0.232	0.767
14	-1.770	-6.844
15	-7.357	-28.087

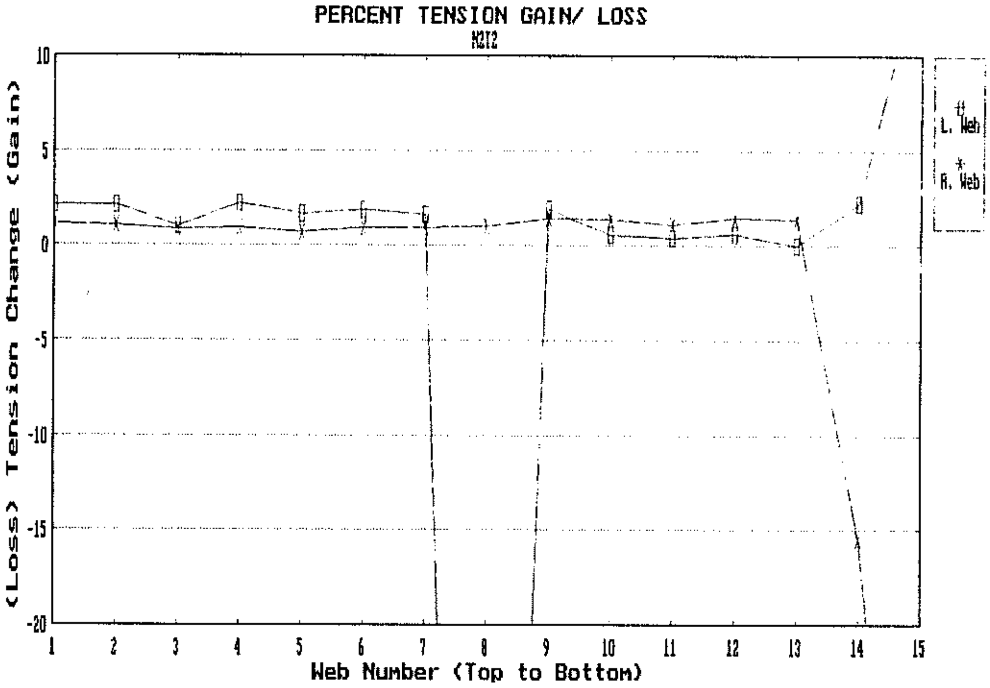
Fig.4 Run N1T2, 700 pli nip, 400 pli tension



Web	L. ~T.	L. %T.
1	0.196	1.419
2	0.159	1.229
3	0.112	0.841
4	0.038	0.278
5	0.000	0.000
6	0.000	0.000
7	-0.039	-0.312
8	-0.143	-1.143
9	-0.186	-1.407
10	-0.268	-2.017
11	-0.415	-2.911
12	-0.372	-2.497
13	0.310	1.982
14	2.735	17.487
15	8.260	47.909

Web	R. ~T.	R. %T.
1	0.268	1.912
2	0.191	1.474
3	0.267	1.832
4	0.223	1.563
5	0.193	1.296
6	0.271	2.012
7	0.270	1.931
8	0.311	2.235
9	0.307	2.252
10	0.346	2.493
11	0.472	3.315
12	0.516	3.877
13	-2.629	-17.566
14	-8.351	-54.936
15	-12.366	-88.187

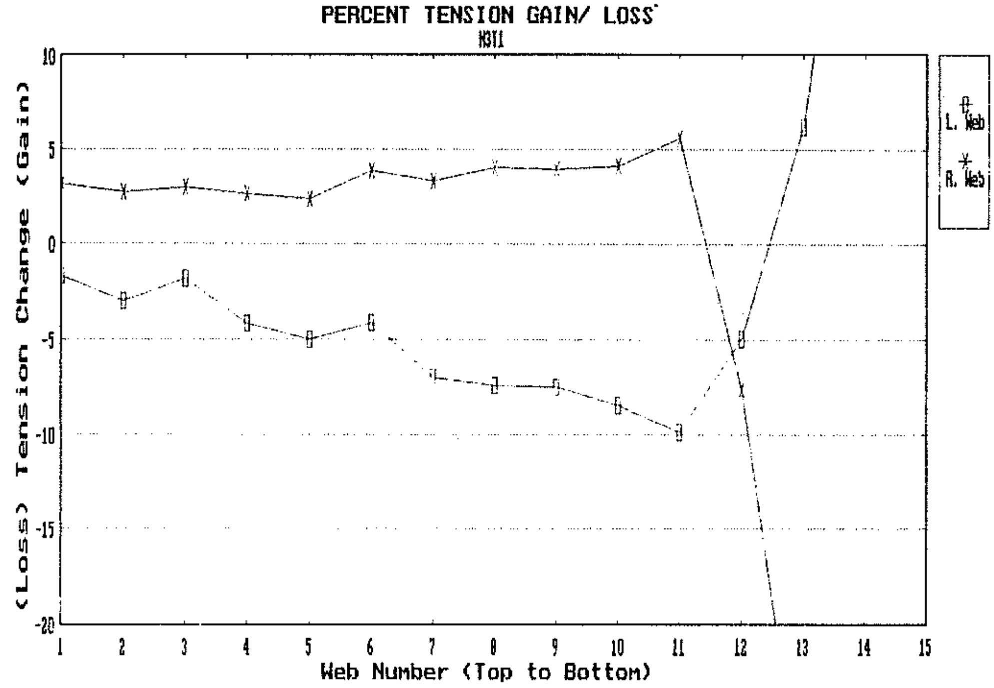
Fig.5 Run N2T1, 1400 pli nip, 200 pli tension



Web	L. ~T.	L. %T.
1	0.550	2.107
2	0.593	2.139
3	0.300	1.038
4	0.606	2.202
5	0.456	1.660
6	0.522	1.864
7	0.427	1.626
8	-14.093	-93.795
9	0.483	1.893
10	0.153	0.558
11	0.113	0.401
12	0.149	0.591
13	0.000	0.000
14	0.577	2.226
15	4.509	15.535

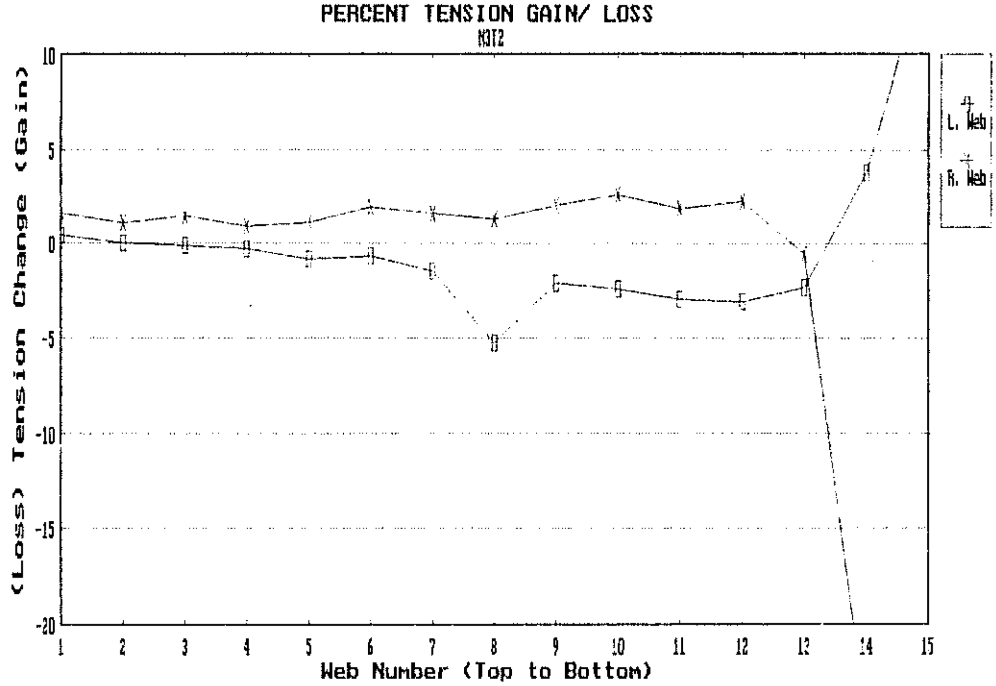
Web	R. ~T.	R. %T.
1	0.306	1.148
2	0.191	1.075
3	0.230	0.878
4	0.260	0.943
5	0.193	0.697
6	0.271	0.951
7	0.270	0.928
8	0.311	1.045
9	0.384	1.436
10	0.385	1.403
11	0.327	1.102
12	0.436	1.504
13	0.425	1.423
14	-3.656	-15.497
15	-10.593	-48.244

Fig.6 Run N2T2, 1400 pli nip, 400 pli tension



Web	L. ~T.	L. %T.	Web	R. ~T.	R. %T.
1	-0.236	-1.675	1	0.460	3.128
2	-0.395	-2.989	2	0.382	2.716
3	-0.262	-1.809	3	0.421	2.958
4	-0.606	-4.158	4	0.372	2.629
5	-0.722	-4.987	5	0.348	2.368
6	-0.596	-4.120	6	0.581	3.846
7	-0.970	-6.985	7	0.501	3.301
8	-0.933	-7.412	8	0.583	4.033
9	-1.077	-7.473	9	0.576	3.915
10	-1.225	-8.462	10	0.616	4.119
11	-1.508	-9.874	11	0.799	5.583
12	-0.745	-4.975	12	-1.112	-7.607
13	0.968	6.220	13	-4.293	-29.681
14	4.700	29.260	14	-9.544	-74.474
15	12.504	78.755	15	-12.750	-89.702

Fig.7 Run N3T1, 2100 pli nip, 200 pli tension



Web	L. ~T.	L. %T.
1	0.118	0.449
2	0.000	0.000
3	-0.037	-0.127
4	-0.076	-0.273
5	-0.228	-0.822
6	-0.186	-0.655
7	-0.388	-1.473
8	-0.036	-5.263
9	-0.520	-2.074
10	-0.651	-2.384
11	-0.829	-2.931
12	-0.782	-3.047
13	-0.658	-2.322
14	1.040	3.765
15	4.926	15.513

Web	R. ~T.	R. %T.
1	0.421	1.617
2	0.306	1.100
3	0.383	1.499
4	0.260	0.962
5	0.309	1.146
6	0.542	1.953
7	0.463	1.629
8	0.389	1.336
9	0.538	2.054
10	0.692	2.575
11	0.544	1.865
12	0.636	2.236
13	-0.154	-0.524
14	-4.965	-25.198
15	-13.483	-68.094

Fig.8 Run N3T2, 2100 pli nip, 400 pli tension

QUESTIONS AND ANSWERS

Q. Have you investigated plastic films?

A. Unfortunately, no, I have not done a similar investigation with plastic film. This apparatus sat more or less idle since 1991 when we very first finished building it until a few weeks ago when I ran this experiment. Probably, we'll do that. It would be interesting.

Q. Have you attempted to sum up the effect of each pass of the N/P as the film piles up to see what the cumulative effect of the nip is on the layer of paper for, say, 20 feet?

A. I haven't attempted such a simulation. Sometimes in an apparatus like this it's interesting to clamp the sheets into position, lift the roller, and bring it back to the start, and try another pass to see what state or condition might have been reached.

Q. The point I'm getting at is that the top sheet seemed to gain tension and the lower sheet seemed to lose tension. So, what's the net effect?

A. The net effect is that the lower sheets do continue to lose tension at a decreasing rate because they become numbered lower in the order of sheets below the top of the nip. So, as they get closer to the core, tension loss is much reduced. And this is the phenomena that causes the J-line distortion. In other words, if you can momentarily strike a straight line on the edge of the roll, and Dr. Good has done this in the lab that we're going to be visiting, he set up an ink jet printer to print a straight line on the edge of the roll to determine in-roll slippage.