United States Patent [19]

Morse

[11] **3,913,813**

[45] **Oct. 21, 1975**

[54] **WEB SUPPORT WITH CASTERED AND GIMBALLED ROLLER**

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[73] Assignee: **Eastman Kodak Company,** Rochester, N.Y.

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[21] Appl. No.: **504,777**

[52] **U.S. Cl.** **226/21;** 226/192

[51] **Int. Cl.^{2}** **B65H 25/26**

[58] **Field of Search** 226/3, 15, 18, 19, 21, 226/192, 194

[56] **References Cited**

UNITED STATES PATENTS

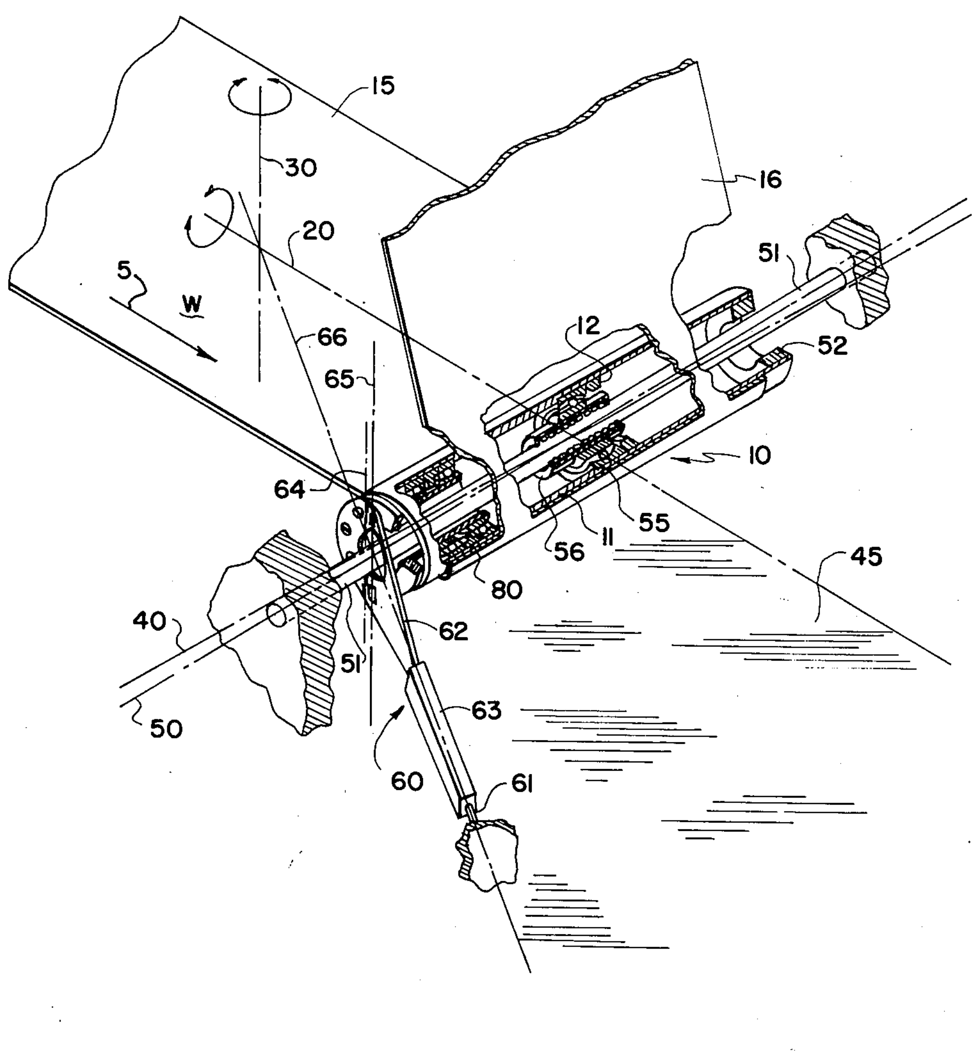
3,596,817	8/1971	Morse	226/21
3,608,796	9/1971	Morse	226/21

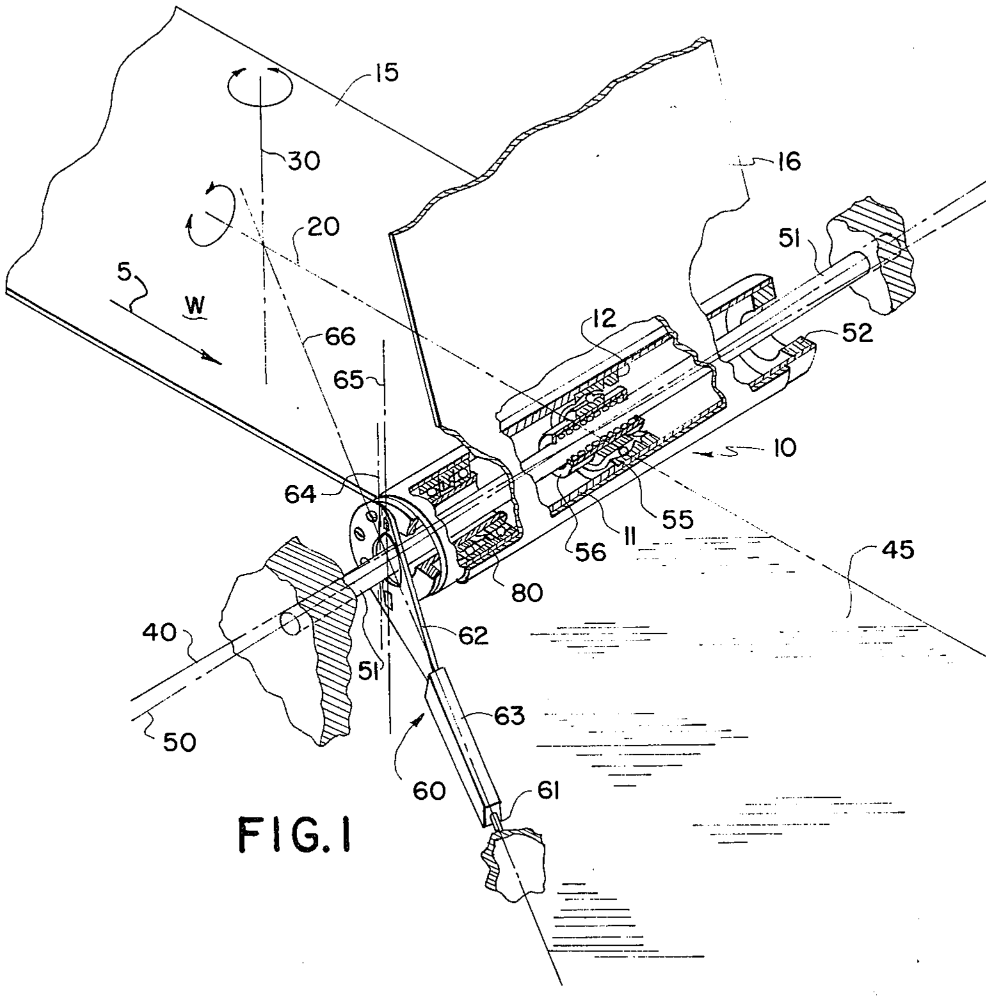
Primary Examiner—Richard A. Schacher
Attorney, Agent, or Firm—J. A. Mathews

[57] **ABSTRACT**

Web support for engaging a fully constrained moving web, having a cylindrical roller which imposes no lateral constraint on the entering portion of the moving web and which angularly decouples the exiting portion of the moving web. An improved mounting mechanism dynamically supports the roller solely at its midpoint along a fixed shaft. A constraining member reduces the movement of the roller to rotation about the longitudinal axis, pivotal movement about a gimbal axis which is parallel to the plane of the entering web portion of the moving web and perpendicular to and intersects the longitudinal axis at the midpoint of the roller, pivotal movement about a castering axis which is substantially perpendicular to the plane of the entering web portion of the moving web and intersects the gimbal axis at a point upstream from the midpoint of the roller, and translational movement along the fixed shaft as required for pivotal movement about the castering axis.

5 Claims, 6 Drawing Figures




15
30
20
5
W
66
65
64
16
51
52
12
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55
11
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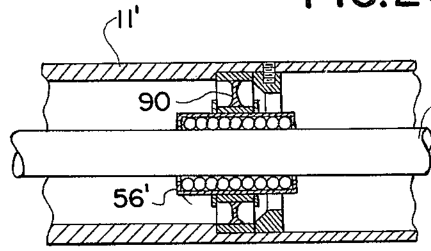
45
80
62
40
51'
63
50
60
61

FIG. 1

FIG. 2c


11'
90
51'
56'

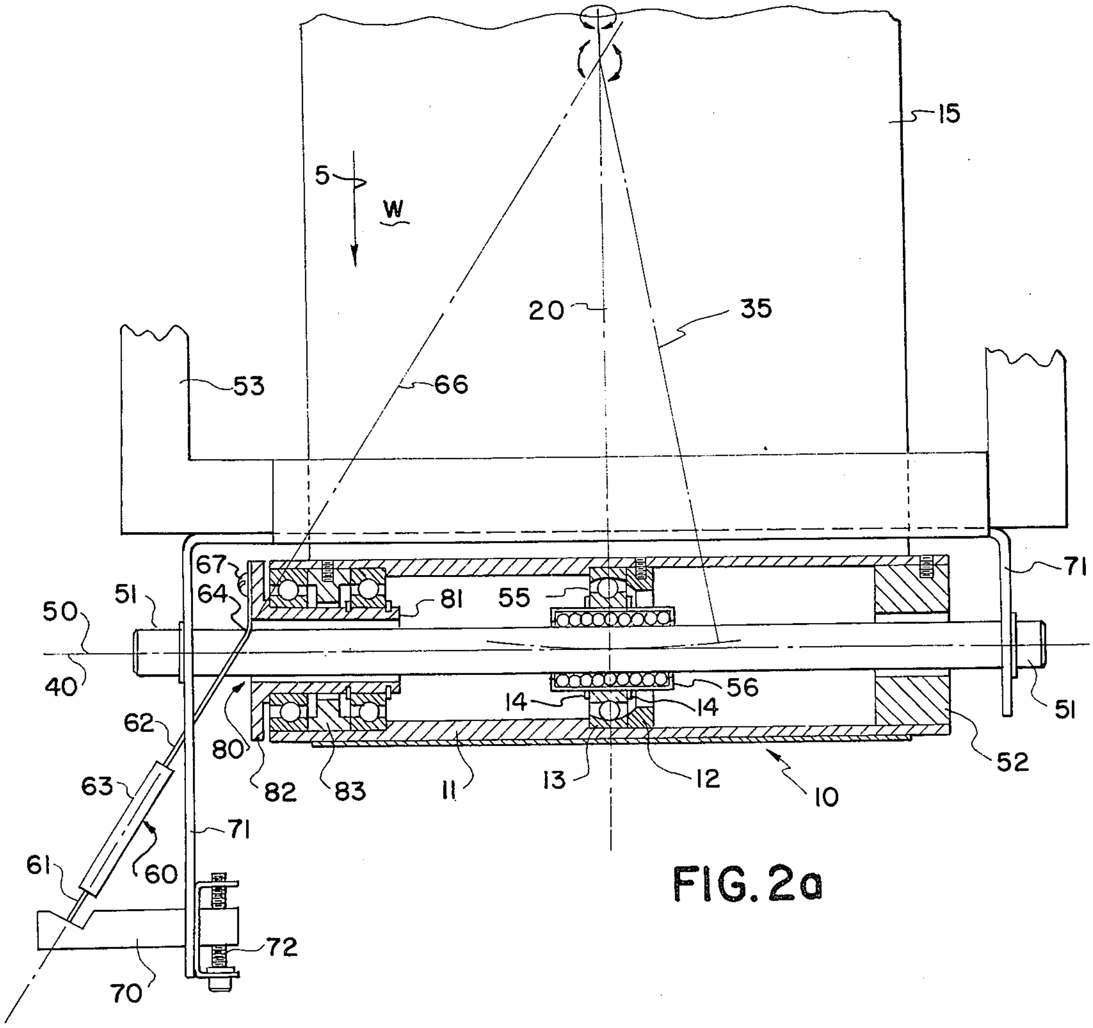

15
5
W
20
35
66
53
71
67
64
51
55
81
50
40
56
14
14
62
80
52
63
82
83
11
13
12
10
71
61
60
72
70
51

FIG. 2a

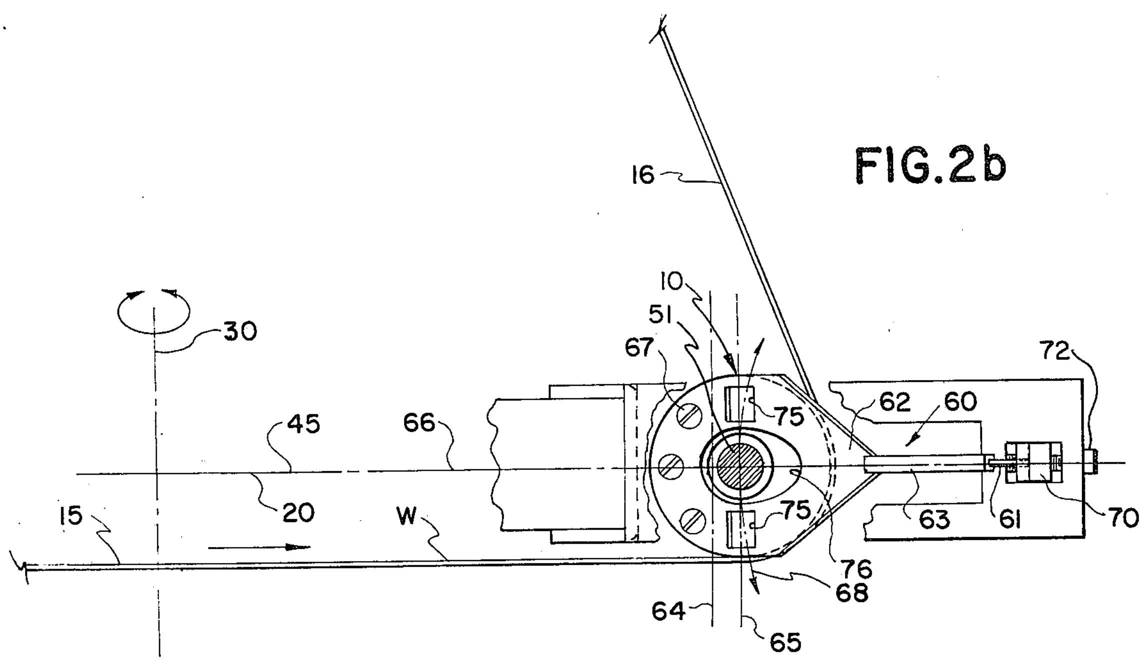
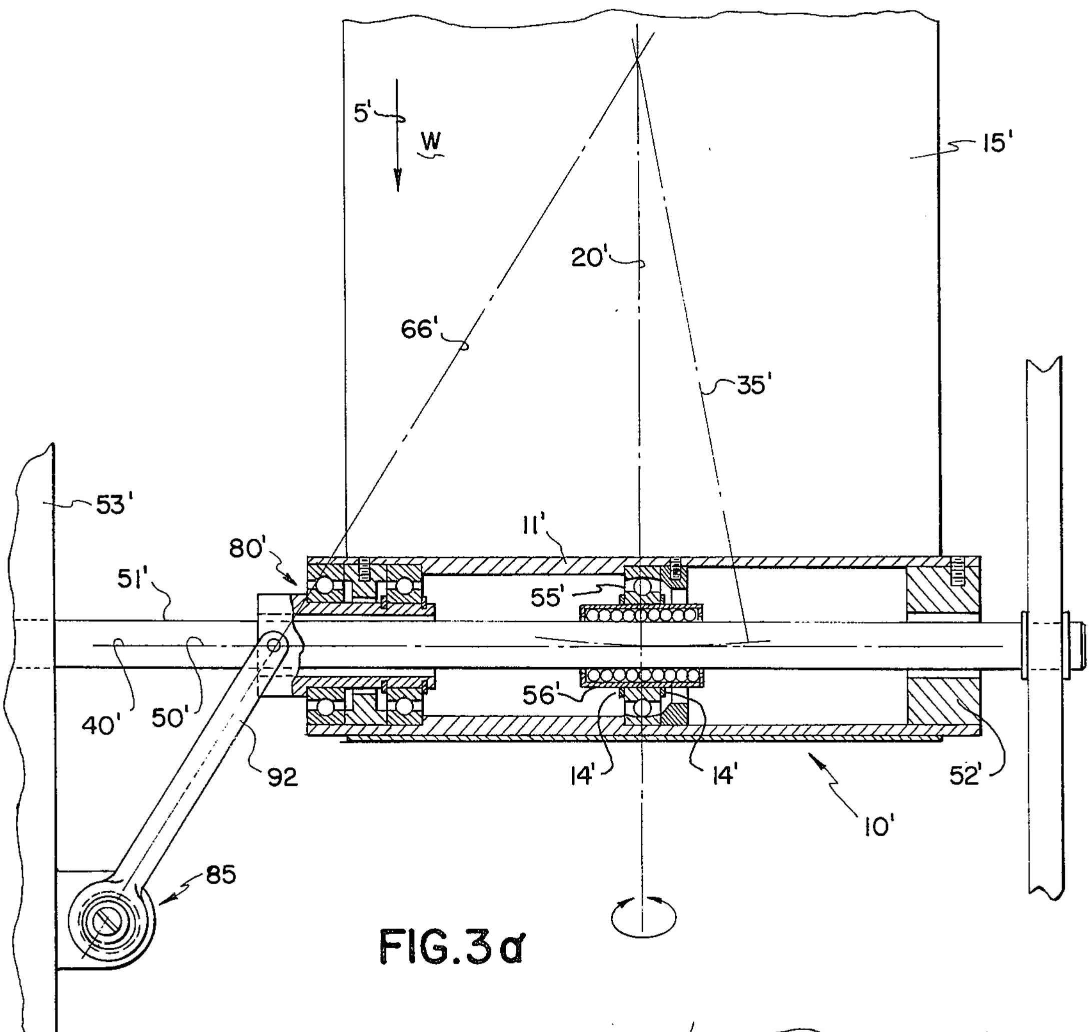

16
10
51
30
67
72
62
60
75
45
66
20
15
W
75
63
61
70
76
68
64
65

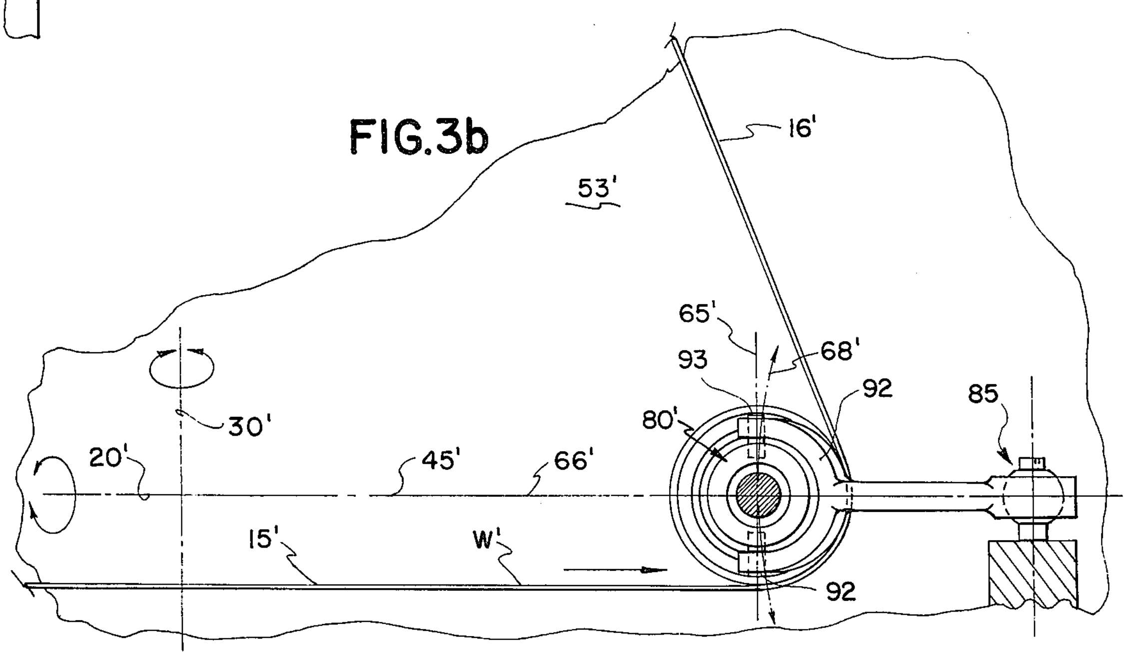
FIG. 2b



5'
W
15'
20'
66'
35'
53'
80'
11'
51'
55'
40'
50'
56'
92
14'
14'
52'
10'
85

FIG.3a

FIG.3b



16'
53'
65'
68'
93
92
85
80'
30'
20'
45'
66'
15'
W'
92

WEB SUPPORT WITH CASTERED AND GIMBALLED ROLLER

CROSS-REFERENCE TO RELATED APPLICATIONS

Reference is hereby made to commonly assigned and copending U.S. Pat. application Ser. No. 504,771, filed Sept. 10, 1974, entitled WEB TRACKING APPARATUS, filed on even data herewith in the names of Thaddeus Swanke, Michael Samuel Montalto, and John Edwin Morse. Reference is also made to commonly assigned and copending U.S. Pat. application Ser. No. 504,778 filed Sept. 10, 1974, entitled POSITIONALLY CONSTRAINING WEB SUPPORT, filed on even data herewith, in the names of Thaddeus Swanke and Richard Thomas O'Marra.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to a web handling device, and more specifically to a mounting mechanism for a web engaging roller in a web support which imposes no lateral constraint to the entering web portion and which angularly decouples the exiting web portion.

2. Description of the Prior Art

Web tracking apparatus for tracking flexible, unidirectionally moving webs on hard surfaced, cylindrical web supports can be considered functionally as comprising basically two types of web supports. The linearly moving web approaching a web support "sees" the support, relative to a fixed frame, either as (1) a laterally constraining support or (2) a laterally non constraining support. A laterally constraining support may be further subdivided into (*a*) an angular lateral constraint in which the entering web is constrained against changing its lateral position, except as its angular position changes, and (*b*) a positional lateral constraint in which the entering web is constrained against changing its spatial lateral position, while remaining free to change its angular position. The web entering a non constraining support, on the other hand, is free to change either its angular or its spatial lateral position without experiencing substantial lateral forces.

Whether a particular web support is a laterally constraining or laterally non constraining support depends as much on its function in the tracking apparatus as on its structure. For example, a rotating fixed-axis cylindrical roller, such as an idler roller or a drive roller in a tracking apparatus, is structurally an angular lateral constraint capable of constraining the moving web against change in its lateral position. To perform functionally as an angular lateral constraint, however, the entering web has to be capable of tracking on the rotating cylindrical surface until the moving web and the rotating surface are in alignment; i.e., until the longitudinal axis of the rotating surface is perpendicular to the direction of travel of the web. This tracking phenomenon is due to frictional forces developed between the linearly moving web and the rotating surface, which in turn are a function of, among other variables, wrap angle, web tension, and the upstream web-span to web-width ratio. Thus, if the wrap angle, for example, is insufficient to create the frictional forces necessary for tracking, the entering web is free to change its angular position and/or its lateral spatial position, without experiencing substantial lateral forces resulting in a web support that is functionally non constraining, although structurally an angular lateral constraint.

Although the above-noted variables upon which tracking depend are usually parameters which are governed by the design of the web tracking apparatus, some generalities can be stated that cover a significant number of situations. Thus, for a flexible web support by hard surface cylindrical supports, the upstream web-span to web-width ratio should be somewhat equal to or greater than one, and the wrap angle should range between approximately 30° and 135°, depending on the coefficient friction of the surfaces in contact, and on web tension. If otherwise, the web could be prevented from tracking, either because of not enough, or too much contact with the web support.

To facilitate the discussion to follow, it will be convenient to refer to a laterally non constraining support as an N support, and to refer to a laterally constraining support as a P support if it is functionally positional lateral constraint and as an A-support if it is functionally an angular lateral constraint.

In designing a closed loop web tracking apparatus of the type discussed above, one of the primary considerations of the design is lateral stability of the lineraly moving web. Generally, stability of the linearly moving web is achieved if the tracking apparatus has at least two laterally constraining supports, at least one of which is further restricted to be a P-support; the remaining web supports, if any, in the tracking apparatus can be either laterally constraining supports (P and A) or non constraining supports (N) as dictated by design considerations.

Although the stability principle stated above will ensure linear stability of the moving web, it does not, without more, ensure uniformity of tension in the moving web. Non-uniformity in tension ordinarily results from inperfections in the manufacture of webs and web supports, and from the lack of perfect parallelism in the longitudinal axes of the mounted web supports. It follows that if manufacturing tolerances are minimized and the supports are mounted with a high degree of parallelism, a degree of uniformity of tension will be achieved. However, such considerations are independent of the stability principle.

If a high degree of uniformity of tension of the web is a requisite of the tracking apparatus design, it can be achieved with little regard to manufacturing or mounting tolerances by conforming the web tracking apparatus to what will be referred to as the uniformity of tension principle. This second web tracking principle dictates that the moving web exiting from a first laterally constraining support must be given freedom, once and only once, to change direction before entering a second laterally constraining support. This freedom is given to the exiting web by "gimballing" the web support; i.e., by mounting the web support, whether of the constraining type or of the non-constraining type, for pivotal movement about a gimbal axis which is parallel to the direction of linear movement of the entering web, and which intersects the longitudinal axis of the support at the midpoint of the support.

The gimbal action of the web support, i.e., the capability of the exiting web to change direction, enables the exiting web to compensate for non-uniformity of tension of the web in the downstream web span. The resultant force of the non-uniform tension across the exiting web is at some perpendicular distance from the centerline of the moving web; the component of that resultant force which is perpendicular to the gimbal axis creates a moment about the gimbal axis which varies with the sine of the wrap angle, since the magnitude of the force component perpendicular to the gimbal axis varies with the sine of the wrap angle. For example, for wrap angles approaching zero or 180° the magnitude of the force component approaches zero and therefore, the exiting web is not free to change direction.

It is clear from the above relationship that the magnitude of the force component perpendicular to the gimbal axis is greatest for a wrap angle of 90°; moreover, as the wrap angle increases appreciably from 180° the exiting web behaves as if the wrap angle were appreciably greater than zero. While the gimbal action may not be appreciably inhibited by large wrap angles (e.g., those appreciably less than 180° and especially those appreciably greater than 180°), such large wrap angles may inhibit the tracking action of a web support, thereby possibly producing an unstable tracking apparatus.

The "once and only once" requirement of the uniformity of tension principle can be illustrated by theorizing a tracking apparatus in which the web exiting from a first laterally constraining support encounters two N-supports before entering a second laterally constraining support. The "once and only once" requirement provides that only one of the three supports, i.e., the first laterally constraining P- or A-support, the first N-support, or the second N-support, be gimballed; the other two must prevent the exiting web from changing direction. For reasons noted above, gimballing one of the supports provides uniformity of tension in the downstream web without affecting lateral stability. However, if more than one support is gimballed before the web enters a second lateral constraint, the lateral position of the web at the second and any subsequent non-constraining gimballed support, becomes unstable and indeterminate. The result could be lateral instability of the web span between the first gimballed support and the second constraining web support, and possible edge damage to the moving web due to such instability. Thus, the "once and only once" requirement ensures lateral stability in the moving web when N-supports are utilized in a tracking apparatus, while providing uniformity of tension.

Theoretically, the above principles would not be violated by a two-support, closed loop web tracking apparatus. However, technical problems such as the gimballing of a drive roller to meet the "once and only once" requirement, and wrap angle considerations upon which the gimballing action depends, as well as practical problems such as utility for such a two-support apparatus, could make such an apparatus commercially unattractive. The introduction of additional supports to a closed loop web tracking apparatus, however, eliminates such technical and practical problems if the combination of supports conforms to the two tracking principles outlined above, and their location relative to each other is such that the respective wrap angles the moving web makes with the three or more supports are within the limits previously discussed. In particular, a gimballed N-support could be located downstream from the drive roller of a web tracking apparatus (an A-support) to decouple the angularly constrained web exiting from the drive roller, thereby providing a web

tracking apparatus which satisfies both web tracking principles: stability and uniformity of tension in the moving web.

Non-constraining N-supports disclosed by the art include low friction cylindrical non-rotating surfaces, and axially compliant rotating web supports. Such disclosed web supports, however, are not gimballed and, therefore, do not impart angular freedom to the exiting web. The art also discloses web supports in which the rotating cylindrical surface of the web support is mounted for pivotal movement about caster and gimbal axes. For example, U.S. Pat. No. 3,596,817 discloses a web support having a castered and gimballed roller in which the pivotal movement about the caster and gimball axes is achieved by mounting the roller on a multiplicity of flexture arms. This type of mounting, although adequate for some purposes, can be impracticable for others. For example, the available space and load requirements may necessitate a different mounting. Also known are web supports having cylindrical rollers which are rotatably mounted for pivotal movement about a gimbal axis. An example is U.S. Pat. No. 3,608,796 in which the rotating cylindrical roller is mounted for pivotal movement about its midpoint. Such midpoint pivotal movement is reduced to pivot movement about a gimbal axis by a constraining member. However, unlike one that is castered and gimballed, such a web support angularly constrains the entering web; i.e., functionally, it is a gimballed A-support.

Accordingly, it is an object of the present invention to provide a web support having a castered and gimballed web engaging roller mounted on a fixed axis support.

It is another object of the invention to provide a web support in which the castering and gimballing pivotal movement of a web engaging roller is controlled by one external member only.

SUMMARY OF THE INVENTION

These and other objects are accomplished according to the preferred embodiment of the present invention by rotatably mounting a cylindrical web engaging roller on a fixed support for pivotal movement of the roller about its midpoint and for translation movement of the roller along the fixed support while statically and dynamically supporting the roller solely at its midpoint. A single constraining member reduces the movement of the roller to pivotal movement about a gimbal axis and about a castering axis, and to translation movement along the fixed support as required for pivotal movement about the castering axis. The gimbal axis is parallel to the plane of the entering web portion of the moving web and is perpendicular to and intersects the longitudinal axis of the roller. The castering axis is perpendicular to the plane of the entering web at a point upstream from the midpoint of the roller.

In the preferred embodiment, a hollow cylindrical roller is supported on a fixed rigid shaft of uniform cross-section by a self-aligning radial ball bearing upon which the roller is mounted with their respective midpoints coincident. The radial ball bearing enables the roller to rotate about its longitudinal axis and pivot about its midpoint, and is fixedly supported by a bushing mounted about the rigid shaft, thus enabling the roller to translate on the rigid shaft. Alternatively, the roller may be journalled on a bushing through a plurality of flexturally mounted members between the outer surface of the bushing and the inner surface of the roller to achieve the same result.

The pivotal and translational movement in either embodiment is controlled by a constraining arm, defining a line of action, one end of which is mounted to the roller through an outboard bearing for pivotal movement about a pivotal axis. The opposite end of the constraining arm is mounted to a fixed frame for pivotal movement about a pivot point. The line of action corresponds to the centerline of the constraining arm and passes through the pivot point, intersecting the longitudinal axis of the roller at an oblique angle and the gimbal axis at a point upstream from the midpoint of the roller. The pivotal axis is defined by the intersection of and is mutually perpendicular to the line of action of the constraining arm and the longitudinal axis of the roller. A counterweight is mounted at the end of the roller opposite the end upon which is mounted the outboard bearing. The counterweight counterbalances the weight of the outboard bearing and the constraining arm so that the roller is statically and dynamically supported on the fixed shaft solely at its midpoint.

The invention and its objects and advantages will become more apparent from the detailed description of the preferred embodiment presented below.

BRIEF DESCRIPTION OF THE DRAWINGS

In the detailed description of the preferred embodiments of the invention presented below, reference is made to the accompanying drawings, in which:

FIG. **1** is an isometric view of the web support of the invention showing the mounting mechanism for the web transporting roller, which is partly broken away, and the relative location of the various axes;

FIG. **2***a* is a longitudinal cross-sectional view of the web support showing the mounting of the roller;

FIG. **2***b* is a partial side view of the web support with its constraining arm;

FIG. **2***c* illustrates another embodiment of the web support of the invention and shows a roller supporting bushing which is flexurally mounted to the roller at its midpoint for achieving translation along the shaft and pivotal movement about the center of the roller;

FIG. **3***a* illustrates still another embodiment of the web support of the invention and shows a constraining arm having a yoke at one end and a ball and socket arrangement at the other end; and

FIG. **3***b* is a side view of the embodiment of FIG. **3***a* and shows the constraining arm pivotally mounted to the roller outboard bearing for pivotal movement about an axis which intersects the longitudinal axis of the roller.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to the drawings wherein like reference numerals have been used in several views and figures for like elements, FIG. **1** illustrates a web support **10** having a castered and gimballed roller **11**, in the form a hollow cylindrical drum, mounted according to the invention. As clearly seen in FIGS. **1** and **2***a*, web support **10** further comprises a self aligning radial ball bearing **55** mounted on a ball bushing **56**, an outboard bearing **80** fixedly connected to constraining arm **60** through outer ring **82**, and a balancing counterweight **52**.

Ball bushing **56** is slidably mounted on fixed shaft **51** which is supported by yoke **71**, which, in turn, is mounted to fixed frame **53**. Bearing **55** is centrally mounted on bushing **56** and roller **11**, and is fixed in position to the bushing and the roller, respectively, by locking rings **14** and locking annulus **12** (see FIG. **2***a*). The radial ball bearing in combination with the ball bushing rotatably supports roller **11** solely at is midpoint while simultaneously enabling the roller to pivot about its midpoint and translate along shaft **51**. The pivotal and translational movement of roller **11** is relative to fixed frame **53** which may be the frame of a web tracking apparatus such as that disclosed in copending application Ser. No. 504,771.

A constraining arm **60**, mechanically connecting roller **11** to yoke **71**, reduces the degrees of freedom of movement of roller **11** to pivotal movement about gimbal axis **20** and castering axis **30** without affecting the rotational movement of the roller about longitudinal axis **40**. Constraining arm **60** comprises a stiff member **63** to which is mounted at one end a resilient wire **61** and at the opposite end a semi-rigid plate **62**. Resilient wire **61** is mechanically connected to yoke **71** by attaching the free end to a member **70** which is adjustably positionable in yoke **71** by screw assembly **72**. Plate **62** of constraining arm **60** is bent along a line **64** (FIG. **2***b*) which is perpendicular to and intersects the line of action **66** of constraining arm **60**. The portion of plate **62** between bend line **64** and rigid member **63** makes an oblique angle with longitudinal axis **40** of roller **11**, whereas the portion between bend line **64** and the end opposite that connected to rigid member **63** is perpendicular to the longitudinal axis of the roller. The significance of the oblique angle will become apparent in the discussion to follow. Further, inspection of FIG. **2***b* will reveal that other side.

The portion of plate **62** which is perpendicular to axis of rotation **40** is mounted to outer ring **82** of outboard bearing **80** by screws **67**. It is readily apparent from viewing outboard bearing **80** in cross-section in FIG. **2***a* that roller **11** is free to rotate about its longitudinal axis **40** (which in FIG. **2***a* is coincident with axis **50** of shaft **51**) while the inner ring **81** of outboard bearing **80** remains stationary. To offset the added weight of outboard bearing **80** and constraining arm **60** at one end of roller **11**, counterweight **52** is added to the opposite end of the roller so that web support **10** is statically and dynamically balanced about the midpoint of roller **11**.

From the foregoing it will be seen that constraining arm **60** is free to pivot in any direction at the end comprising resilient wire **61**, and free to pivot about pivotal axis **65** only at the end comprising plate **62**. The mounting of constraining arm **60** on outboard bearing **80** is such that the line of action **66** of constraining arm **60**, pivotal axis **65**, and longitudinal axis **40** of roller **11**, intersect at a common point. Moreover, pivotal axis **65** is substantially perpendicular to the imaginary plane **45** formed by line of action **66** and longitudinal axis **40** (see FIG. **1**) which, for convenience, will be referred to as the entrance plane.

The resultant freedom of movement of roller **11**, due to the various mechanical parts of web support **10** described above, is (1) pivotal movement about a gimbal axis **20**, lying in the entrance plane **45**, which is perpendicular to and intersects longitudinal axis **40** at the midpoint of roller **11**; and (2) arcuate movement, having a radius **35**, about a castering axis **30** (FIGS. **1** and **2***b*) which is substantially perpendicular to and intersects entrance plane **45** at the intersection between gimbal axis **20** and line of action **66** of constraining arm **60.** It is clear that the magnitude of radius **35** is dependent on the oblique angle line of action **66** makes with horizontal axis **40.**

Inspection of the geometries of FIGS. **1** and **2***a* will reveal that arcuate radius **35** varies according to the amount of translation of the midpoint of the roller along shaft **51.** If translation of roller **10** is toward flexure arm **60,** the castering radius becomes longer. If, on the other hand, the translation is away from flexure arm **60,** the castering radius becomes shorter. However, for small translations from nominal, the castering radius remains relatively constant to a close approximation. Similarly, the gimbal axis **20** varies slightly from its nominal position. As seen in FIG. **1,** and more clearly in FIG. **2***b,* the ends of roller **10** have arcuate motion indicated by arrow **68** rather than straight line motion along pivotal axis **65.** This is due to the pivotal action of flexure arms **60.** As with variations in arcuate radius **35,** for small pivotal movement of roller **10** about axis **20** the ends have linear motion rather than arcuate motion, to a close approximation. These variations from nominal are indicated solely for clarity; they do not limit the function of the web support in any significant way.

In an apparatus incorporating the preferred embodiment of the invention illustrated in FIGS. **1**–**2***b,* the surface of roller **11** is polished aluminum, the web in contact with roller **11** is polyethylene tenephthalate and has a thickness in the order of 7 mils, the wrap angle of web W around roller **11** is in the order of 120°, the ratio of upstream web span to web width is approximately one, and the web tension of the web W is approximately one-half ounce per inch. It should be noted at this point that web support **10** is unidirectional, i.e., it must be assembled in relation to the entering plane of the web and its direction of travel. As seen in FIGS. **1** and **2***b* the plane of entering web portion **15** of the web is substantially parallel to entrance plane **45,** while the direction of travel of the web is such that the castering axis **30,** which is substantially perpendicular to the plane of entering web portion **15** of moving web W is upstream of web support **10.**

In operation, the fully constrained entering web portion **15** of web W, moving in the direction indicated by arrow **5,** does not "see" web support **10** as a lateral constraint since roller **11** will pivot about castering axis **30** until longitudinal axis **40** is perpendicular to the direction of travel of entering web portion **15.** That is, through the phenomenon of tracking discussed above, roller **11** will align itself to the entering web portion **15** by pivoting about axis **30** until its longitudinal axis is perpendicular to the direction of travel of the entering web portion. Any pivotal resistance about castering axis **30** imposed by frictional or mechanical forces which would prevent roller **11** from fully aligning itself to the direction of travel of the entering web portion **15** (thus imposing a small lateral constraint on the web), is compensated by providing roller **11** with a low-friction, polished aluminum surface which promotes slippage between the surface of roller **11** and the web in contact with such surface.

It is noted for illustrative purposes, that the alignment of roller **11** to the fully constrained entering web portion **15** of the moving web illustrated by the apparatus of the instant invention is the reverse of what occurs when a moving web, not fully constrained, enters an angularly constraining web support such as a fixed axis, cylindrical drum. In this latter situation, it is the entering web which aligns itself to the web support so that its direction of travel becomes perpendicular to the fixed longitudinal axis of the rotating cylindrical drum.

Exiting web portion **16** of moving web W is given freedom to change its angular direction, thereby angularly decoupling the fully constrained entering web portion **15** of moving web W. This freedom in exiting web portion **16** to change angular direction without affecting the lateral spatial and/or angular position of the upstream entering web portion **15** is due to the capability of roller **11** to pivot about gimbal axis **20** in response to downstream conditions. Although from viewing the arcuate movement of the end of roller **11** indicated by arrow **68** in FIG. **2***b* it may appear that movement of roller **11** about gimbal axis **20** will produce a change in the perpendicularity of longitudinal axis **40** and the direction of travel of entering web portion **15** (which would affect the lateral position of entering web portion **15**), closer examination will reveal that roller **11** will automatically compensate for any changes in perpendicularity by simply pivoting about castering axis **30.** Thus, exiting web portion **16** is free to change angular direction without affecting the lateral position of the entering web portion **15.**

As noted earlier, the surface of roller **11** is polished aluminum and the wrap angle of the web about roller **11** is approximately 120° which is in proper range for tacking and for gimballing. Since it is an N-type support, lateral slippage between roller **11** and the web in contact with roller will be beneficial to the function of the web support, which function is to present no lateral resistance to the entering web.

FIGS. **2***c* through **3***b* illustrate other embodiments of various parts of the invention. FIG. **2***c* illustrates a bushing which is flexurally mounted to the roller to provide the center pivot feature. That is, the pivotal movement of roller **11'** about its midpoint is achieved through flexure member **90** rather than self-aligning bearing **55** as shown in FIG. **2***a.* FIGS. **3***a* and **3***b* illustrate the use of a yoke **92** mounted on a ball-and-socket arrangement **85,** rather than flexure arm **60** as illustrated in FIG. **2***a.* Ball and socket **85** allows yoke **92** to pivot in any direction. Yoke **92** is pivotally mounted to outboard bearing **80'** by pins **93.** The centerline of pins **93** intersects the axis of rotation of roller **11'.** As in the preferred embodiment, the castering radius and the gimbal axis vary slightly from nominal. However, as noted earlier, this places no apparent restrictions on the function of the web support.

The invention has been described in detail with particular reference to preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

I claim:

1. In a web support for engaging a fully constrained moving web having an entering portion and an exiting portion relative to such web support, said web support being of the type having a web engaging cylindrical roller which presents no lateral resistance to such entering web portion and which angularly decouples such exiting web portion, the improvement which comprises:

a. a fixed support defining a fixed axis;

b. means for mounting said roller on said fixed support to statically and dynamically support said roller solely at a midpoint, and to provide for rotational movement of said roller about a longitudinal axis, pivotal movement of said roller about said midpoint, and translational movement of said roller along said fixed axis; and

c. means for constraining said pivotal and translational movement of said roller to pivotal movement about a gimbal axis perpendicular to and intersecting said longitudinal axis at said midpoint of said roller and extending in a plane substantially parallel to such entering web portion, pivotal movement about a castering axis substantially perpendicular to such entering web portion and intersecting said gimbal axis at a point upstream from said midpoint of said roller, and translational movement along said fixed axis as required for pivotal movement about said castering axis.

2. The invention of claim **1** wherein said fixed support is a rigid shaft of uniform cross-section.

3. The invention of claim **1** wherein said roller mounting means includes a radial ball bearing having a midpoint coincident with said midpoint of said roller for enabling said roller to pivot about its midpoint, and a bushing about said rigid shaft for fixedly supporting said radial ball bearing, and for enabling said roller to translate along said shaft.

4. The invention of claim **1** wherein said roller mounting means includes a flexure member having a midpoint coincident with said midpoint of said roller for enabling said roller to pivot about its midpoint.

5. The invention of claim **1** wherein said constraining means includes:

a. an outboard bearing mounted at one end of said roller;

b. a constraining arm, defining a line of action, one end of which is mounted to said roller through said outboard bearing for pivotal movement about a pivotal axis, the end opposite said one end of which is mounted to a fixed frame for pivotal movement about a pivot point, said line of action passing through said pivot point and intersecting said longitudinal axis at an oblique angle and said gimbal axis at an upstream location, said pivotal axis being defined by the intersection of and being mutually perpendicular to said line of action and said longitudinal axis; and

c. a counterweight mounted at the end opposite said one end of said roller for counterbalancing said outboard bearing and said constraining arm to statically and dynamically balance said roller solely at its midpoint.

* * * * *