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(54) **Dual traction roller**

(57) A dual traction roller surface provides a constant, intermediate traction coefficient by combining two different surfaces, one low and one high traction. The dual traction surface eliminates web slippage and scratches without increasing wrinkle sensitivity.

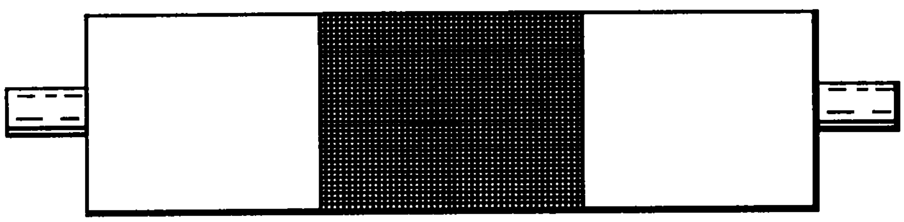

Fig. 2A

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Description

The present invention relates to rollers. More particularly, the present invention relates to rollers that provide a constant traction to eliminate web slippage and scratches.

In many manufacturing processes, a continuous sheet of paper, film, foil, non-woven, or woven material is transported through one or more processes to convert or rewind the material. Web handling is used in manufacturing adhesive tapes, magnetic tapes, printed products, abrasive products, medical tapes, medical drapes, face masks, photographic films and papers, reflective sheeting, fabrics, foils and other products.

In transporting a web through a typical web converting operation the web passes through a series of rollers to support, guide, drive, and tension the moving web. Each roller typically has three components: a shaft, a shell, and bearings. The surface material and texture of the shell is an important part of its design. The combination of the friction and the lubrication between the web and roller, called traction, is determined by the operating conditions and the two surfaces involved. Control of the web requires traction forces between the web and rollers.

Poor traction in the crossweb and machine directions results in slip-related defects. Radial or roller slip causes web scratches. Lateral slip or web shift causes web position errors or wrinkles. Very high traction can promote wrinkles and creases. Because web scratches, weave, and wrinkles result in product defects in many web processes, web traction principles are used in product and equipment design. Some thicker, higher modulus webs are not sensitive to wrinkles and can rely on a rule that "high traction is best." Some products are not scratch or slip sensitive and can rely on the rule that "low traction is best." However, many modern products are designed for minimum raw materials and require thin, wrinkle-sensitive webs. They also require scratch-free, debris-free surfaces.

An idler roller can scratch the web when the roller surface speed is less than the web surface speed. This occurs when the force to turn the roller is greater than the force available from the web-to-roller friction. Slip and scratches often occur as the speed increases in a web handling process. As speed increases the force to turn or accelerate the roller increases. Figure 1 shows a comparison of the web speed and the torques. The torque required (T_R) to turn the roller and the torque available (T_A) to drive the roller are compared. The torque required increases with increasing speed and the torque available decreases with increasing speed. The roller will slip at a speed S when the driving torque available is less than the torque required to turn the roller, shown as the intersection of the two curves.

Any body in motion through a fluid develops a boundary layer. In web handling, an air boundary layer develops near to the web's surface and moves with the web. The air layer reduces friction between the roller and the web. The air layer thickness is a function of roller radius, air viscosity, velocity, and tension, and the thickness and lubrication effects increase with increased speed, increased radius, and decreased tension. As web speed increases, the air layer increases and floats the web off the roller. The tensioned web wrapped around a roller develops a pressure which will compress the air layer between the web and roller. This pressure decreases with increased radius and decreased tension.

A transition from high to low traction occurs when the air layer thickness overcomes the combined roughness of the web and roller surfaces. The high to low traction transition can be shifted with increases in web or roller roughness. Large air layers of high speed, low tension web handling (greater than 152.4 m/min (500 ft/min), less than 1.75 N/cm (1 lb/in) require roller design changes to maintain good traction.

Roughened or textured roller surfaces are effective in improving high speed traction. A textured surface allows the air to escape from between the web and roller. Figure 1 shows that adding texture to a roller, such as by grooving or knurling, will reduce slip by preventing lubrication, keeping the available torque ($T_{A,T}$) greater than the required turning torque. Several different roller roughness patterns can be used including: spiral grooved (herringbone pattern); dual spiral grooved (diamond pattern); plasma sputtered; sand blasted; knurled; and various machined roughnesses.

Grooves cut into the surface of a roller may not be sufficient to prevent air lubrication. If the spacing between grooves is greater than 2.5 cm (1 in) and the surface roughness between the grooves is smooth, the web will float between the grooves without significantly preventing lubrication. An overall roughness, like knurling, sand blasting, or plasma coating, is the best way to eliminate air lubrication problems.

The general concept of texturing a roller to prevent air lubrication and traction losses is known. However, high traction is not always desired. Even though high traction prevents slip and scratch defects, high traction promotes web wrinkle defects. A wrinkle is a web buckled in the crossweb direction while it is in contact or wrapped on a roller surface. Wrinkle-free web handling is desired.

The traction between a web and roller is an important condition which determines if a web will wrinkle on the roller. A roller is naturally a wrinkle prevention device because webs do not easily buckle or bend in two directions at once. This is the concept of shape stiffening. As a web bends to conform to the cylindrical shape of the roller it will gain stiffness or resistance to buckling in the crossweb direction. A web can buckle in the upstream web span as it approaches a roller and then lay flat with no wrinkle on the roller. What determines whether a wrinkle will form is the web-to-roller traction. If the web-to-roller traction is high, the buckled web approaching a roller will be unable to slide laterally to a wrinkleless shape. If the web to roller traction is low, the web will slide laterally and not wrinkle.

As mentioned above, increased roughness through any of several textures in a simple surface texture roller will reduce traction losses from air lubrication. However, these textures can only maintain the friction at the initial value or adjust the rate of lubrication. They can not provide a constant, controllable traction level and do not address high traction wrinkle sensitivity. Thus, there is a traction window between web scratches and web wrinkles. The desired traction between a web and roller is above the low traction required to prevent slip and scratches and below the high traction capable of holding wrinkles.

Many different rollers and bearings attempt to improve web handling. For example, air bearings replace standard oil or grease ball bearings to greatly reduce the force required to drive a roller. This addresses slip and scratch problems but does nothing for wrinkle sensitivity.

The Vacutex roller by Pagendarm reduces slip and scratches in low wrap roller positions. The Vacutex roller combines a roller bearing system with an air nozzle system. A live shaft roller is mounted in the cradle of two wheels using a shaft and wheel arrangement to create a mechanical advantage of greater than fifty to one. This bearing system reduces the force required to drive a roller. The nozzle system creates a Coanda effect suction and increases the wrap and force of the web on the roller. Similar to air bearings, this device reduces slip and scratch defects, but will not aid wrinkle sensitivity.

The bowed roller is banana-shaped with a constant diameter and a curved shaft or axis of rotation. It is formed as a series of narrow rollers stacked next to each other on a curved shaft. An expandable elastomeric cover is stretched over the rollers to form a continuous, wide surface. The bowed roller spreads the web based on the web tracking rule of normal entry, where each lane of web attempts to enter the downstream roller perpendicular to the axis of rotation. Since the rotation of the bowed roller causes the center of the web to track straight and each edge to track laterally, it results in a laterally taut, wrinkle-free web. The percent the web spreads can be calculated from span length, wrap angle, web width, and bow depth. Excessive bow depth leads to slip on the roller, abrasion, and web breaks. Bowed rollers usually require a high force to drive them to line speed and are unacceptable for low tension applications. Other disadvantages include short cover life, complexity, and speed limitations due to high drag and air lubrication problems.

Both reverse crown and tape bumpered rollers feature a crossweb roller diameter variation where the diameter of the roller is greater at the edges than at the center. These rollers require good traction, no-slip conditions between the web and roller. The large diameter edges change the web tension crossweb profile entering the roller with higher tension at the edges than at the center. This creates a moment in each side of the web. The opposite moments cause the web to spread as is enters the downstream roller. These rollers have similar disadvantages as bowed rollers.

Edge puller nips are used extensively in the fabric industry for low modulus webs. Two narrow rollers are nipped together with a spring loading. The nips grip the web span between rollers. The web develops traction to these nips and will attempt to follow the normal entry rule. If the nips are angled outwardly, the web will spread laterally. These nips are difficult to use with high modulus materials, require two-sided contact, and can damage crush-sensitive webs.

The Flex spreader by Bingham and the Arco-Stretcher by American Roller are two bevel-grooved rubber covered spreaders. The surface of these rollers flexes as the web tension presses down. The individual spiral fins created by the grooves flex laterally, and pull the web taut in the width direction. These rollers have a nearly straight cylinder and gentle spreading action, but cannot be used in contact with an adhesive-coated side of a web, have limited spreading, and allow thin webs to fall into the grooves.

A "D" bar is a bent bar or crowned cylinder which the web is dragged over to increase the path length and the tension of the center of the moving web. Tightening the center of the web creates lateral bending from the center to the edge and reduces wrinkles. This device requires the web to slip on the "D" bar and is not used on scratch sensitive products.

Expander rollers expand and contract laterally during each revolution. The web is wrapped around the circumference of expander roller for part or all of the 180 degrees of lateral expansion. The WrinkleStop roller, the Polyband roller and the Menzel roller are expander type rollers.

WrinkleStop rollers, manufactured by Converter Accessories Corp., are similar to bowed rollers. Segments rotating on a shaft support a flexible sleeve or covering. However, the WrinkleStop roller is cylindrical, not bowed. The spreading action is created by angling the end plates of the sleeve. The web bonds to the elastomeric surface and is spread laterally as the roller rotates. Polyband expander rollers, originally manufactured by Lembo, are similar to the WrinkleStop and other expander rollers. Several polymeric bands, similar to surgical tubing, are stretched between two angled end plates. The web wraps the roller on the band expanding side, pulling out wrinkles. Polyband rollers are limited to speeds of one thousand rpm due to centrifugal forces. These rollers usually are high drag torque devices requiring high web tension or torque assist motors and their complex design has high maintenance costs.

There is a need to provide a roller surface of a desired traction level over a wide range of process tensions, speed, and roller radii. There is a need for such a roller which works with wrinkle-sensitive, scratch-sensitive products.

The present invention is a roller surface that handles a web without slip or scratch defects and does so over a wide range of web tensions, web speeds, and roller diameters. The present invention is also a roller having this surface. The roller surface can have a plurality of surfaces each having a coefficient of traction that differs from the coefficient of traction of the adjacent surface.

The plurality of surfaces can form axial or circumferential stripes. Three circumferential surfaces can be formed, with the axial center surface having a high coefficient of traction and the axial end surfaces having lower coefficients of traction. Alternatively, the axial center surface can have a low coefficient of traction with the axial end surfaces having lower coefficients of traction. The axial end surfaces can have equal coefficients of traction.

This invention will be described in detail in connection with the drawings.

Figure 1 is a graph comparing the web speed, the torque required to turn the roller, and the torque available to drive the roller.

Figure 2A is a plan view of a roller surface of the present invention.

Figure 2B is a plan view of a roller surface of another embodiment of the present invention.

Figure 3 is a plan view of a roller surface of another embodiment of the present invention.

Figure 4 is a plan view of a roller surface of another embodiment of the present invention.

Figure 5 is an enlarged cross-sectional view of a preferred knurl pattern.

Figure 6 graphs two variations of the roller compared to a 100% smooth or 100% rough roller surface.

The present invention is a roller and roller surface used to transport a moving web or other flexible, continuous sheet of material such as paper, film, foil, non-woven, woven, composite or laminate of these materials, in coated or uncoated forms. The surface can be applied to idler rollers driven by the web, whether stationary or part of a moving apparatus, and driven rollers powered by speed or torque control. The roller combines low traction portions (surfaces having a low coefficient of traction) which prevent wrinkle problems and high traction portions (surfaces having a high coefficient of traction) which prevent slip problems. The different surfaces are shown in Figures 2-4.

One embodiment combines a high traction, rough surface in the center 25-50% of the roller contact width, and low traction, smooth surfaces on the ends, as shown in Figure 2A. Alternatively, as shown in Figure 2B, a low traction, smooth surface can be located in the center of the roller with a high traction, rough surface on the ends.

Figures 3 and 4 show alternative embodiments of using both high and low traction surfaces. In Figure 3, a plurality of circumferential rough and smooth stripes are used and in Figure 4, a plurality of axial rough and smooth stripes are used. Also, embodiments with various surfaces having three or more different coefficients of traction can be used.

The preferred rough surface for thin film applications is a knurl pattern, as shown in Figure 5. The distance a between the centers of adjacent knurl grooves is 0.25 cm (0.1in). The height of the knurls is less than 0.025 cm (0.010 in). This knurl pattern prevents air lubrication traction losses at typical high speeds of 152.4-609.6 m/min (500-2000 ft/min) and low tensions of 0.44-1.75 N/cm (0.25-1.0 lb/in) found in many converting processes. Among rough surface options, the knurled surface is preferred for ease of cleanup and reduced traction changes due to abrasion.

Variations of a dual traction roller surface can he designed with different materials, textures, or geometric patterns. One geometric surface pattern has a simple, laterally changing, high traction center which is easy to machine. Other patterns resulting in a percentage split of low and high traction surfaces include radial striping, lateral striping, and low traction center patterns.

The coefficient of traction (COT) for web-to-roller cases uses the belt equation to describe the relationship of the coefficient of friction to a wrapped cylindrical surface (the roller). The belt equation is an analytically derived equation:

$$T_{high}/T_{low} = emq$$

where T_{high} is the force on the side toward which the belt will slip and T_{low} is the force on the side from which the belt will slip. q is the wrap angle in radians and m is the coefficient of friction. This equation can be rearranged to solve for the coefficient of friction:

$$m = [\ln (T_{high}/T_{low})]/q$$

A simple test determines T_{high}. The test requires a non-rotating roller, a strip of web, a weight, and a force-measuring spring scale. Attach the weight to one end of the web and wrap the web around the roller so the weight hangs vertically. Attach the scale to the other end of the web. Pull on the web in a horizontal plane while maintaining a constant wrap angle q of 90 degrees (1.57 radians). The weight is T_{low}. The force on the scale required to cause the weight to rise and the web to slip relative to the roller is T_{high}.

This same test can be performed under conditions representing actual web handling conditions at high web speeds. The web strip and spring scale test is unrepresentative of productions processes because it is performed at relatively slow web speeds. As speeds increase, air entrainment and resulting air lubrication change the relationship of the force ratio required to slip the web on the roller. Experiments which apply the belt equation to a web-to-roller system which includes air lubrication measure the coefficient of traction.

Direct coefficient of traction measurement can also be performed by measuring the force on the web using tension transducer rollers. The web is threaded through a three roller system; the first is a force-measuring roller, the second is a roller with the surface to be tested, and the third is another force-measuring roller. While running the web through these three rollers at the selected process conditions, the torque of a brake connected to the second roller increases until that roller slips. At the point of initial slip, the two force-measuring rollers measure the T_{high} and T_{low} for the selected process conditions. At slow speeds, the results will be similar to the belt equation test. At higher speeds, air lubrication effects are seen and the calculated m value is the coefficient of traction.

For the roller surface of Figure 2, the average coefficient of traction can be calculated from the percent ratio of the smooth, low traction surface, and the rough, high traction surface, using the following equation:

$$COT_{AVG} = (x)COT_{low} + (1\text{-}x)COT_{high}$$

where x is the percentage of area of the low traction surface, (1-x) is the percentage of area of the high traction surface, COT_{low} is the coefficient of traction of the low traction surface, COT_{high} is the coefficient of traction of the high traction surface, and COT_{AVG} is the weighted average coefficient of traction of dual traction surface. For this invention, the average coefficient of traction can be any value between the coefficient of traction of the low traction surface, and the coefficient of traction of the high traction surface.

Figure 6 is a graph showing two variations of the roller compared to the single surface extremes of a 100% smooth or 100% rough roller surface. The fully smooth roller lubricates quickly and can not overcome bearing drag at less than 152.4 m/min (500 ft/min). The fully rough roller with 100 percent knurled surface did not show any significant air lubrication up to 457.2 m/min (1500 ft/min). The roller surface of the present invention creates a constant traction value over a wide operating range 152.4-457.2 m/min (500-1500 ft/min). The 50 percent rough version has a traction coefficient which is half way between no lubrication and full lubrication. The 25 percent rough version has a traction coefficient which is one quarter of the way between no lubrication and full lubrication traction.

Claims

1. A roller surface having a plurality of portions each having a coefficient of traction that differs from the coefficient of traction of the adjacent portion.

2. The roller surface of claim 1 wherein the plurality of portions form axial stripes.

3. The roller surface of claim 1 wherein the plurality of portions form circumferential stripes.

4. The roller surface of claim 3 comprising three circumferential portions wherein the axial center portion has a high coefficient of traction and the axial end portions have coefficients of traction that are lower than that of the axial center portion.

5. The roller surface of claim 4 wherein the axial end portions have equal coefficients of traction.

6. The roller surface of claim 3 comprising three circumferential portions wherein the axial center portion has a low coefficient of traction and the axial end portions have coefficients of traction that are higher than that of the axial center portion.

7. The roller surface of any of claims 1 to 6 which spreads a web passing around the surface to eliminate wrinkling.

8. A roller having the surface of any of claims 1-7 having a plurality of portions each having a coefficient of traction that differs from the coefficient of traction of the adjacent portion.

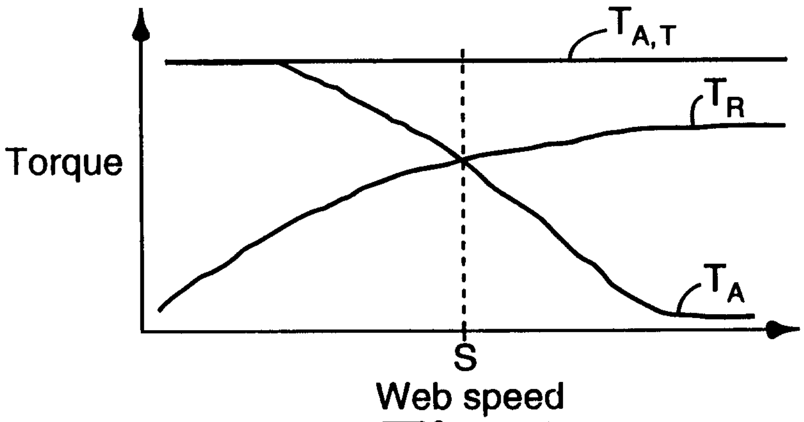

Fig. 1

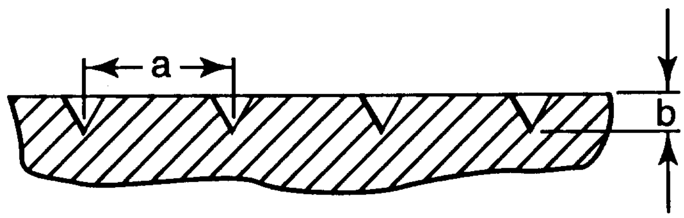

Fig. 5

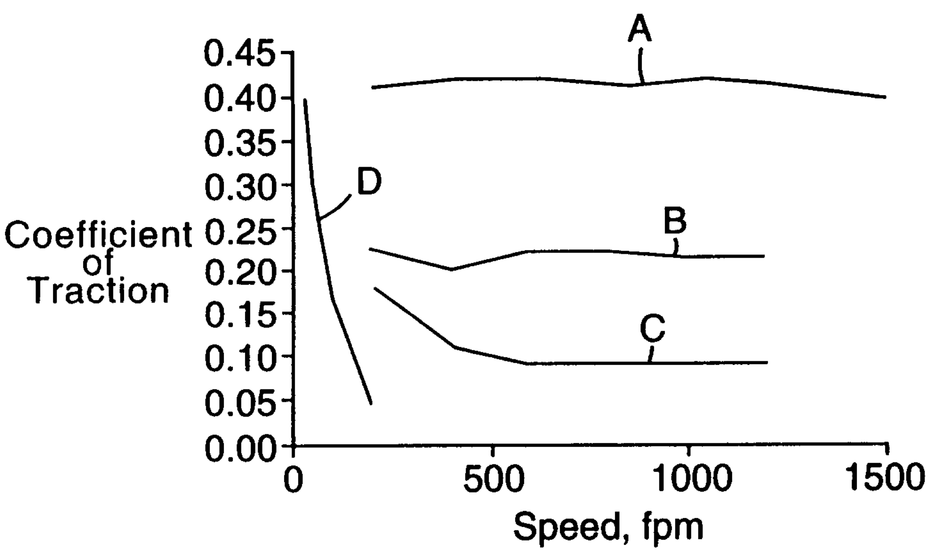

Fig. 6

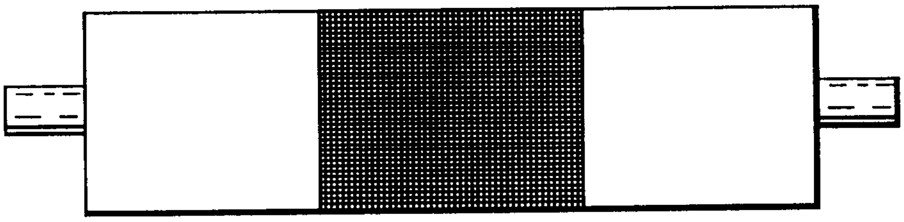

Fig. 2A

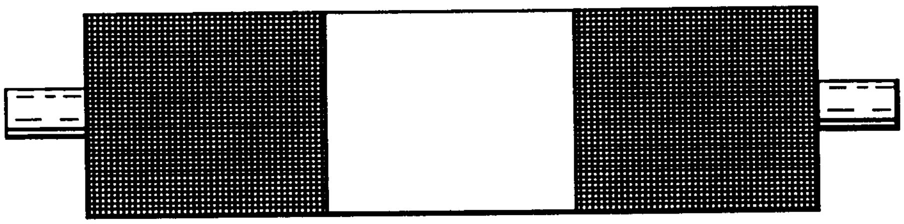

Fig. 2B

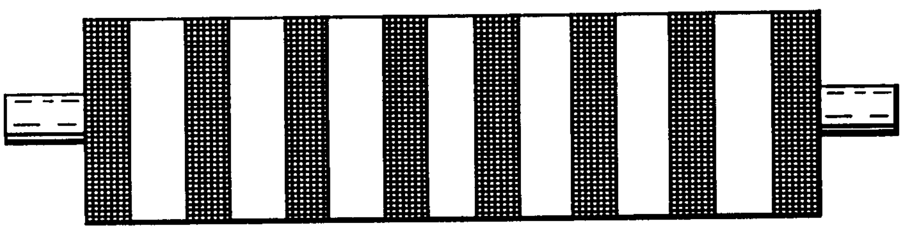

Fig. 3

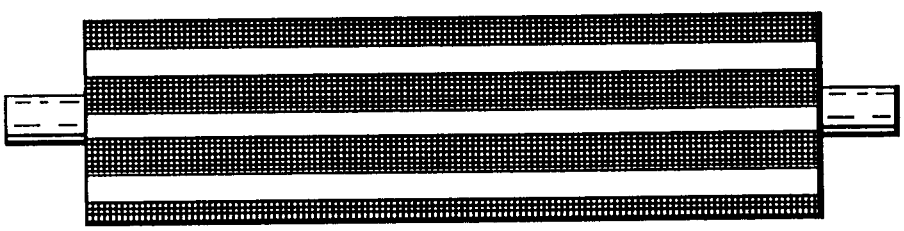

Fig. 4