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CA 2089710 C 2003/07/29

(11)(21) 2 089 710

(12) BREVET CANADIEN
CANADIAN PATENT

(13) C

(22) Date de dépôt/Filing Date: 1993/02/17

(41) Mise à la disp. pub./Open to Public Insp.: 1993/08/20

(45) Date de délivrance/Issue Date: 2003/07/29

(30) Priorité/Priority: 1992/02/19 (837,130) US

(51) Cl.Int.^{5}/Int.Cl.^{5} B21C 37/12

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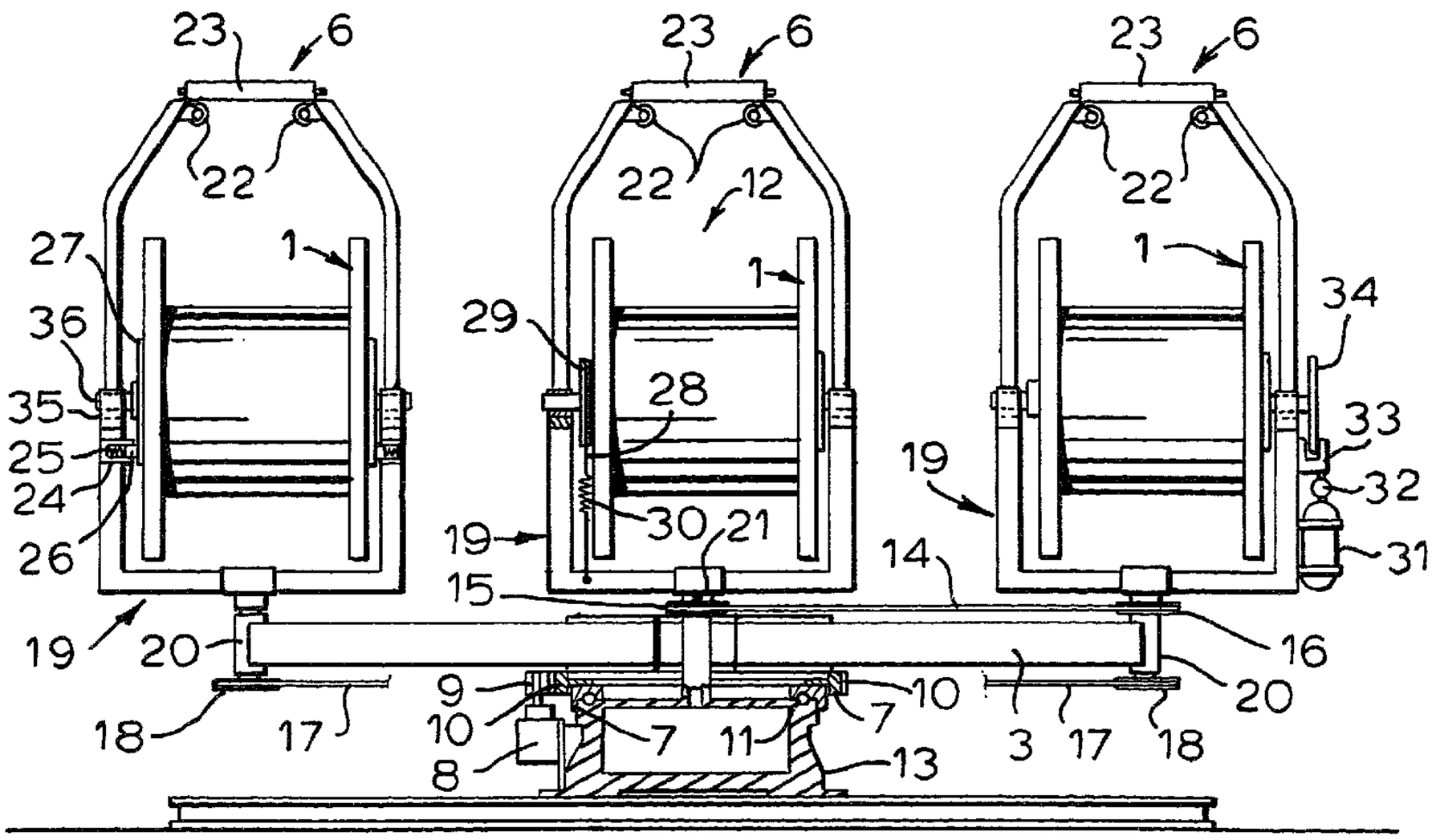
(54) Titre : CAROUSEL SERVANT A FABRIQUER DES FAISCEAUX HELICOIDAUX DE TUBES
(54) Title: CAROUSEL ASSEMBLY OF HELICAL TUBE BUNDLES



(57) Abrégé/Abstract:
A helical bundle of tubes is fabricated with a carousel-type machine, preferably rotating about a vertical axis. Spools of coil tubing are mounted on radial beams extending from a central rotating hub, and are indexed to maintain the spool axes of the spools in a constant direction. In the preferred vertical rotating axis configuration, the tubes are pulled off the spools by an overhead capstan, and the finished bundle is deposited on a take-up reel. A preferred means of indexing the spools uses chains passing around equal size sprockets attached to the vertical support shafts with at least one of the chains passing around a stationary central sprocket.

T 8474

A B S T R A C T

CAROUSEL ASSEMBLY OF HELICAL TUBE BUNDLES

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T 8474

CAROUSEL ASSEMBLY OF HELICAL TUBE BUNDLES

This invention relates to an apparatus to assemble helical tube bundles.

A fast and efficient method for installing small diameter flowlines and control lines offshore is by means of reel, tensioner, and straightener devices mounted on a floating vessel. However, this "pipe reel" method becomes awkward if multiple lines must be laid simultaneously, as is often the case for flowlines and control lines laid to, or originating at, seafloor wellheads. A typical flowline bundle to such a subsea well consists of production flowlines, annulus access line, chemical injection line, hydraulic power line and electrical control cable. When multiple lines are to be laid in a single bundle, it becomes necessary to spool each line onto a separate reel, and then either (1) lay each line separately off the floating vessel while carefully monitoring each suspended span, or (2) bring the separate lines together and wrap them with tape to form a "flowline bundle" which is then laid into the water as a single entity. Alternately, a flowline bundle may be placed inside a large "carrier pipe" and towed into position, instead of being laid from a vessel.

When lines are brought together and simply wrapped to provide a multiple tube bundle without twisting the tubes, the wrapped bundle has very poor mechanical behaviour in bending. The tube bundles cannot be spooled onto reels or pulled through curved conduits such as J-tubes, etc., due to the buckling of the tubes on the inside radius as they are placed in compression. This buckling of the tubes due to bending may be avoided by first winding the tubes into a continuous rope-like set of helixes. For applications requiring bending a bundle of tubes, the helical bundle configuration is therefore highly desirable.

An apparatus for preparing such a helical bundle is disclosed in U.S. Patent No. 4,843,713. This apparatus is capable of

preparing bundles of pipe and tubing by laying out straight lengths of the pipe and tubing, then rotating and translating the end of the bundle after it passes through a special twist head. Alternately, the bundle may be formed by rotating the straight lengths of pipe and tube and simply translating the end of the bundle after passing through the twist head. The sections of helically bundled pipe and tube can then be joined with other helical bundles and rolled onto a reel from which the bundle may be carried offshore and laid.

The apparatus of U.S. Patent '713 can only bundle separate lengths of pipe and tubing which are not longer than the length of the work space available. These limited lengths must then be joined. The resultant connections slow the fabrication process and create discontinuities in the external corrosion coating. It would be preferable to provide an apparatus and method to prepare helically coiled tube bundles wherein spools of tubing could be wound to provide extended lengths of bundles without coupling.

Helically wound bundles are also disclosed in U.S. Patent Nos. 607,932, 2,832,374, 3,269,422, 3,315,703, 3,400,737, 3,526,086, and 4,256,146, Great Britain Patent Publication Nos. 838,070, 923,816, 1,160,508, 1,210,206, 1,601,122, and 2,038,988, and European Patent Application No. 0 177 475. The cables of these references, with the exception of U.S. Patent No. 607,932, are each strapped or wrapped. The tension and bending stress required to maintain a helical configuration according to the present invention are not suggested or disclosed by any of these references.

U.S. Patent 3,269,422, at column 5, lines 10-19, discloses using a cabling machine to prepare the helically wound bundle. A cabling machine typically has a rotating spindle of spools, from which wires are pulled and twisted together. The length of cables, or twisted tube bundles, which can be prepared without coupling is limited only by the capacity of the spools.

It is therefore an object of the present invention to provide a method and apparatus to prepare helical wound bundles of externally coated metal tubing wherein the bundles do not require

strapping to hold the bundles together, and wherein the bundles can be prepared in long lengths without coupling.

The invention provides an apparatus for making a bundle of helical wound metal tubes, which apparatus comprises: a base having a central axis; a spider that is rotatable with respect to the base around the central axis; a plurality of rotating spools supported by the spider, each rotating spool containing a tube rolled around the spool about a primary axis, which primary axis lies in a plane that is perpendicular to the central axis, each rotating spool being rollable about the primary axis, and each rotating spool being rotatable about a secondary axis parallel to the central axis from a rotational position in a direction opposite to the direction of rotation about the central axis and at the same speed; a haul-off means for pulling the individual tubes off the spools at a rate relative to the rate of rotation of the spider about the central axis, so that, during normal operation a helical configuration of tubes is obtained in the form of a constant pitch length helix having at least one outermost tube; and a braking means acting on each spool so that during pulling a tension on the tube of that spool is maintained, wherein the tension is equal to or greater than $2Yd^2t/D$, wherein Y is the yield stress of the individual tube, d is the outside diameter of the tube, t is the wall thickness of the tube metal, and D is the diameter to which the tube is bent around the spool, and wherein the bending stress due to the helical configuration of the outermost tubes is cY, wherein c is in the range of from 0.5 to 1.

An apparatus such as this is capable of preparing helically twisted bundles of tubing, which bundles do not require strapping, the individual tubes preferably being

one-half inch in diameter and two inches in diameter. The bundles can be over a mile and typically as long as 5 miles without coupling. As such, the tubing

bundles can be used to provide flowlines and control lines to subsea wellheads which are remote from an oil or gas production platform.

In a preferred embodiment the central axis of the bundling apparatus is vertical. A vertical central axis results in easy access to the spider, and enables a much larger spider to be utilized. The larger spider can permit spools containing longer lengths of tubing, larger diameter tubing, or more tubes to be incorporated in the bundle. An apparatus with a vertical central axis can also be provided which conveniently enables utilization of a wide variety of different spiders. This enables production of tubing bundles of various configurations without major changes to the apparatus.

Figure 1 is a schematic drawing of a preferred embodiment of the present invention.

Figure 2 is a drawing of a preferred rotatable spider of this invention.

Figure 2A is a side view of the details of one braking means.

Referring to Figure 1, a preferred embodiment of the apparatus of this invention is shown. Spools, 1, containing coils of individual tubing, 2, are mounted on a spider, 3. The spider rotates as the haul-off means, shown as a capstan, 4, supported above the spider, draws the individual tubes from the spools 1 and passes the finished helical bundle over to the take-up reel 5. Guides, 6, enable the tubes to exit the spools without contacting the side flanges of the spools which would damage any external coating on the tubing. Spider 3, is mounted on a turntable, 7, which is capable of supporting the weight of the spools while being rotatable about the vertical central axis. A base to a crane would generally function well as such a turntable. Due to the weight to be supported, a vertical orientation for the axis of rotation is convenient, but a horizontal axis of rotation could also be used.

Details of the preferred embodiment's turntable, spider, and individual tubing spools are shown in Figure 2. Turntable, 7, is rotated by a motor, 8, which drives a gear, 9, which engage gear

teeth, 10, on the turntable. The turntable is supported by bearings, 11, which provide for relatively easy rotation of the turntable. A central non-rotating spool, 12, is shown supported directly from the base, 13. The counter rotation of the individual spools is provided by a positioning chain, 14, which engages a sprocket 15 on the non-rotating central spool, 12, and a sprocket on one of the rotating spools, 16. The other spools are coordinated with the rotating spool to which the positioning chain is attached, by a coordinating chain, 17, connected to coordinating sprockets, 18.

The rotating spools are thus rotated in a direction opposite to the rotation of the turntable, 7, at the same speed the turntable is rotated, which provides that the spools all "face" one direction as the turntable rotates, and which therefore minimizes twisting of the tubes. The individual spools are supported on brackets, 19, which are rotatably supported on the spider by bearings, 20. The direction of the non-rotating centre spool, 12, can be adjusted by loosening a set screw, 21, and rotating the spindle of the non-rotating centre spool. The chains will rotate each of the rotating spools in the same direction and by the same amount as the centre non-rotating spool spindle is rotated. This adjustment feature is preferred because the winding of the tubes will gradually develop an axial torsion which can be relieved by this rotation. As the helical tubing bundle of this invention is being prepared, it is therefore preferred to occasionally relieve the axial torsion by adjusting the position of the sprocket on this non-rotating spool.

Guides, 6, which may include rollers 22 and 23, are shown above the spools, 1, to help limit the position of the individual tubes as the individual tubes roll off the spools.

Three different braking means are shown in Figure 2. The first embodiment of braking means shown comprises a cylinder, 24, containing a spring, 25, which urges a brake pad, 26, against a metal plate, 27, which is attached to the side of the spool, 1. An acceptable brake pad material is Texolite. The tension on the

spring, 25, is preferably adjustable. This first braking means is preferred due to its simplicity. The second embodiment of braking means shown comprises a belt or cable 28 which passes around a pulley 29 attached to the side of the spool 1. Belt 28 is fastened to the frame 19 and is tensioned by an adjustable spring 30. In the third braking means, bottles of compressed gases, 31, provide a pneumatic pressure through regulators, 32, to calipers, 33. The calipers press together on rotating disks, 34. It is envisioned that standard automotive disk brakes can be utilized in this embodiment.

The spools are preferably supported on U-shaped bearings, 35, by axles, 36, protruding from the spools. The spools can then be conveniently lifted on to and off from the brackets by a crane or other lifting means.

Many different arrangements of spools can be envisioned. The tubes may be of the same size or may be of varying sizes. One preferred arrangement is for the central tube to be larger than the others, and have the central tube surrounded by six to ten smaller tubes, which can, of course, be of varying sizes.

It should be noted that the apparatus of this invention differs from the existing wire rope cabling machines primarily in the following ways: (1) greater braking force, (2) larger diameter spool hubs, (3) longer pitch length, and (4) no need for a closing head.

The tension which must be maintained on the tube of each spool by the braking means is equal to or greater than:

$$\frac{2Yd^2t}{D}$$

wherein

Y is the yield stress of the tube;

d is the outside diameter of the tube;

t is the wall thickness of the metal tube; and

D is the diameter of tube curvature around the spool.

This tension will prevent the tubing from "springing out" or back-lashing" from the spool.

The outer tubes must be bent around the helix sufficiently to hold the bundle together, but not so much as to plastically bend the outermost tubes significantly past the yield point. If a bundle of tubes is formed into a helix which is tight enough to yield the outermost tubes, the forces holding the bundle together do not increase in spite of the increased rotational effort of the bundling machinery and in spite of the additional length of tubing required. Further, it will be difficult to straighten a coiled bundle wherein tubes have yielded. Hence, an optimum pitch length exists wherein the bending stresses in the outer tubes are at yield or just below yield.

The pitch length of the helix at the yield point may be expressed as:

$$2\pi r \left[\frac{Ed}{2Yr} - 1\right]^{1/2}$$

wherein

r is the radius between the outer tube and bundle centrelines;

E is the modulus of elasticity of the tube;

d is the diameter of the outer tubes in the bundle; and

Y is the yield stress of the tube.

Table 1 summarizes ranges of pitch length to outer tube diameter for various bundle configurations which will result in the bending stress due to the helical configuration being within a range of about one-half of yield to about yield. These dimensions are for a typical coil tubing product, QT-700 or equivalent, having a yield stress of about 70 ksi. N is the number of tubes in the bundle, d_o is the outside diameter of a central tube or tubes, d is the outside diameter of tubes surrounding the central tube(s), od is the diameter of the bundle and r is the radius of the bundle. The configurations having 7 through 10 tubes have a single central tube having an outside diameter of d_o surrounded by tubes having an

outside diameter of d. The bundle having 12 tubes contains 3 inner tubes surrounded by nine outer tubes, all of the same diameter. The 19-tube bundle contains a seven-tube bundle core surrounded by 12 outer tubes. The pitch length l is defined as the length of the bundle required for each tube to wrap around the helix and back to its initial position.

Table 1

N	do/d	od/d	r/d	l/d
3	-	2.1547	0.5774	69.79 - 98.77
7	1.0000	3.0000	1.0000	91.76 - 129.92
8	1.3048	3.3048	1.1524	98.47 - 139.45
9	1.6131	3.6131	1.3066	104.81 - 148.46
10	1.9238	3.9238	1.4619	110.83 - 157.00
12	3 x 1.00	4.0551	1.5275	113.27 - 160.48
19	7 x 1.00	5.0000	2.0000	129.47 - 183.52

When tubing which contains a polymeric coating is formed into a helical bundle, the tubing must be handled in such a way that the coating is not damaged. An individual tube coated with high-density polyethylene can be bent to a radius which is equal to or greater than about 25 times the diameter of the tube. For a bundle of tubes, this minimum radius is about 50 times the diameter of the largest tube. This minimum radius is critical in choosing the sizes of spools to be employed with the present invention bundling machine, or in conversion of a typical wire cable wrapping machine to a tube bundle preparation service. Because wire cable is very flexible, wire cable wrapping machines may require spools which have larger hubs and addition of rollers to increase the radius of bending at any given contact point to prevent damage to the external coating, whether polymeric or other type of coating. A wire cable wrapping apparatus will also require installation of a more substantial brake means to provide sufficient tension and the

removal of any existing "closing head", to be useful as the apparatus of this invention. Such a modified wire cable wrapping machine would be suitable for preparation of six or seven tube bundles in the size range of one-half to three-fourth inch diameter tubes. The larger size cabling machines are capable of producing tube bundle of this size in lengths of more than a mile with each run.

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CLAIMS:

1. An apparatus for making a bundle of helical wound metal tubes, which apparatus comprises:

a base having a central axis;

a spider that is rotatable with respect to the base around the central axis;

a plurality of rotating spools supported by the spider, each rotating spool containing a tube rolled around the spool about a primary axis, which primary axis lies in a plane that is perpendicular to the central axis, each rotating spool being rollable about the primary axis, and each rotating spool being rotatable about a secondary axis parallel to the central axis from a rotational position in a direction opposite to the direction of rotation about the central axis and at the same speed;

a haul-off means for pulling the individual tubes off the spools at a rate relative to the rate of rotation of the spider about the central axis, so that, during normal operation a helical configuration of tubes is obtained in the form of a constant pitch length helix having at least one outermost tube; and

a braking means acting on each spool so that during pulling a tension on the tube of that spool is maintained,

wherein the tension is equal to or greater than $2Yd^2t / D$, wherein Y is the yield stress of the individual tube, d is the outside diameter of the tube, t is the wall thickness of the tube metal, and D is the diameter to which the tube is bent around the spool, and wherein the

bending stress due to the helical configuration of the outermost tubes is cY, wherein c is in the range of from 0.5 to 1.

2. The apparatus of claim 1, wherein the rotational position of the rotating spools can be readjusted so as to relieve or offset axial torsion of the tubes.

3. The apparatus of claim 1, wherein the central axis is a vertical axis.

4. The apparatus of claim 1, further comprising a central non-rotating spool supported by the base, which central non-rotating spool contains a tube rolled around the spool about a primary axis, which primary axis lies in a plane that is perpendicular to the central axis, and which central non-rotating spool is rollable about the primary axis.

5. The apparatus of claim 4, wherein from six to ten tubes are helically wound around a central tube from the central non-rotating spool.

6. The apparatus of claim 1, wherein the individual metal tubes have outside diameters of about 0.5 to about 2.0 inches.

7. The apparatus of claim 1, wherein the braking means comprises one of the group of a brake pad urged against a metal plate attached to a side of the spool, a taut belt or cable wrapped partially around a pulley which is attached to the side of the spool, and a hydraulically, pneumatically, or spring-actuated disk brake.

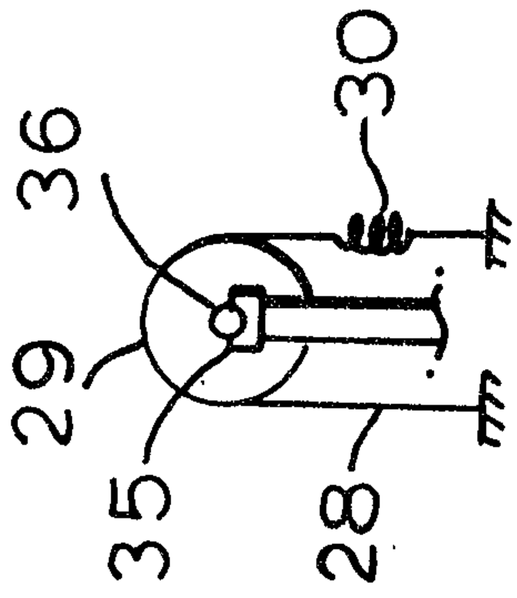

FIG.2A

FIG.1

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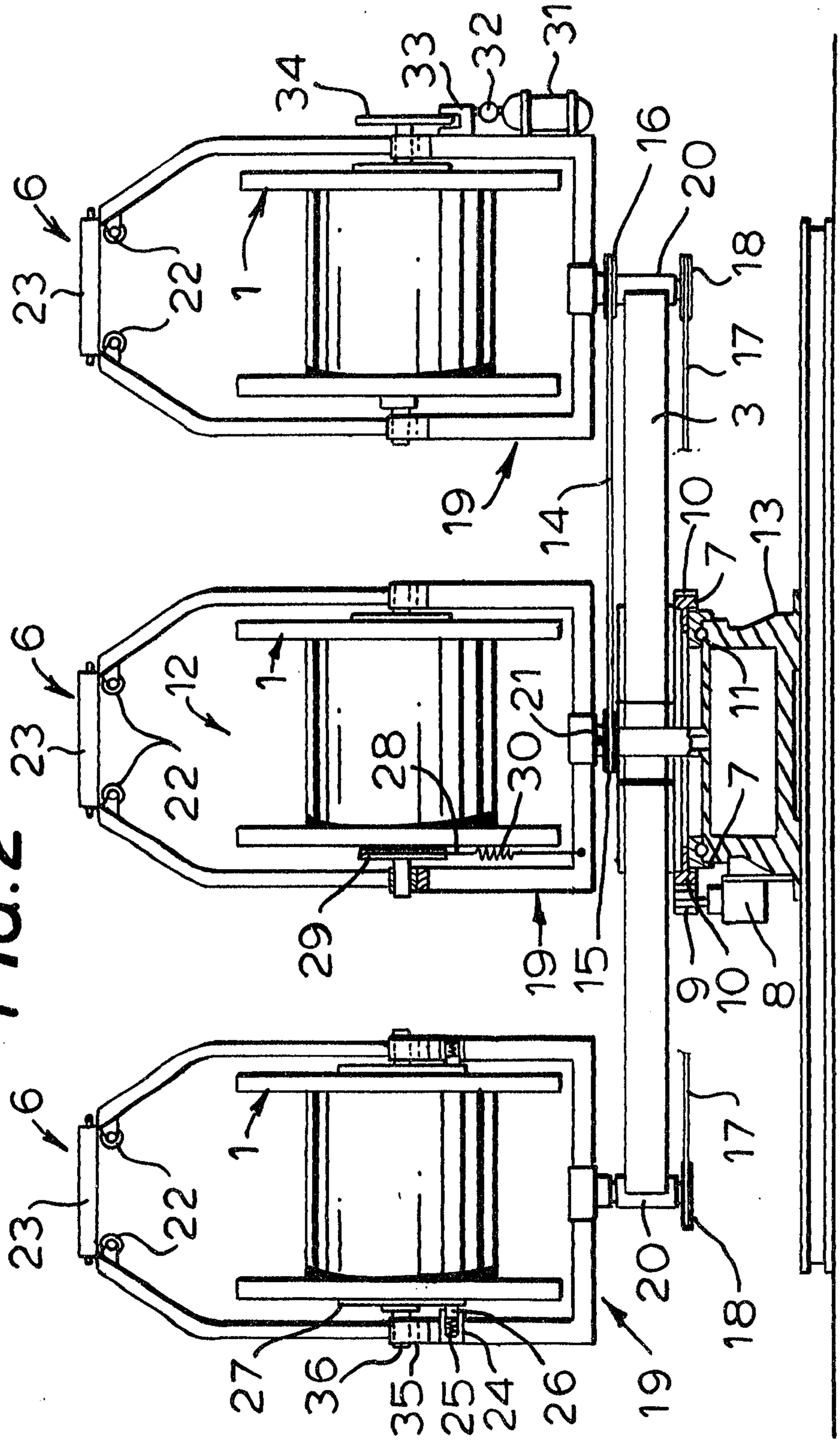

FIG. 2

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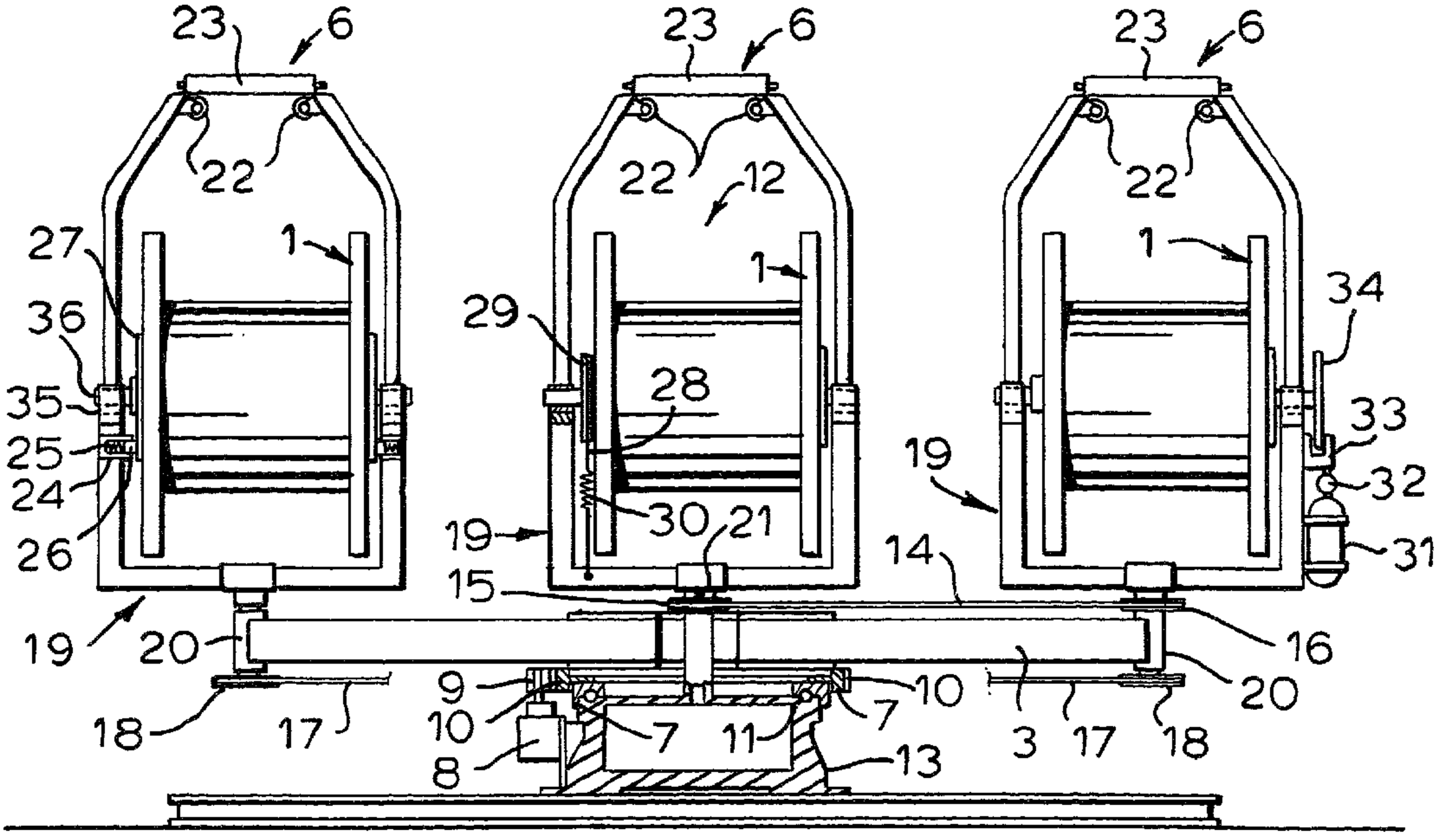
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