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(54) **Roller with contoured surface for conveying ultrathin webs and apparatus comprising such a roller**

(57) A web conveying roller (18) is provided with circumferentially or spirally extending grooves (42) and lands (44), the lands having convex curvatures (46, 48; 54) to cause a conveyed, ultrathin web (30), at the beginning of a wrap angle (α) onto the roller, to undulate along the width of the roller over the lands and into the grooves while remaining spaced from the convex curvatures of the lands; so that, air entrained between the web and the lands can flow into the grooves.

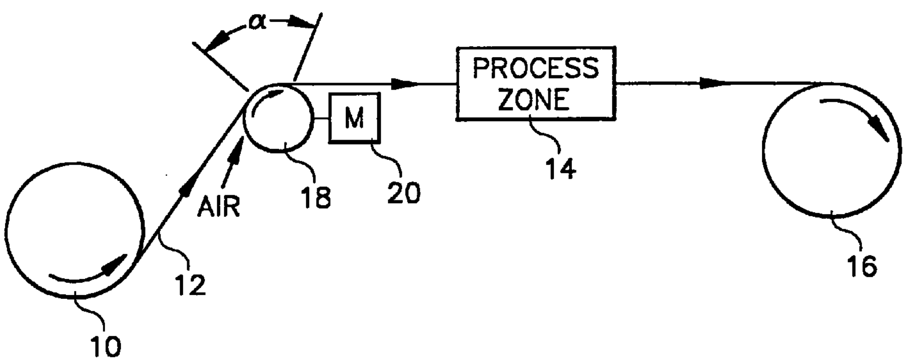

FIG. 1

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Description

The invention concerns apparatus for conveying web material such as indeterminate lengths of plastic sheet or paper. More particularly, the invention concerns such apparatus which includes rollers having specially contoured surfaces for conveying at high speeds wide webs of ultrathin or very small thickness, such as less than 0.001 inch (0.0254 mm).

Figure 1 illustrates schematically one example of a wide variety of manufacturing apparatus for conveying and treating web materials. A source 10, such as a stock roll, provides a web 12 of indeterminate length. In the familiar manner, the web is conveyed through a process zone 14 to a take-up roller 16 by means of a plurality of right circular cylindrical driver and idler rollers 18, only one being illustrated, which typically have widths greater than the width of the web. Rolls 10 and 16 also may be driven. Some rollers 18 may be driven by means such as a motor 20. The relative positions of the rollers and other conventional web guidance features in the apparatus, not illustrated, serve as means to guide the web to wrap onto each roller over a wrap angle α, which may be in the range of 10 to 300°. Various surface treatments may be performed on the web in the process zone, such as coating, printing, surface texturing and the like, which often require that there be no slippage between the web and the driver or idler rollers. Slippage or loss of traction between a web and a roller is undesirable since it may cause problems for the web such as weaving movement, electrostatic charging, scratching, creasing and the like. Sufficient frictional force is required between the web and each roller to prevent such slippage, this force commonly being known as roller traction.

Roller traction can be achieved with smooth-surfaced rollers at low web speeds; however, as web speed increases to as much as 100 feet per minute (30.5 meters per minute), air typically becomes entrained between the web and the roller, as indicated by the arrow in Figure 1. The entrained air causes the web at least partially to lose contact with the roller; so that, slippage can occur. To permit entrained air to escape from between the web and the roller, surface patterns of various types have been provided on roller surfaces, thus permitting adequate traction to be maintained at low and high web speeds.

Figure 2 illustrates schematically an axial cross section of one such surface pattern and an engaged web, just at the beginning of wrap angle α. The exterior surface of roller 18 is provided with a plurality of circumferentially extended grooves 24, which may be individual annular grooves or one or more continuous spiral grooves. The grooves are separated by circumferentially extended lands 26 whose outer surfaces are flat or straight when viewed in such an axial section. That is, the lands have a flat profile when viewed in the direction of movement of the web through the apparatus. There may be, for example, 6 to 60 such grooves per inch (2.36 to 23.6 grooves per cm), the axial widths of the grooves and lands being about the same and each groove having a depth in the range of 0.002 to 0.010 inch (0.0508 to 0.254 mm).

When a polyethyleneterephthalate web having a thickness t in the range of 0.002 to 0.0075 inch (0.0508 to 0.191 mm) is conveyed using 2.8 inch (71.1 mm) diameter rollers of the type illustrated in Figure 2, the web has sufficient stiffness, beam strength or bending resistance to enable it to engage fully the flat profile surfaces of lands 26 at the beginning of wrap angle α, in the manner illustrated in Figure 2. Thus, any air moving with the web at the beginning of the wrap angle is forced into grooves 24 and good traction is maintained due to the engagement of the web with the lands.

Figure 3 illustrates how, for such relatively thick webs, the coefficient of friction between a 0.0025 inch (0.0635 mm) thick, 54 inch (1372 mm) wide web and a grooved, 2.8 inch (71.1 mm) roller changes only slightly over a range of web speeds up to 1,000 feet per minute (305 meters per minute). A somewhat larger drop in coefficient of friction is observed for web tension of 15 pounds or 0.27 pounds per linear inch across the web (6.8 kg or 0.0048 kg per mm), compared to a tension of 25 pounds or 0.45 pounds per linear inch across the web (11.34 kg or 0.008 kg per mm).

However, if web 12 is ultrathin, with a thickness of less than 0.001 inch (0.0254 mm), rollers of the type shown in Figure 2 fail to provide adequate traction at web speeds above a few hundred feet per minute. Traction no longer remains essentially constant but rather becomes a function of web thickness and web speed. We have discovered that this degradation in performance of such grooved rollers results from a decrease in the bending resistance of the ultrathin web. For the thicker webs, the bending resistance is sufficient to enable the webs to bridge the grooves and engage the lands of known grooved rollers with minimal radial deformation of the web, as shown in Figure 2. For the ultrathin webs, however, the webs are so flimsy that at the beginning of the wrap angle they bend into the grooves and lift above the lands in the manner illustrated in Figure 4. A similar effect can be observed with webs thicker than 0.001 inch (0.0254 mm), depending on the material of the web and the geometry of the lands and grooves. An ultrathin web 30 thus deforms transversely into a series of relatively high ridges 32 and low valleys 34; so that, web 30 makes contact with the roller essentially only at the edges or corners 36, 38 of each land. As a result, a volume 40 of air can become more or less trapped beneath high ridges 32 since contact of the web with edges 36, 38 prevents or severely impedes flow of air into the grooves. With essentially line contacts between the web at the edges 36, 38, traction is reduced drastically, leading to the problems previously mentioned.

Figure 5 illustrates how, for a 0.00025 inch (0.0064 mm) thick, 55 inch (1397 mm) wide, polyethyleneterephthalate web running on a 5.6 inch (142.2 mm) grooved roller, the coefficient of friction between the web and the roller drops rapidly over a range of web speeds up to 800 feet per minute (244 meters per minute). A somewhat larger drop in coefficient of friction is observed for web tension of 10 pounds or 0.18 pounds per linear inch across the web (4.5 kg or 0.0032 kg per mm), compared to a tension of 15 pounds or 0.27 pounds per linear inch across the web (6.8 kg or 0.0048 kg per mm) or to a tension of 25 pounds or 0.45 pounds per linear inch across the web (11.34 kg or 0.008 kg per mm).

Thus, a need has existed for a roller which can convey ultrathin and other webs, which tend to deform into conventional grooved rollers, with good traction at elevated web speeds.

The primary objective of our invention is to provide an improved roller for conveying ultrathin webs at elevated web speeds, without substantial loss of traction or risk of damage to the web.

This objective is given only by way of an illustrative example; thus other desirable objectives and advantages inherently achieved by the disclosed invention may occur or become apparent to those skilled in the art. Nonetheless, the scope of the invention is to be limited only by the appended claims.

Our invention is defined by the claims. One embodiment of our apparatus is particularly suited for conveying ultrathin webs having a width. A source of a web to be conveyed, such as a stock roll, feeds the web over at least one cylindrical roller having an exterior surface with a length, the length being longer than the width of the web to be conveyed and a portion of the web being wrapped onto the roller over an angle α. Uniquely in accordance with our invention, the roller comprises a plurality of circumferentially extending, axially spaced grooves formed in the exterior surface along the length, each groove having an axial width; and a plurality of lands formed in the exterior surface and extended between the grooves, each land having an axial width and a central surface with a convex curvature, the convex curvature having a maximum radius from a centerline of the roller. The lands may be continuous. For best conveyance of ultrathin webs, the convex curvatures of the lands and the axial widths of the grooves and lands are chosen so that, at about a beginning of the wrap angle α during rotation of the roller, the web undulates along the width of the roller over the lands and into the grooves but is spaced from the convex curvatures of the lands, so that air entrained between the web and the lands can flow into the grooves. Some contact at the apex of the convex curvature is acceptable at this location.

Typically, a minimum clearance between the web and the exterior surface occurs at the maximum radius of the convex curvature and the clearance between the web and the convex curvature increases with axial distance from the minimum clearance. The wrap angle α may be in the range of 10 to 300°. Means may be provided for moving the web at a speed in the range of 300 to 1,000 feet per minute (91.4 to 305 meters per minute). The roller may be an idler roller or a driven roller. The convex curvature may have a radius of curvature in the range of 0.020 to 1.2 inch (0.508 to 30.5 mm); the axial width of the grooves may be in the range of 0.020 to 0.105 inch (0.508 to 2.67 mm); and the axial width of the lands may be in the range of 0.020 to 0.105 inch (0.508 to 2.67 mm). The cylindrical roller may have a diameter in the range of 1.5 to 10.0 inch 38.1 to 254 mm).

Rather than circumferentially extending grooves and lands as just described, the roller of our invention may include at least one spiral groove formed in the exterior surface along the length, the spiral groove having an axial width; and at least one continuous spiral land formed in the exterior surface and extended between turns of the spiral groove, the spiral land having an axial width and a central surface with a convex curvature, the convex curvature having a maximum radius from a centerline of the roller. As in the previous example, the convex curvatures of the spiral land and the axial widths of the spiral groove and spiral land may be chosen so that, at a beginning of the wrap angle α during rotation of the roller, the web undulates along the width of the roller over the turns of the land and into the turns of the groove but is spaced from the convex curvature of the spiral land, so that air entrained between the web and the spiral land can flow into the spiral groove. The spiral groove and spiral land may be formed by at least one wire wound onto the roller.

The apparatus and conveying rollers according to our invention provide various advantages. Ultrathin webs can be conveyed at elevated web speeds with good traction. Web weaving and scratching are minimized due to maintenance of adequate traction. The coefficient of friction between ultrathin webs and rollers of our invention varies only moderately over a wide range of web speeds. The wound wire embodiments of our roller have a high quality surface finish and are simple and economical to manufacture and maintain. Existing apparatus is easily modified for conveying ultrathin webs simply by replacing prior art rollers with those of our invention.

The foregoing and other objectives, features and advantages of the invention will be apparent from the following more particular description of the preferred embodiments of the invention, as illustrated in the accompanying drawings.

Figure 1 illustrates schematically a manufacturing apparatus for conveying and treating web materials, of the general type suitable for use of rollers in accordance with our invention.

Figure 2 illustrates a fragmentary, sectional view in the direction of web movement, showing the engagement of a relatively thick web with a prior art grooved roller just as the web enters the wrap angle α in the apparatus of Figure 1.

Figure 3 illustrates how the measured coefficient of friction varies with web speed for a web and roller pair of the type shown in Figure 2.

Figure 4 illustrates a fragmentary, sectional view in the direction of web movement, showing the engagement of an ultrathin web with a prior art grooved roller just as the web enters the wrap angle on the roller.

Figure 5 illustrates how the coefficient of friction varies with web speed for a web and roller pair of the type shown in Figure 4.

Figure 6 illustrates a fragmentary, sectional view in the direction of web movement, showing the engagement of an ultrathin web with one embodiment of a contoured roller in accordance with our invention just as the web enters the wrap angle on the roller.

Figure 7 illustrates a schematic, sectional view in the direction of web movement, showing the engagement of an ultrathin web with a further embodiment of a contoured roller in accordance with our invention just as the web enters the wrap angle on the roller.

Figure 8 illustrates a calculated radial displacement of an ultrathin web as a function of axial position along a convex land on a contoured roller in accordance with one embodiment of our invention.

Figure 9 illustrates a calculated interfacial air pressure between an ultrathin web and a convex land on a contoured roller in accordance with the embodiment of our invention of Figure 8, as a function of axial position along the land.

Figure 10 illustrates a schematic, sectional view in the direction of web movement, showing the engagement of an ultrathin web with a still further embodiment of a contoured roller in accordance with our invention just as the web enters the wrap angle on the roller.

Figure 11 illustrates a calculated radial displacement of an ultrathin web as a function of axial position along a convex land on a contoured roller in accordance with another embodiment of our invention.

Figure 12 illustrates a calculated interfacial air pressure between an ultrathin web and a convex land on a contoured roller in accordance with the embodiment of our invention of Figure 11, as a function of axial position along the land.

Figure 13 illustrates how the measured coefficient of friction varies with web speed for an ultrathin web and a 5.2 inch (132.1 mm) diameter roller of the type shown in Figure 10.

Figure 14 illustrates how the measured coefficient of friction varies with web speed for a relatively thick web and a 3.7 inch (94 mm) diameter roller of the type shown in Figure 10.

The following is a detailed description of the preferred embodiments of the invention, reference being made to the drawings in which the same reference numerals identify the same elements of structure in each of the several Figures.

Figure 6 illustrates a fragmentary, sectional view in the direction of web movement, showing the engagement of ultrathin web 30 with one embodiment of a contoured roller in accordance with our invention, just as the web enters the wrap angle α on roller 18. In accordance with our invention, the flat profile grooves and lands of the prior art rollers are replaced with an undulating, contoured surface somewhat geometrically similar to the shape assumed by an ultrathin web when used with a prior art grooved roller, as shown in Figure 4. Our contoured surface may be provided on right cylindrical or concave rollers; however, we have found that concave rollers are preferable for more flimsy webs. Our recognition of the advantages of such a contoured surface was, in our experience, contrary to the expectations of persons skilled in the web conveying arts. Prior to our invention, the typical expectation of the skilled persons was that a contoured surface such as used in our invention would result in poor traction due to anticipated line contact. We have found, surprisingly, that such contoured surfaces are quite effective when used with ultrathin webs.

In accordance with our invention, the exterior surface of roller 18 is provided with a plurality of circumferentially extended grooves 42, which may be individual annular grooves or one or more continuous spiral grooves. The grooves are separated by circumferentially extended lands 44. At least the central portion of the outer surfaces of lands 44 have convex curvatures when viewed in the illustrated, axial section. That is, lands 44 have an outwardly rounded profile when viewed in the direction of movement of the web through the apparatus. In the illustrated embodiment, which may be formed by diamond turning, for example, grooves 42 may have a generally concave surface with an axial width w_1 in the range of 0.020 to 0.105 inch (0.508 to 2.67 mm). Lands 44 may have a generally convex central portion on surface 46 with an axial width w_2 in the range of 0.020 to 0.105 inch (0.508 to 2.67 mm). Surface 46 may have a circular, elliptical, parabolic or similar convex shape with a central location of maximum radius or high point 48. When surface 46 is circular, as illustrated, the radius of curvature may be in the range of 0.020 to 1.2 inch (0.508 to 30.5 mm). When grooves 42 and lands 44 are shaped and spaced in this manner, at about the beginning of wrap angle α and upon rotation of roller 18, web 30 will undulate along the width of the roller over the lands and into the grooves while remaining spaced slightly from the surfaces of the lands and grooves. Because web 30 assumes this undulating configuration at about the beginning of the wrap angle, air entrained between the web and the lands can flow readily into the grooves to permit the web to engage the roller further along in the wrap angle.?

Figure 7 illustrates another embodiment of a roller made in accordance with our invention. In this instance, roller body 18 is wrapped with a circular cross section wire 50 to provide spiral grooves 42 and lands 44. Wire 50 may have a radius of about 0.020 inch (0.508 mm), for example, and be wrapped tightly onto the roller so that successive turns of the wire abut in the manner illustrated. Roller body 18 may be a circular cylinder having a diameter in the range of 1.5 to 10.0 inch (38.1 to 254 mm). When the roller is to be used to convey more flimsy webs, a concave axial profile may be advantageous. A concave profile is suitable whose diameter tapers about 0.2% from its ends to its center.

Figure 8 illustrates a calculated radial displacement of an ultrathin web at about the beginning of the wrap angle as a function of axial position along a convex land on a contoured roller in accordance with the embodiment of Figure 7. A web 30 having a thickness of about 0.00025 inch (0.0064 mm) was assumed to be wrapped onto a roller having a diameter of about 2.75 inch (69.85 mm). As shown in the figure, the clearance between the web and the convex land was calculated to be a minimum at the point of maximum radius of the land, corresponding to high point 48 in Figures 6 and 7. On either side of the point of maximum radius, the clearance between the web and the land was calculated to increase, thus indicating that air would be able to escape into the neighboring grooves.

Figure 9 illustrates a calculated interfacial air pressure at about the beginning of the wrap angle between web 30 and convex land 44 on a contoured roller in accordance with the embodiment of Figure 7, as a function of axial position along the land. Consistent with Figure 8, this plot indicates that the calculated pressure between the web and the convex land decreases from a maximum at high point 48 to a minimum at the center of the neighboring groove. The convex shape of the curve indicates that the relatively high pressure air at the center of the land can escape readily into the lower pressure area in the grooves.

Figure 10 illustrates yet another embodiment of a roller made in accordance with our invention. In this instance, roller body 18 is wrapped with an essentially rectangular cross section wire 52 to provide spiral grooves 42 and lands 44. Wire 52 may have a convex surface 54 with a radius of curvature in the range of 0.020 to 1.2 inch (0.508 to 30.48 mm), side walls 56 with a radial dimension in the range of 0.035 to 0.045 inch (0.889 to 1.143 mm) and a base wall 58 with an axial dimension in the range of 0.040 to 0.210 inch (1.016 to 5.334 mm), for example. Wire 52 is wrapped tightly onto the roller so that successive turns of the wire abut along side walls 56 in the manner illustrated. Roller body 18 may be a circular cylinder having a diameter in the range of 1.5 to 10.0 inch (38.1 to 254 mm). A concave profile also may be used.

Figure 11 illustrates a calculated radial displacement of an ultrathin web at about the beginning of the wrap angle as a function of axial position along a convex land on a contoured roller in accordance with the embodiment of Figure 10. A web 30 having a thickness of about 0.00025 inch (0.0064 mm) was assumed to be wrapped onto a roller having a diameter of about 2.75 inch (69.85 mm). As shown in the figure, the clearance between the web and the convex land was calculated to be rather uniform across the land, thus indicating that air would be able to escape into the neighboring grooves.

Figure 12 illustrates a calculated interfacial air pressure at about the beginning of the wrap angle between web 30 and convex land 44 on a contoured roller in accordance with the embodiment of Figure 10, as a function of axial position along the land. This plot indicates that the calculated pressure between the web and the convex land is relatively constant but decreases to a minimum at the edge of the neighboring groove.

Figure 13 illustrates how, for a 0.00025 inch (0.0064 mm) thick, 55 inch (1397 mm) wide polyethyleneterephthalate web running on a 5.2 inch (132.08 mm) diameter contoured roller in accordance with the embodiment of Figure 10, the coefficient of friction between the web and the roller drops very slightly over a range of web speeds up to 1,000 feet per minute (305 meters per minute). A concave profile was used. A somewhat larger drop in coefficient of friction is observed for web tension of 10 pounds or 0.18 pounds per linear inch across the web (4.5 kg or 0.0032 kg per mm), compared to a tension of 15 pounds or 0.27 pounds per linear inch across the web (6.8 kg or 0.0048 kg per mm) or to a tension of 25 pounds or 0.45 pounds per linear inch across the web (11.34 kg or 0.008 kg per mm). As illustrated, our roller provides with ultrathin webs a reasonably constant coefficient of friction over a wide range of web speeds, much like the prior art rollers with much thicker webs.

Figure 14, similar to Figure 3, illustrates how, for a relatively thick 0.0025 inch (0.0635 mm) thick, 54 inch (1372 mm) wide polyethyleneterephthalate web running on a 3.7 inch (93.98 mm) diameter contoured roller of the type shown in Figure 10, the coefficient of friction between the web and the roller changes very little over a range of web speeds up to 1,000 feet per minute (305 meters per minute). A somewhat different change in coefficient of friction is observed for web tension of 10 pounds or 0.18 pounds per linear inch across the web (4.5 kg or 0.0032 kg per mm), compared to a tension of 15 pounds or 0.27 pounds per linear inch across the web (6.8 kg or 0.0048 kg per mm); to a tension of 25 pounds or 0.45 pounds per linear inch across the web (11.34 kg or 0.008 kg per mm); or to a tension of 35 pounds or 0.68 pounds per linear inch across the web (15.88 kg or 0.012 kg per mm). This illustrates clearly that our rollers also will convey much thicker webs with essentially the same performance as prior art rollers.

10	source of web, such as stock roll
12	web of indeterminate length, having width and thickness
14	process zone, such as coating machine
16	take-up roll for web
18	right cylindrical roller, having length longer than width of web
20	motor, optional
α	wrap angle of web onto roller
24	conventional circumferentially extended groove or valley, circular or spiral
26	conventional circumferentially extended land, circular or spiral
t	thickness of web
30	ultrathin web at beginning of wrap angle
32	high ridge
34	low valley
36, 38	edges of land
40	volume of trapped air

42	circumferentially extended groove or valley of invention, circular or spiral
w_1	axial width of groove 42
44	circumferentially extended land of invention, circular or spiral
w_2	axial width of land 44
46	convex surface of land 44
48	central location of maximum radius or high point of land 44
50	wire wrapped onto 18
52	essentially rectangular cross section wire
54	convex surface of wire 52
56	side walls of wire 52
58	base wall of wire 52

Claims

Having thus described our invention in sufficient detail to enable those skilled in the art to make and use it, we claim as new and desire to secure Letters Patent for:

1. Apparatus for conveying a web having a width, comprising:
   a source of a web to be conveyed;
   at least one cylindrical roller having an exterior surface with a length, the length being longer than the width of the web to be conveyed, a portion of the web being wrapped onto the roller over an angle α;
   a plurality of circumferentially extending, axially spaced grooves formed in the exterior surface along the length, each groove having an axial width;
   a plurality of lands formed in the exterior surface and extended between the grooves, each land having an axial width and a central surface with a convex curvature, the convex curvature having a maximum radius from a centerline of the roller; and
   the convex curvature of the lands and the axial widths of the grooves and lands being chosen so that, at a beginning of the wrap angle α during rotation of the roller, the web undulates along the width of the roller over the lands and into the grooves but is spaced from the convex curvatures of the lands, so that air entrained between the web and the lands can flow into the grooves.

2. Apparatus as claimed in Claim 1, wherein a minimum clearance between the web and the lands occurs at the maximum radius of the convex curvature.

3. Apparatus as claimed in Claim 1, wherein the wrap angle α is in the range of 10 to 300 °.

4. Apparatus as claimed in Claim 1, wherein the web is ultrathin, having a thickness less than 0.001 inch.

5. Apparatus as claimed in Claim 1, wherein a minimum clearance between the web and the exterior surface occurs at the maximum radius of the convex curvature; and the clearance between the web and the convex curvature increases with axial distance from the minimum clearance.

6. Apparatus for conveying a web having a width, comprising:
   a source of a web to be conveyed;
   at least one cylindrical roller having an exterior surface with a length, the length being longer than the width of the web to be conveyed, a portion of the web being wrapped onto the roller over an angle α;
   at least one spiral groove formed in the exterior surface along the length, the spiral groove having an axial width;
   at least one continuous spiral land formed in the exterior surface and extended between turns of the spiral groove, the spiral land having an axial width and a central surface with a convex curvature, the convex curvature having a maximum radius from a centerline of the roller; and
   the convex curvature of the spiral land and the axial width of the spiral groove and spiral land being chosen so that, at a beginning of the wrap angle α during rotation of the roller, the web undulates along the width of the roller over the turns of the land and into the turns of the groove but is spaced from the convex curvature of the spiral land, so that air entrained between the web and the spiral land can flow into the spiral groove.

7. Apparatus as claimed in Claim 6, wherein the spiral groove and spiral land are formed by at least one wire wound onto the roller.

8. Apparatus as claimed in Claim 6, wherein the web is ultrathin, having a thickness less than 0.001 inch.

9. A roller for conveying a web having a width, comprising:
   a cylindrical roller having an exterior surface with a length, the length being longer than the width of the web to be conveyed, during use of the roller a portion of the web being wrapped onto the roller over an angle α;
   a plurality of circumferentially extending, axially spaced grooves formed in the exterior surface along the length, each groove having an axial width;
   a plurality of lands formed in the exterior surface and extended between the grooves, each land having an axial width and a central surface with a convex curvature, the convex curvature having a maximum radius from a centerline of the roller; and
   the convex curvature of the lands and the axial widths of the grooves and lands being chosen so that, at a beginning of the wrap angle α during

rotation of the roller, the web undulates along the width of the roller over the lands and into the grooves but is spaced from the convex curvatures of the lands, so that air entrained between the web and the lands can flow into the grooves.

10. A roller as claimed in Claim 9, wherein the convex curvature has a radius of curvature in the range of 0.020 to 1.2 inch; the axial width of the grooves is in the range of 0.020 to 0.105 inch; and the axial width of the lands is in the range of 0.020 to 0.105 inch.

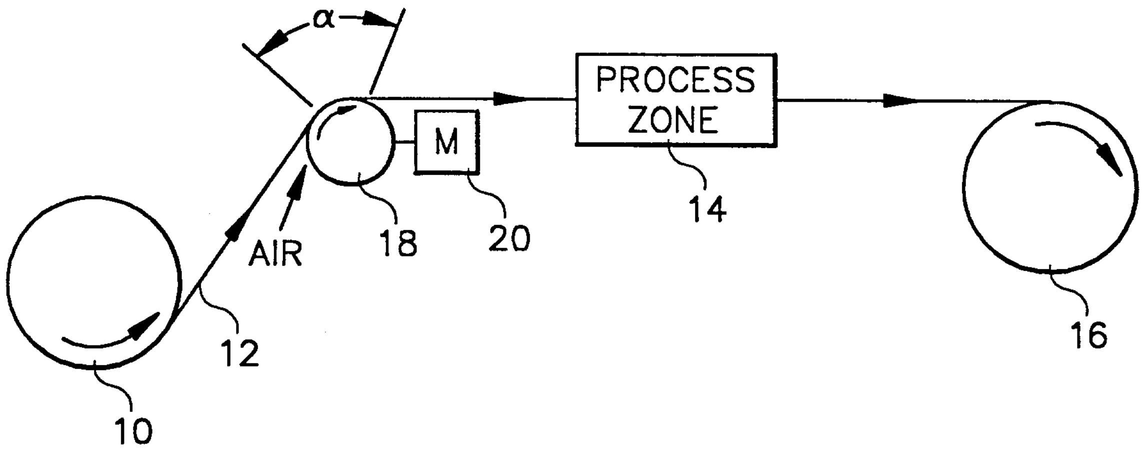

FIG. 1

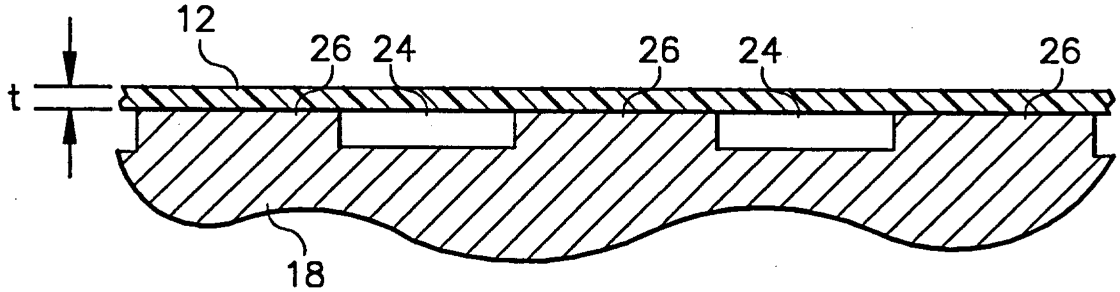

FIG. 2
(PRIOR ART)

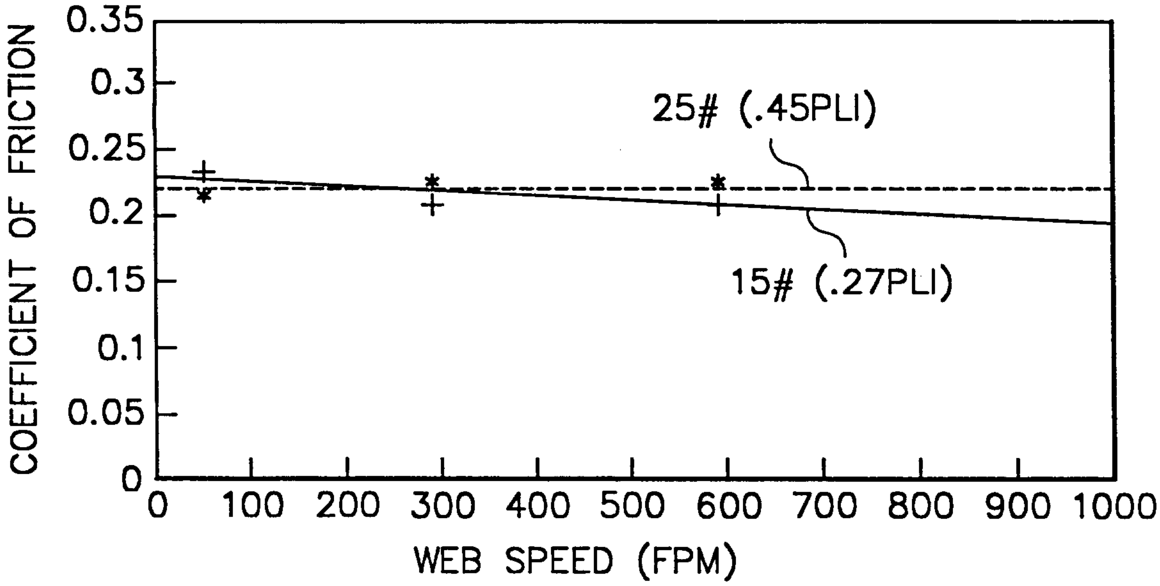

FIG. 3
(PRIOR ART)

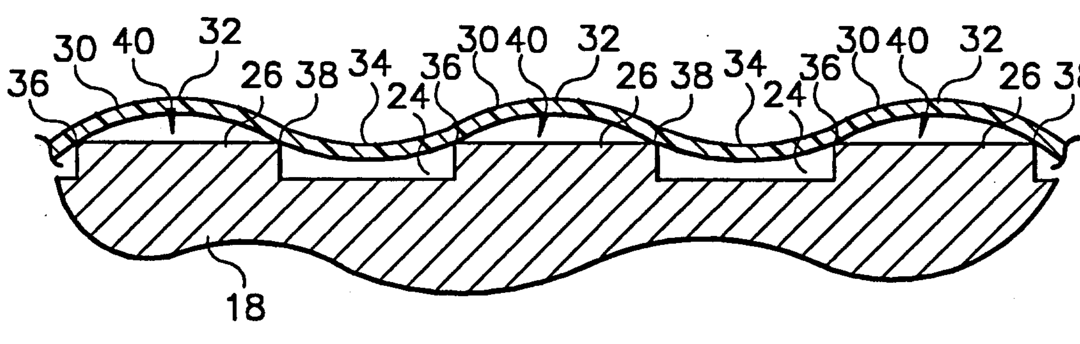

FIG. 4
(PRIOR ART)

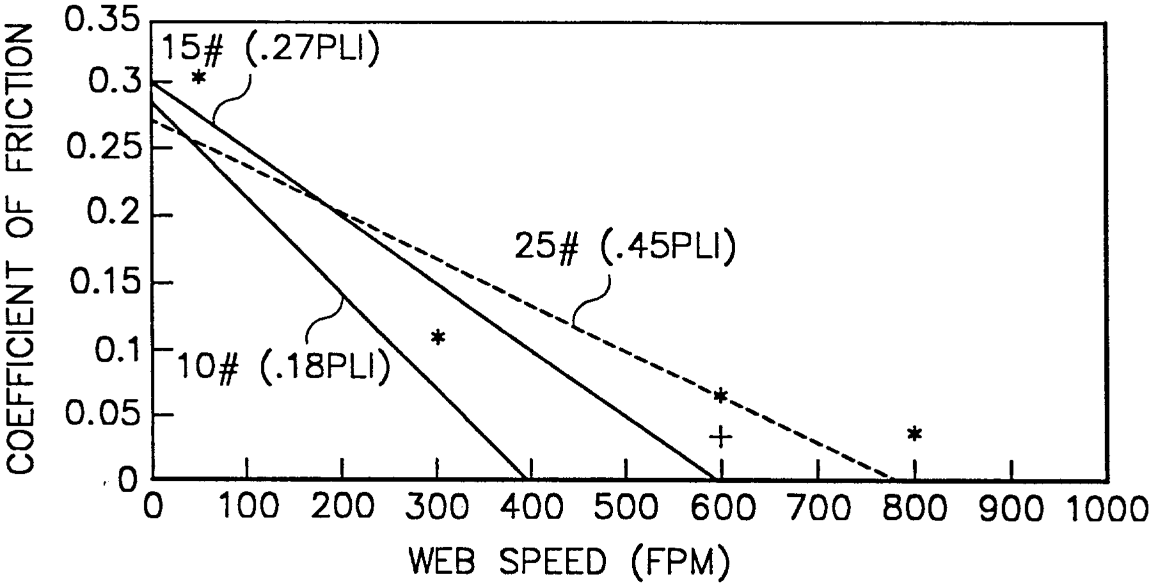

FIG. 5
(PRIOR ART)

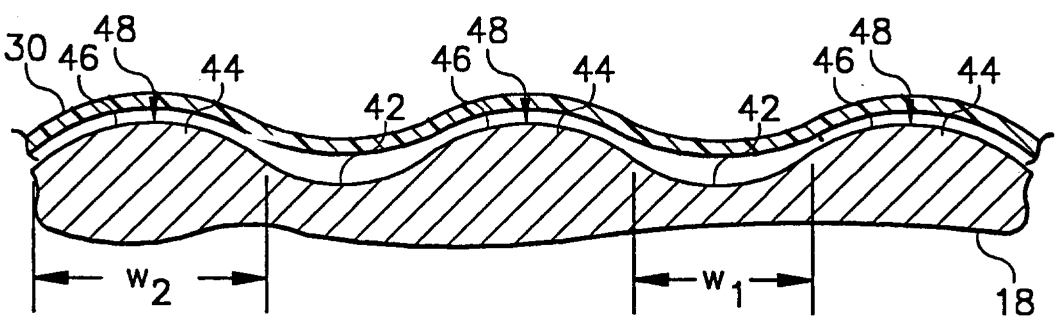

FIG. 6

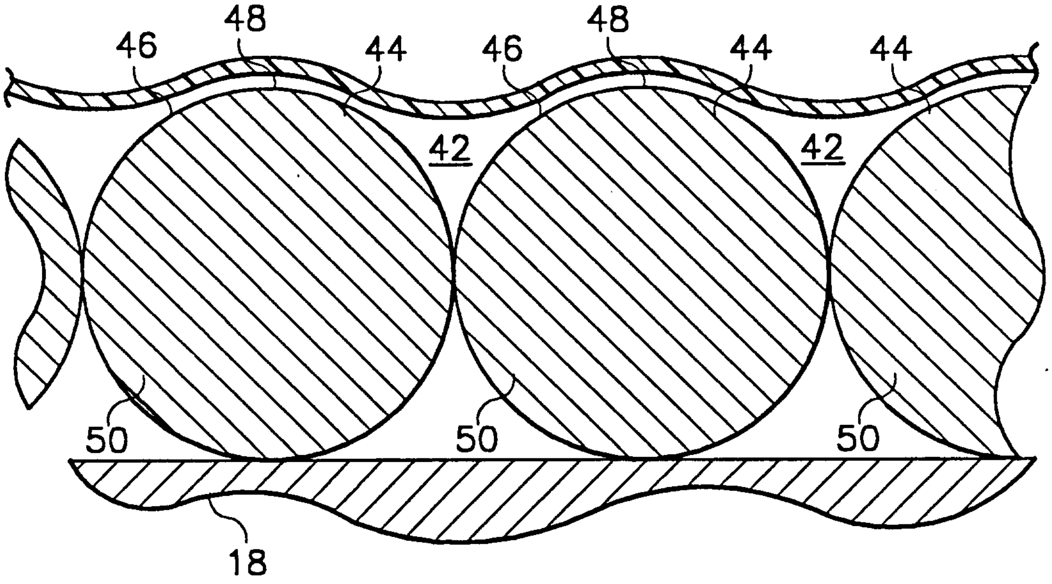
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FIG. 7

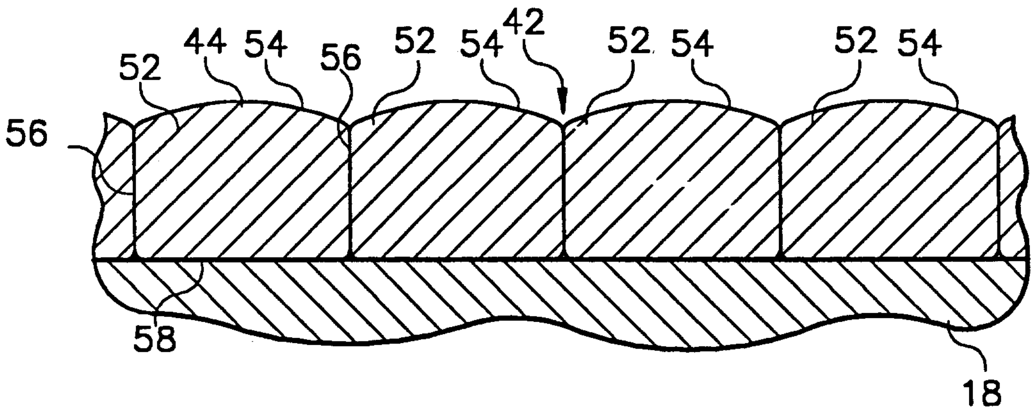
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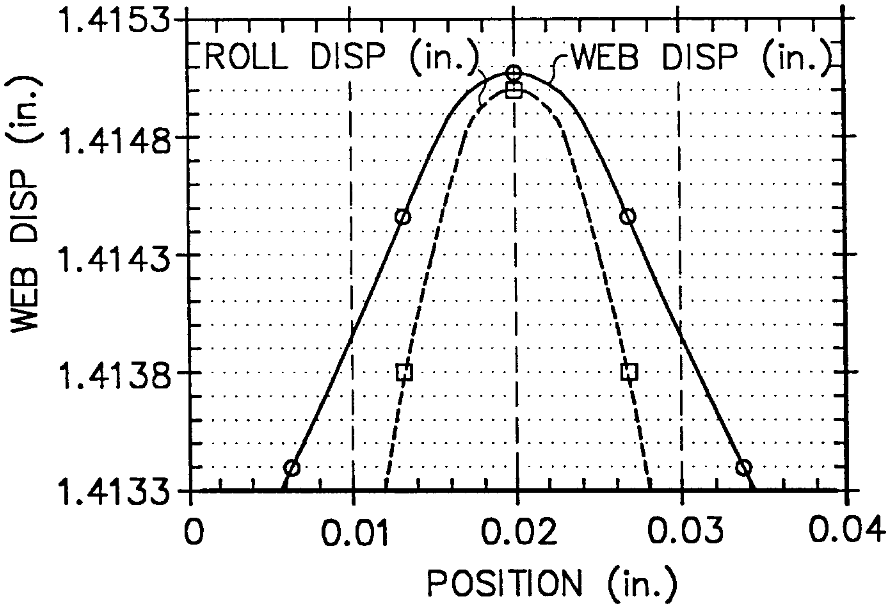
FIG. 10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1.4133
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ROLL DISP (in.)
WEB DISP (in.)
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0.01
0.02
0.03
0.04
POSITION (in.)

FIG. 8

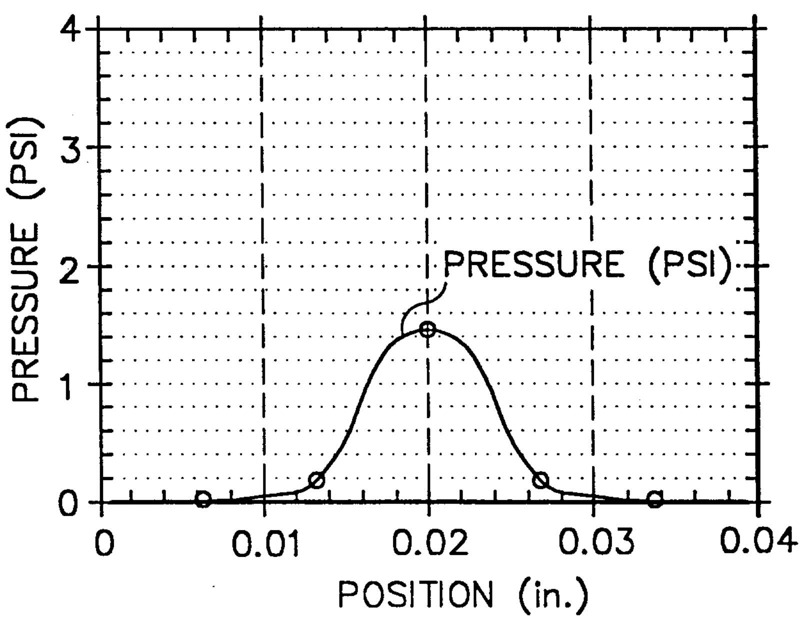

4
3
2
1
0
PRESSURE (PSI)
PRESSURE (PSI)
0
0.01
0.02
0.03
0.04
POSITION (in.)

FIG. 9

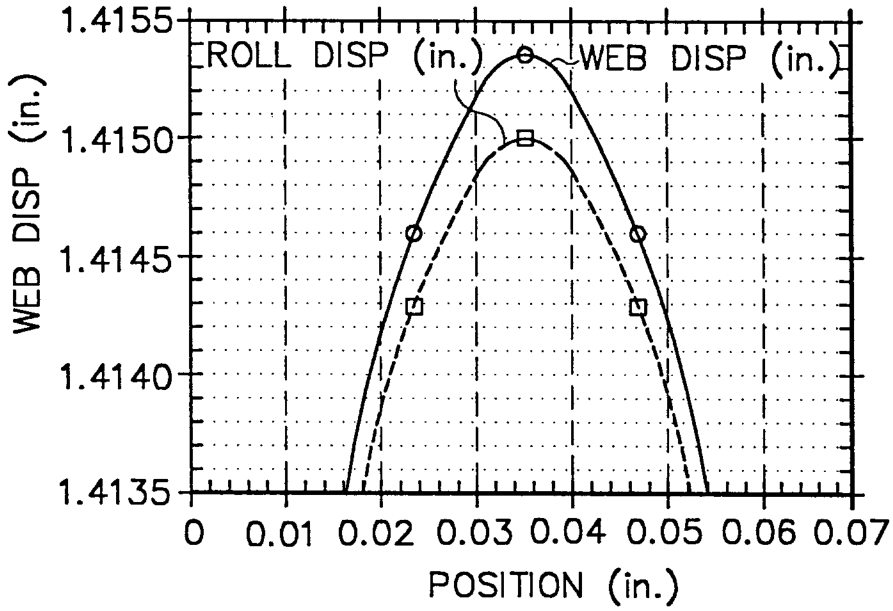

1.4155
1.4150
1.4145
1.4140
1.4135
WEB DISP (in.)
ROLL DISP (in.)
WEB DISP (in.)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
POSITION (in.)

FIG. 11

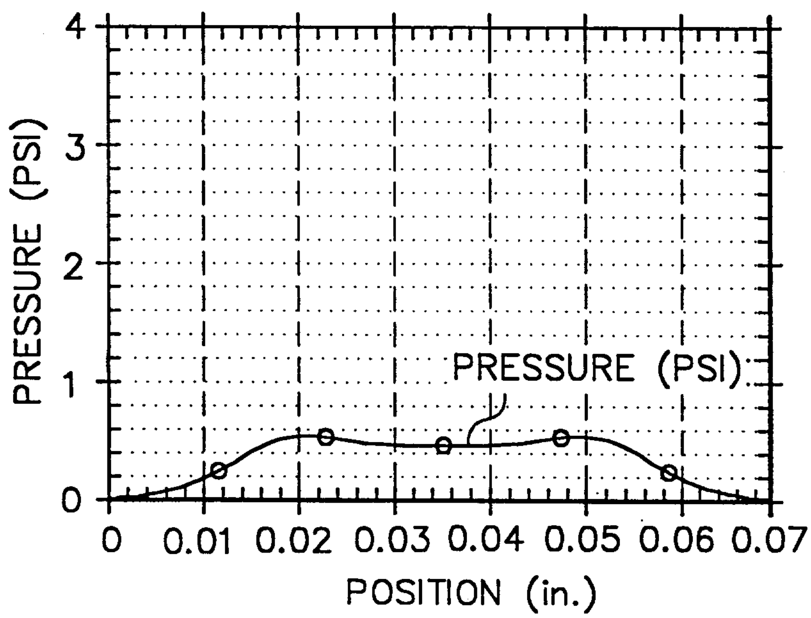
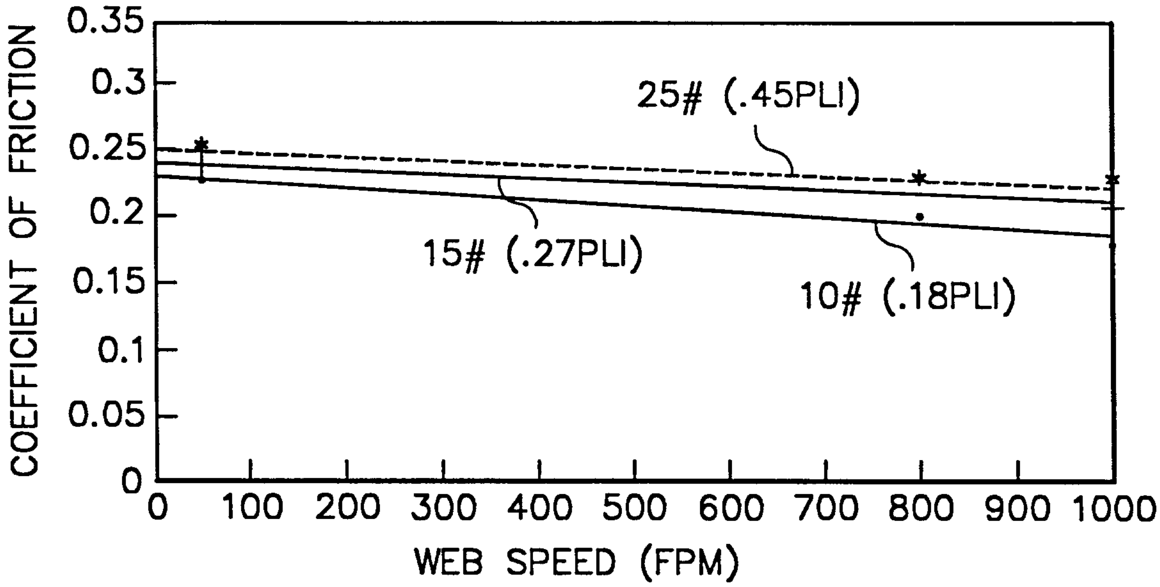
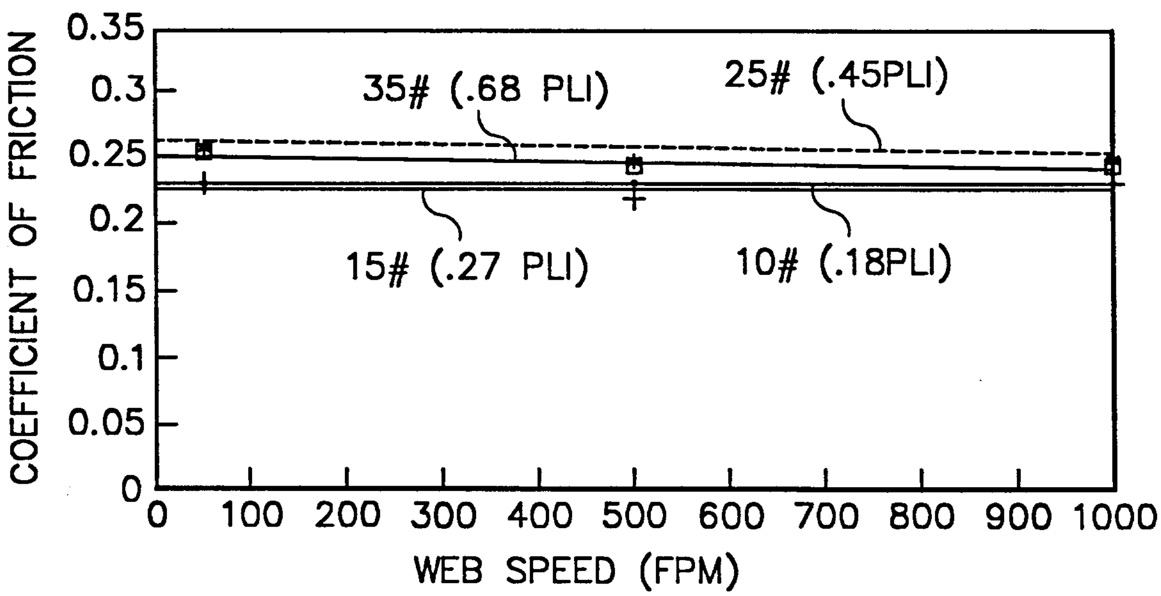

4
3
2
1
0
PRESSURE (PSI)
PRESSURE (PSI)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
POSITION (in.)

FIG. 12



COEFFICIENT OF FRICTION
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
25# (.45PLI)
15# (.27PLI)
10# (.18PLI)
0
100
200
300
400
500
600
700
800
900
1000
WEB SPEED (FPM)

FIG. 13



COEFFICIENT OF FRICTION
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
35# (.68 PLI)
25# (.45PLI)
15# (.27 PLI)
10# (.18PLI)
0
100
200
300
400
500
600
700
800
900
1000
WEB SPEED (FPM)

FIG. 14