EFFECTS OF WEB CAMBER ON HANDLING

by

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ABSTRACT

The definition of camber and a laboratory method of measurement of camber are presented. Common problems caused by camber and methods for avoidance of these problems are discussed.

Analysis of the behavior of a web on a tapered roller is applied to a cambered web for explanation of tests run in 1969 and 1971, as well as a recent test of the lateral behavior of a cambered belt. In these tests, steeping was toward the long side. The lateral steering toward the short side of the web caused by tilting of a complaint carriage of an accumulator because of the off-center tension in a cambered web is analyzed.

Although a precise prediction of the effects of camber on lateral behavior is seldom practical, a qualitative understanding of basic phenomena will aid in avoidance and correction of problems caused by camber.

NOMENCLATURE

C	offset at $x = L$ from tangent at $x = 0$ of untensioned cambered web
D	distance from arc of untensioned span of cambered web to chord of length L
E	modulus of elasticity
KL	a dimensionless parameter equal to $(L/W)\sqrt{12T / EtW}$
L	length of a web span
M	bending moment in the web
R	radius of roller
R_c	radius of tapered roller at its center
T	tensile force
t	thickness of web
V	velocity of web
W	width of web

β angle of arc of web on tapered roller

θ slope of a misaligned roller

θ_W angle of wrap of a roller by the web

ϕ angle of radial taper of roller; also, angle of arc of untensioned web

ρ radius of correcture of web

ρ_r radius of curvature on roller

INTRODUCTION

Definition of Camber

A common problem with webs of all materials, from thin, soft plastic to steel, is the inability to lie in a plane when untensioned but constrained to a straight line as intended. If the entire web will flatten on a plane surface, but forms a circular arc, it has *uniform camber*. If the web flattens on a plane surface except for a machine-direction band (a "baggy lane", or a "baggy edge" if the non-flattening lane is at the edge), it has *local camber*. A baggy lane is the same property as camber, because a web with continuous baggy lanes can be slit into multiple webs, each of which will display uniform camber (or zero camber), if the width and location of the slit webs are strategically located across the original web.

The term *camber* has long been used in the steel industry. An equivalent term is *curvature*, while other terms are used to describe this property in individual industries and companies.

Measurement of Camber

Uniform camber or local camber across a certain band width can be expressed as the radius of curvature in the untensioned condition. Off-line measurements of an untensioned web lying on a flat surface can easily be converted to the radius of curvature, but measurement and rationalization of measurements on a tensioned, running web are difficult.

Uniform camber can be measured in the laboratory by making the web conform to a flat surface by straightening out creases, if necessary squeezing the air from underneath it, and measuring the distance between the arc of the web and the chord formed by a taut string between two points on the arc, with the measurement midway between the points, as shown in Figure 1. If D is the distance between the arc and the chord and L is the length of the test section of web, the radius of curvature ρ is

$$\rho = L^2/8D. \tag{1}$$

Equation (1), an approximation which is accurate if D/L is small, shows the arc of a circle is approximately a parabola, with D varying with the square of L. The measurement of D is therefore meaningless without the specification of L.

Any measurement of the local tension across a running web is potentially an on-line measurement of camber; however, no method has yet proven reliable and economical enough for widespread acceptance.

Origin of Camber

The possibility of a problem with camber is often overlooked in the design and pre-production development of a new web process, while emphasis is placed on such obviously important parameters as dimensions, strength, and finish. Commercialization may thus pass the point of no return before camber is recognized as a chronic problem.

Any process which is nonuniform across the web, perhaps intended to achieve a uniform thickness, should be suspected as a cause of camber. For example, a roller in a calender or laminator may be crowned to compensate for deflection, but the larger center would transport more length per unit time than the ends of the roller, resulting in a baggy center of the web.

Any process which controls the mass per unit area across a web, perhaps with sensing by a scanning beta gage, but which does not control the actual thickness or hardness, may generate camber by stretching edges or lanes in the web at bands of large diameter in the wound roll of material. Examples are nonwoven and foamed webs.

Baggy edges may result from misalignment of roller(s), yielding one or both edges of the web without yielding the center. The magnification of the stress beyond the average stress for an initially straight web is 2.0 at the point of borderline slackness of one edge, and increases rapidly as misalignment increases further.

Camber may be generated in a zone of high tension and a high but nonuniform (in the cross-web direction) temperature, so that yielding differs across the web. The resulting camber may be a serious problem, even though the reduction in thickness associated with the yielding may not be detrimental or even measurable.

Problems Caused by Camber

Camber probably is the most troublesome problem associated with a web in printing. If the tension cannot be high enough to pull all lanes taut, the web will not lie flat on the impression cylinder, resulting in catastrophic wrinkles. The same problem occurs in any other process which requires that the web be nipped.

The entrainment of air (or liquid in the case of rod coating and other liquid/web processes) is dependent on the local tension. The transfer of heat to or from a roller and many other processes which need uniform entrainment of fluid are therefore adversely affected by camber.

A uniformly cambered tensioned web has a triangular or trapezoidal distribution of tension. The off-center resultant force may cause problems in handling such a web: (1) rollers which are inadequately constrained for maintaining parallelism with other rollers will steer the web toward the tighter side, perhaps also causing wrinkles, as the rollers tilt and each entering web span aligns itself perpendicularly to the roller. Examples of machine elements which often are too compliant are dancers and carriages of accumulators. The latter is particularly troublesome as a source of lateral error because spans are long when the accumulator is full, each of many rollers on the carriage contributes lateral error, and adequate stiffness may be difficult to achieve. (2) A spreading device such as a bowed roller or a concave roller which depends on tension for a frictional grip of the web, will steer the cambered web toward its tight side, perhaps causing wrinkles which it was intended to eliminate. (3) The higher tension on one side of the web makes that side of a winding roll smaller, creating a conical wound roll, and perhaps causing wrinkling as the web feeds onto the roll. (4) Similarly to the above item, a resilient roller or resilient web causes behavior like a tapered roller, causing tracking toward the looser side.

As slackness of the looser side of a cambered web is approached, the ability of a roller in simple frictional contact with the web to isolate a differential tension across the roller on that side is lost. A small misalignment of a given roller then results in the transfer of moment (profiled tension) across the next upstream roller to the pre-entering span of the misaligned roller. Such transfer of moment may occur across several rollers, making precision alignment of the first several rollers after a long span particularly important if a cambered web is being handled.

Eliminating Camber or Minimizing Effects of Camber

Camber can rarely be eliminated after the web is formed; therefore, the fundamental process of manufacturing should be analyzed in the earliest stages of design of a new web-forming machine, with the goal of minimizing nonuniformities of manufacturing across the web. For example, a "cold" drawing process which is intended to increase the yield strength of a web will generate different properties near the edges (if unconstrained against neckdown) from those near the center, and the edges are likely to be baggy because of less stretching and the resulting lesser recovery.

Camber is sometimes reduced by pulling a relatively high tension through an oven or furnace, so that more creep occurs in short lanes than in long lanes. On the other hand, camber may be worsened in such processes, particularly in the steel industry, if rollers are crowned (purposely by machining or because of temperature differences from their centers to their ends) or if nonuniformities of temperature occur.

In the metals industry, camber is reduced but not eliminated by a "stretcher/leveler", where a web is wrapped at high tension around small rollers, first one way and then the other, thus alternating between tensile and compressive yielding of the surfaces of the web.

Simple tensioning of a cambered web to a level which pulls all long lanes taut, whether or not the short lanes are yielded, eliminates some problems of handling a cambered web. Problems associated with an uneven distribution of tension remain, however.

Goals of Understanding the Behavior of a Cambered Web

The original goal of analysis and testing of a cambered web was to predict during the design of a process line the amount of lateral error at given points in the line, based on tolerances of camber along with physical properties of the web, configuration of the line, and operating conditions. Experiments of 1969 and 1971 were not explained by attempts at analysis at that time, and the difficulty of experimenting preluded a coverage of the vast variety in web handling by means of testing. The original goal of general, simple quantification was therefore changed to goals of analytical explanation of specific experimental results and prediction of the many effects of camber for avoidance or correction of specific problems.

Awareness of the problems of handling and winding cambered webs may provide web processors with the incentive to establish goals of reduction of camber. If a troublesome amount of camber is unavoidable, the processor should minimize harmful effects of camber by careful design and implementation of the process line.

IDEAL BEHAVIOR ON CYLINDRICAL ROLLERS

Derivation of Critical Tension:

Figure 2 shows an untensioned cambered web which will be analyzed by application of beam theory. Beam theory requires that all angles be small, or that $L >> C$ for this case. Furthermore, the radius of curvature of the untensioned web must be very large in comparison to its width for superposition of initial curvature and induced curvature to be valid.

The moment required to straighten a web with an initial radius of curvature ρ_1 is the same as the moment required to induce a numerically equal radius of curvature ρ_1 in an initially straight web with the same dimensions and properties, as long as all points are under tension and the above requirements are not violated.

From beam theory:

$$\rho = EI/M. \tag{2}$$

From Figure 2(b):

$$M = T_{cr}\, W/6. \tag{3}$$

The moment of inertia of the cross section of the web about its centroidal axis is $tW^3/12$. This relationship, when combined with equations (2) and (3), results in:

$$T_{cr} = \frac{EtW^2}{2\rho}. \tag{4}$$

Equation (4) may be expressed as

$$\frac{T_{cr}}{W} = \frac{EtW}{2\rho}, \tag{4a}$$

showing that the force per unit width required to straighten a web with an untensioned radius of curvature ρ varies in proportion to the width of the web. Therefore, a wide web which would have unacceptable camber may be satisfactory when slit into narrower webs.

Analysis of Steady-State Steering

If the tension is equal to the critical tension of equation (4), the web establishes its steady-state distribution of tension as it approaches a roller as shown in Figure 2(b), if the distributed tension in the next downstream span is isolated, such as by a vacuum roller or a nip. The reason for this downstream boundary condition is that a cylindrical roller (in the absence of slippage around the roller) must transport the same tensioned length per unit time at all points across the width of the web. This condition can be satisfied only if the web is straightened at the downstream roller. The very act of tensioning a web which is located by parallel rollers (or dead bars) also tends to straighten a cambered web.

The initial curvature, $2C/L^2$ from Figure 2(a), can be superimposed on the elastic curve by equations of beam theory. Equilibrium of forces along with the downstream condition of zero curvature can be satisfied only if the downstream error is zero, resulting in the conclusion that a cambered web does not create a lateral error, for the assumed conditions of a tension at least as great as critical and transport over parallel, cylindrical rollers. If the web is thin enough for its buckling strength in compression to be negligible, the same argument can be applied to a cambered web with a tension lower than critical: The taut portion then behaves as a complete web, running straight and without error between parallel, cylindrical rollers, with the slack edge drooping in horizontal spans and ballooning around rollers. If the buckling strength is significant, the web is not completely straightened, and steering toward the long side occurs.

The flaw in the above arguments, regardless of the level of tension relative to critical, is that a simply-wrapped cylindrical roller does not behave ideally when the web is cambered; instead, it behaves as if it were tapered, because the tighter side of the web conforms more intimately to the roller than the looser side. This behavior is similar to the well-known behavior of a stack of samples from a web (the "stack test" used for analysis of winding), where the apparent modulus of elasticity in compression increases with increasing pressure from a very low initial value as the asperities in contact increase in size and number.

BEHAVIOR ON TAPERED ROLLERS

Steering of an Initially Straight Web on a Tapered Roller

If a web conforms to the surface of a conical roller as shown in Figure 3(a), its flattened state under identical conditions of stress appears as in Figure 3(b). The difference in length of the two edges which are in contact with the roller is $\phi W \theta_w$, and is also equal to βW. Therefore, $\beta = \phi\theta_w$, and $\rho_r = R_c/\phi$. The curvature of the web on the roller therefore is

$$\frac{1}{\rho_r} = \frac{\phi}{R_c} \tag{5}$$

Equation (5) is a geometric boundary condition for any web which conforms to a tapered roller. If the web was initially straight, Figure (4) shows the curvature of equation (5) to be a downstream boundary condition for the tensioned web span, using the sign conventions of the Shelton thesis [1]. The differential equation is

$$y^{IV} - K^2 y = 0. \tag{6}$$

The solution to equation (6) for the boundary conditions shown in Figure (4) is the deflection curve of the moving web in its steady state:

$$y = \frac{\phi}{R_c K^2}\left[\cosh Kx - 1 - \frac{\sinh KL}{\cosh KL - 1}(\sinh Kx - Kx)\right]. \tag{7}$$

The steering at the downstream end because of the radial taper ϕ is

$$y_L = \frac{\phi L^2}{R_c}\left[\frac{KL \sinh KL - 2(\cosh KL - 1)}{(KL)^2(\cosh KL - 1)}\right]. \tag{8}$$

For small values of KL (as large as 2.6 for errors less than 10 percent):

$$y_L = \frac{1}{6}\frac{\phi L^2}{R_c}. \tag{9}$$

The steering caused by a misaligned cylindrical roller [1] is:

$$y_L = L\theta_L \left[\frac{KL \cosh KL - \sinh KL}{KL(\cosh KL - 1)}\right]. \tag{10}$$

Or, for accuracy within 10 percent for values of KL smaller than 2.6:

$$y_L = \frac{2}{3} L\theta_L. \tag{11}$$

The angle of a roller for neutralizing the steering caused by taper of the roller therefore is

$$\theta_L = \frac{1}{4}\frac{\phi L}{R_c}. \tag{12}$$

The presence of L^2 in equation (9) and L in equation (12) shows that the effect on steering of a tapered roller is large if spans are long, and small if spans are short. A practical application of this knowledge, besides the following study of the behavior of a cambered web, is in winding a roll which tends to be tapered or otherwise non-cylindrical, wherein steering, including local steering (wrinkling), is minimized by minimizing the length of the span preceding the winding roll by means of a carriage which moves as the radius increases, known as "proximity" or "gap" winding.

The simplified (for small KL) equation for the downstream steering caused by misalignment of the upstream roller by the angle θ_o is

$$y_L = \frac{1}{3} L\, \theta_o. \tag{13}$$

Testing of Cambered Endless Belt

Making a uniformly cambered continuous web for the purpose of verification of theories is difficult. A short cambered belt for running on two rollers is more practical. If verification is accomplished, the theory can then be applied to practical web handling problems.

Figure 5 shows two tapered, misaligned rollers for handling an endless belt. If lateral steering is nullified by equal adjustment of the angle of each roller, the two spans are identical, and $\theta_o = \theta_L$. The algebraic sum of equations (9), (11), and (13) is

$$y_L = \frac{1}{3}L\theta_o + \frac{1}{6}\frac{\phi L^2}{R_c} - \frac{2}{3}L\theta_L$$

or, because $\theta_L = \theta_o$ for cancellation of steering:

$$-\frac{1}{3}L\theta_L + \frac{1}{6}\frac{\phi L^2}{R_c} = 0$$

or

$$\theta_L = \frac{1}{2}\frac{\phi L}{R_c}. \tag{14}$$

If only one roller in a two-roller belt test is misaligned for cancellation of the steering caused by taper of the two rollers, the required angle is twice the value of equation (14), if KL is small.

If KL is larger, as in the following report of the 1997 test of a cambered belt, the angle of one roller for cancellation of the steering caused by two tapered rollers is:

$$\theta_L = \frac{2\phi L f_\phi}{R_c(2f_\theta - 1)}, \tag{15}$$

where f_ϕ is the expression inside the brackets in equation (8), and f_θ is the expression inside the brackets in equation (10).

Induced Taper

The theory of steering of a cambered web toward the long side because of the lower radial pressure on the long side than on the short side is based on induced taper of the roller. Whether the roller actually becomes tapered or the surface of the web is compressed more on the tight side than on the loose side is immaterial; in either case, the neutral plane of the web is transported faster on the loose side in proportion to the apparently larger radius.

A test for the effect of radial pressure on taper of the roller is similar to a stack test for winding, but obviously only one web/roller-surface interface is of interest in this case. If sensitivity of measurement of strain is inadequate for testing one interface, several interfaces in series can be tested, and the result for one interface can then be calculated.

A study of steering caused by induced taper by application of equation (14) is primarily of academic interest for verification of the theory and an explanation of a perplexing aspect of the lateral behavior of a cambered web. The tests necessary for quantitative application to real processes are too tedious to be generally practical; furthermore, most webs in high-volume processing are so wide that the angle of induced taper is extremely small. A noteworthy exception is the metals industry, where long spans of narrow, highly cambered strip may suffer large lateral errors.

TEST RESULTS AND COMPARISONS TO THEORY

1969-1971 Tests

A severely cambered (ρ = 39.4 m), narrow (W = 76.2 mm), thick (t = 0.23 mm) web was cut from a flat web of oriented polystyrene and was spliced to form an endless belt with a length of 9.16 meters. The cambered belt was then run on the machine shown in the Shelton thesis [1] in the photograph of Figure 2.2.1 and the schematic of Figure 2.2.2. The test span for measurement of lateral steering was the span between the nip assembly and the steering guide (which was locked in its centered position) at the upper right corner of the machine. For the last test (September 8, 1971), the single downstream roller was replaced with a nip assembly; however, the web still wrapped the lower roller a few degrees before the nip point, as indicated by the upwardly sloping span shown in Figure 2.2.1. (Figure 2.2.2 incorrectly shows this span to be horizontal.)

Tests of 5/5/69 were inconclusive, and are not reported here. The primary problem was misaligned rollers, but scatter of data probably was worsened by movement of the mechanical scales for measuring the lateral shear force. This lateral force, incidentally, was of the order of 0.1 percent of the tensile force.

A roller was built in 1971 with each of ¼-inch-wide segments mounted on a ball bearing, allowing the web to travel at different velocities across its width. Little was learned from experiments with this segmented roller, except that the theory of transfer of moment across the roller was qualitatively confirmed. A major contributor to lateral steering still appeared to be misalignment of rollers, a problem which could not be rendered insignificant because of the shortness of the rollers and the fact that three rollers were cantilevered to allow threading of an endless belt.

The ¼-inch segments were then locked together and covered with Scotch-Tred, a 3M product resembling emery cloth, which had a surface with sharp abrasive particles intended to provide a high-friction surface for pedestrian walks and steps. Figure 6 shows the average of two tests using this roller, with camber in opposite directions. The observed steering at values of T/T_{cr} of 1.0, 2.0, and 3.0 correspond to values of radial taper ϕ of 0.00039, 0.00025, and 0.00021 according to equation (8), or taper across the width of the web of 0.03 mm, 0.02 mm, and 0.016 mm, respectively. Such microscopic values make the theory of induced taper credible, without proving it.

The test machine with the roller of the previous paragraph was run on July 22, 1971, with all guides centered, to check for an overall tendency of tracking of a cambered web. During the passage of the 9.14 meters of length of the cambered belt in eleven spans, at T/T_{cr} values of 0.25, 0.5, 1.0, and 3.0, and with the belt turned over for camber in the two directions, steering varied from 6.4 mm toward the concave (tight) side to 12.7 mm toward the convex side, adding to the perplexity at that time over steering of a cambered web.

The last test of the fabricated polystyrene cambered web, on September 8, 1971, was with a nip before and after the test span. The results are shown in Figure 7. The amount of steering at the critical tension, 1.83 mm, would result from an angle ϕ of induced taper of 0.00028, according to equation (8), or a radial taper of 0.021 mm across the width of the web.

1997 Tests

A conveyor belt, called by the manufacturer a machine tape, was cut at a constant radius of curvature and bonded in a high-quality zig-zag joint. The intention was for the conveyor to sweep through an arc of nearly thirty degrees, and the initial thought was that the belt would run on two pulleys which had their conical surfaces and their axes converging to the center of curvature of the belt. Analysis by application of the theories of lateral behavior of a web, however, showed that the tensioning of the web would reduce the curvature, causing the belt to be steered toward the concave edge, or the small ends of the conical rollers. With the axes of the rollers still converging to the center of curvature of the untensioned belt, the curvature could be restored only by greatly increasing the taper of the rollers. The belt system then operated at a stable position without crowning of the rollers, because a change in parameters which caused an increase in tension reduced the curvature and caused the web to steer toward the smaller ends of the rollers, reducing the tension; conversely, a tendency toward decreasing tension was canceled by steering toward the large ends of the rollers because of the increased curvature. Whether or not the variation in operating location of the belt was acceptable depended on the application and the variation of conditions and parameters, such as the change of length and elasticity with temperature.

The curved conveyor belt had several advantages as a specimen for verification of the theory of induced camber: (1) The uniformity of the camber and the general quality of the belt and its splice should minimize test noise. (2) The permissible elongation was high (11 percent). (3) The textured surface allowed compression under a force normal to the belt to occur without significant expansion in the plane of the belt, thereby allowing a compression test to be run without concern over the size or shape of the test specimen. (4) The low stiffness ($E = 10.4\ N/mm^2$) allowed strain to be measured as an indicator of tension. (5) The extreme curvature ($\rho = 0.93$ m to the center line) was an exaggeration of camber, allowing testing in a practical range of precision. A disadvantage of testing with large curvature and large strain may have been a loss of precision in the application of beam theory, which assumes small deflections.

A stress/normal-deflection curve of the belt is shown in Figure 8. The deflection is for one face, but is the average of the two faces, which appeared to be identical in texture, and were of the same soft material (NBR). Tests of steering of the belt, however, consistently showed more steering when the green side of the belt was in contact with the rollers than when the black side was in contact, leading to the suspicion that the green side was softer. The compression tests of Figure 9 verified this suspicion; however, the tests found the green side to be only approximately 25 percent more compressible than the black side, whereas the steering tests found the angle required to stabilize the belt to be at least 40 percent greater for wrap on the green side than for wrap on the black side.

At the critical tension on the belt-testing machine, L was calculated from the manufacturer's specifications as 470 mm, and KL as 3.75. From Figure 9 and equation (15), the required slope of one roller, θ_L, was calculated as 0.0030 for wrap on the black side and 0.0038 for wrap on the green side. A preliminary test on April 28, 1997, found a stable operating condition with deflection of the roller shafts canceling the steering caused by camber with $\theta_L = 0.0032$ with the black side in contact with the rollers. The critical condition was judged by observation of tautness of the long edge.

The belt-testing machine was modified to allow pivoting of one roller, and tests were run at tensions near critical to determine the effect of the two surface conditions. The direction of the camber was reversed with the hope of minimizing the effect of non-cylindrical rollers (with a taper as great as 0.05 mm). The average of θ_L for four tests at a stable running condition was 0.0059 for contact by the black surface and 0.0090 by the green. Although the correlation between the tests and the prediction of 0.0030 and 0.0038, respectively, is poor, the trends of all tests were as predicted; that is, steering was always toward the long side before correction by the pivoting roller, and more correction was always required with contact by the green surface than by the black surface. It should be further noted that the semi-destructive compression tests were run on a catalog sample, not the actual belt.

ANALYSIS OF COMPLIANT CARRIAGE

Steering by Cambered Web

The carriage of an accumulator for zero-speed splicing at an unwinder or changing of rolls at a winder is positioned and is intended to be constrained for parallelism by such devices as lead screws, chains, or cables. Such mechanical elements often have inadequate stiffness for resisting tilting caused by a cambered and off-center web, resulting in excessive lateral errors; furthermore, space for the proper installation of a web guide is often at a premium. The carriage may not only tilt in a plane, but may also twist as the web steers farther from center as it progresses through the accumulator.

Although there are circumstances in which a web approaching a misaligned roller has little curvature in a span, with most of the deflection occurring because of shear stresses, the long spans and the usual stiffness in shear of webs handled in accumulators usually make equations (11) and (13) reasonably accurate. From equation (11), the lateral error in the entering span is two thirds as great as if the web formed a straight line perpendicular to the tilted roller. However, equation (13) shows that one half of this error is canceled in the exiting span, making the net error for each roller which is tilted at an angle θ

$$y = 1/3\ L\theta. \tag{16}$$

The moment from each roller on the carriage which is trying to tilt the carriage, from Figure 2(b), is (1/3)WT at the condition of critical tension, plus the tension multiplied by twice the lateral error toward the concave side at each roller on the carriage. Calculating the amount of error caused by tilting of the carriage thus is a relatively simple problem in algebra if the stiffness of the carriage can be calculated. It may then be practical to design enough stiffness into small accumulators for prevention of excessive lateral error. For large, tall accumulators for high-speed metals lines, especially if positioning is accomplished with a cable at each corner, sensing of the angle of tilting and servo control of levelness is recommended.

Instead of correcting the problem of a tilting carriage, the steel industry often crowns some or all of the rollers in the accumulator. Crowning of rollers is ineffective in steering a straight web, as proven by unpublished analysis as well as experience in the steel industry as reported by Lorig [2]. Crowning of rollers for handling a cambered web may be harmful, causing erratic lateral behavior. The web may be steered excessively toward its convex side when occasional conformation of a portion of a cambered web to a portion of the crowned roller, as illustrated for a uniformly tapered roller in Figure 3 and expressed in equation (5). The steering (toward the convex side) is expressed by equation (8) or (9); however, if the effective value of KL is large because of slackness across much of the width of the web, the function inside the brackets in equation (8) is uncertain because of the varying effective width along the span of the web. Equation (9), however, predicts the maximum possible amount of steering in long spans of isotropic webs, and is seldom grossly incorrect because of the insensitivity of equation (8) to variations in KL.

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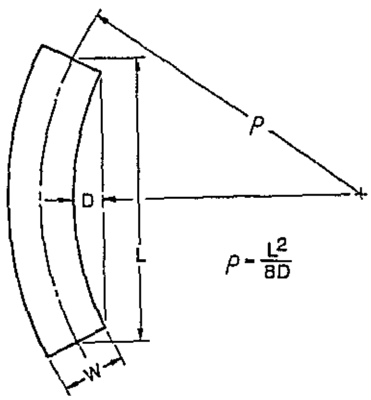
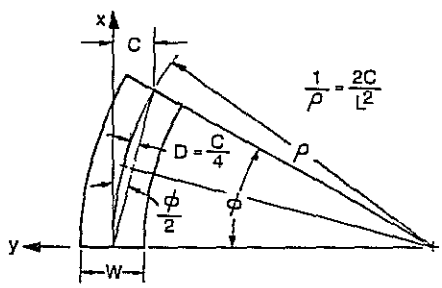
2. Lorig, E. T., "Automatic Self-Centering Rolls and Pulleys", AISE Annual Convention, Cleveland, Ohio, 1950.

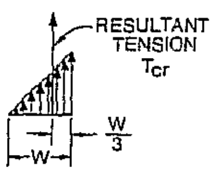


MEASUREMENT OF CAMBER

FIGURE 1

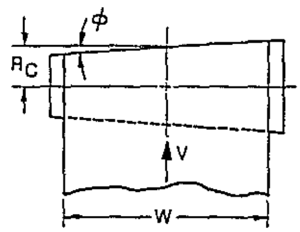


(a) GEOMETRY

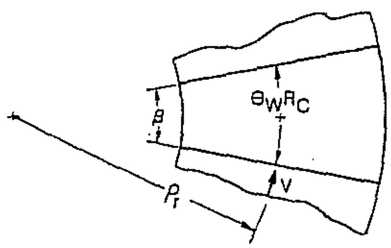


(b) DISTRIBUTION OF CRITICAL TENSION

CRITICAL TENSION
FIGURE 2



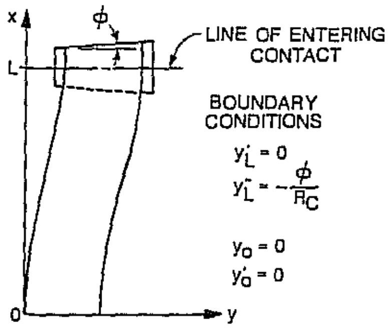
(a) WEB CONFORMING TO
TAPERED ROLLER



(b) FLATTENED WEB UNDER CONDITIONS
OF CONFORMATION

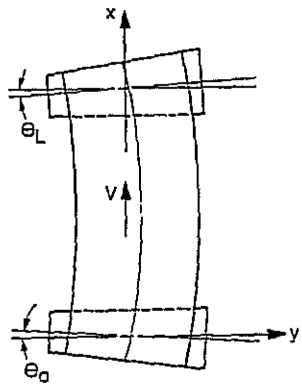
GEOMETRY OF A WEB ON A TAPERED ROLLER

FIGURE 3



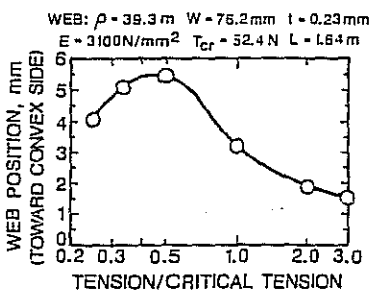
STEERING OF AN INITIALLY STRAIGHT WEB ON A TAPERED ROLLER

FIGURE 4



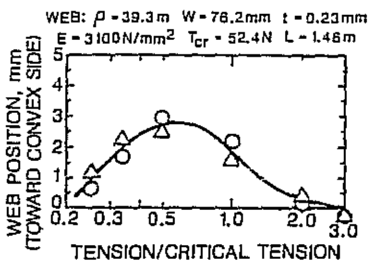
MISALIGNMENT OF TWO TAPERED ROLLERS FOR CANCELLATION OF STEERING EFFECT FOR ENDLESS BELT

FIGURE 5



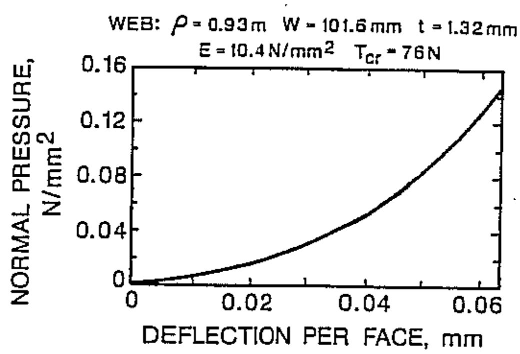
BEHAVIOR OF CAMBERED WEB ON ROLLER COVERED WITH SCOTCH-TRED AVERAGE OF TWO TESTS OF 7/20/71 WITH CAMBER IN OPPOSITE DIRECTIONS

FIGURE 6



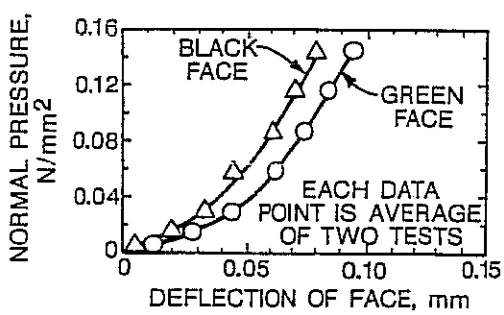
BEHAVIOR OF CAMBERED WEB ON NIPPED ROLLER COVERED WITH TEXTURED RUBBER TAPE TWO TESTS OF 9/8/71 WITH CAMBER IN OPPOSITE DIRECTIONS

FIGURE 7



HABASIT MAT-02H BELT
TEST OF APRIL 7, 1997

FIGURE 8



HABASIT MAT-02H BELT TEST
OF EACH FACE - MAY 12, 1997

FIGURE 9

Question - Am I correct in that a cambered web will not steer if it is going over perfectly straight, perfectly aligned rollers?

Answer - Yes, here I was trying to explain the rather small amount of steering in some rather extreme tests. And for your cases I think that what you said you can fairly generalize. Now in the steel industry, yes there is steering. Bruce will tell you toward the slack side and in other cases but this is the only explanation I have for the things that I have observed in trying to run tests. But the primary lateral behavior of a cambered web is very small involving, they're secondary things that are microscopic and very hard to trace down.

Question - What consequences have you come across on roll quality. Would you link it to wrinkling?

Answer - On roll quality, if you don't wind it above the critical tension you have wrinkles into the rolls and if you don't have up to the critical tension going into the roll you'll have wrinkles forming through nips so a cambered web can be really be troublesome. If you are above critical tension a wound roll will be bigger on the long than on the small end and will retain more air because there is more tension. So it may be larger there and may stretch it further as it sits. So there are serious implications to cambered web baggie lanes and baggie webs and such unwinding which I am not covering here in an effort to do a little bit of justice to the mysteries that have been haunting me over the years.

Question - How much in normal films is camber consistent, than my experience that camber can change every 100 feet, 50 feet, maybe thats the reason we don't see so much is that if you put a mark on a roller often times you see the web walk around that mark and as it wanders around is, it a function of tension variation, camber or slit edge, whatever it is. Do you have any comments on what kind of lets say periodicity or band width in cambers starts to be critical?

Answer - Well, in films, this varies. There are different opinions, I'm not sure how much it varies. The baggy edge due to something in the process, a consistently baggy edge is fairly common, but in steel industry uniform camber for a long period of time is fairly common. Wouldn't you say Bruce? (Yes, he said.) In other industries, even in cloth the salvage edge is likely to be floppy. If you trim this floppy edge off then you would have uniform camber if you trimmed it small enough. This happens in various processes in the film industry, consistently floppy edge. You have much more experience than I do in different processes in different plants in variation of camber in one way or another.

Question - I have to replace endless count of belts on a regular basis and every time we put a new belt on we have to reset the steering position. Could this be explained by a misaligned joint causing basically a cambered conveyor belt?

Answer - Yes that would be a momentary thing that would repeat every time around so that would be one local camber situation at a joint in the belt where it isn't aligned properly.