March 25, 1969 E. GROSKOPFS 3,434,674

STORABLE TUBULAR EXTENSIBLE MEMBER DEVICE

Filed May 1, 1967

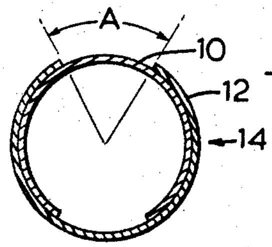

FIG. 1

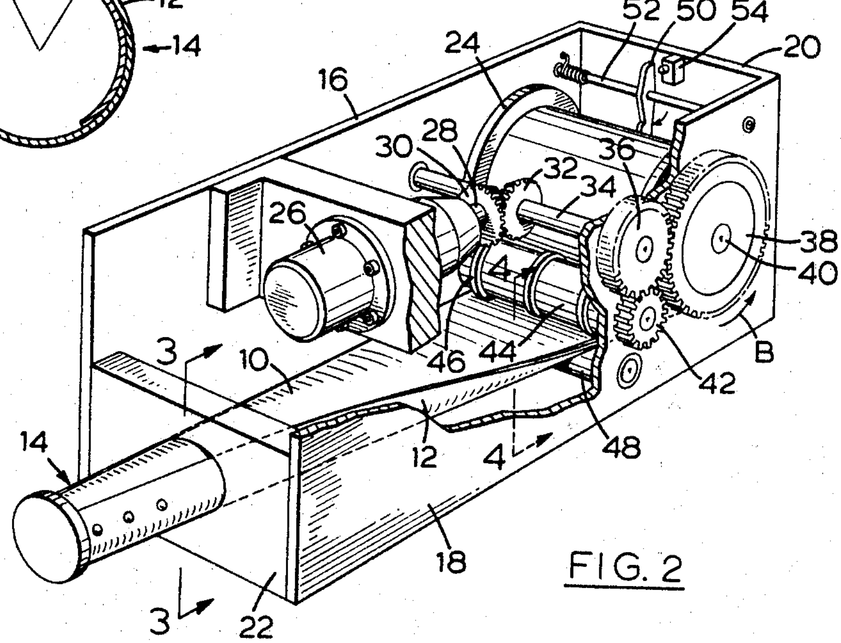

FIG. 2

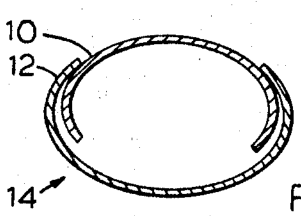

FIG. 3

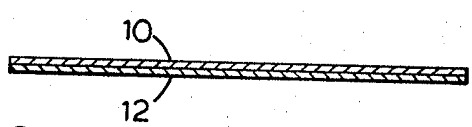

FIG. 4

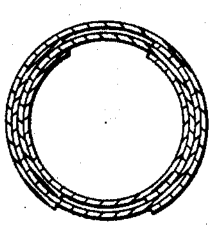

FIG. 5

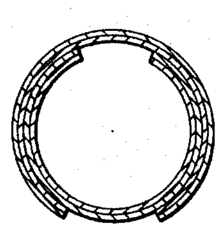

FIG. 6

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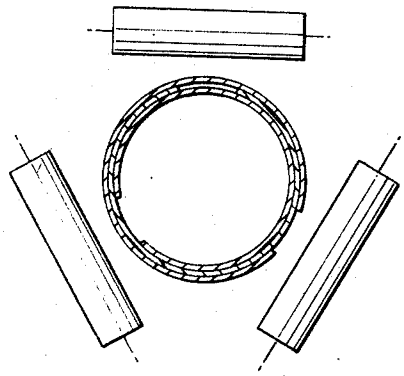

FIG. 7

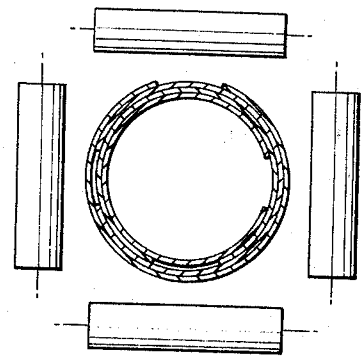

FIG. 8

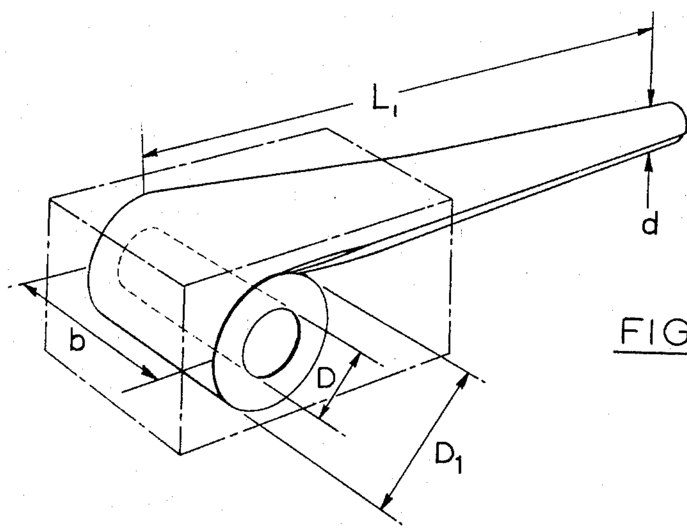

FIG. 9

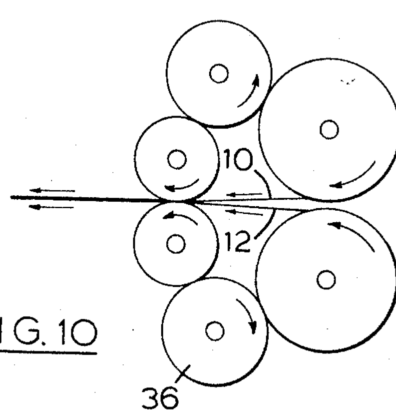

FIG. 10

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STORABLE TUBULAR EXTENSIBLE MEMBER DEVICE

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ABSTRACT OF THE DISCLOSURE

This invention provides a storable tubular extensible member device which is characterized by a member formed of at least two partially tubular strips arranged with their concave surfaces facing one another as contrasted with members known heretofore and formed of one or more fully tubular elements, each of which is overlapped upon itself. With the improved extensible member of the invention it is possible to achieve greater compactness of the device as a whole. The member of the invention also has advantageous strength, straightness, thermal deflection resistance and other qualities. The invention also provides an improved storage and extending mechanism characterized by a particular geared connection between a drive roller and the storage spool or spools.

This invention relates to devices incorporating storable tubular extensible members.

Devices of the type broadly defined above are now well known, particularly in the aerospace industry where the extensible members have been used as antennas, booms or actuators. The majority of the known devices deploy tubular members which are formed of a single overlapped strip of pretreated springy material, a commonly a steel, copper, or titanium alloy. The strip is usually stored by being wound on a drum as a coil whose axis is at right angles to the longitudinal axis of the strip. As the strip is deployed by unwinding from the drum it reverts to a tubular formation. Several variations have been proposed including the use of two or more strips, each of which reverts to its own tubular formation so that the tubular member as a whole is comprised of two or more coaxial tubes.

Devices of the type generally defined above have proved particularly advantageous as antennas, instrument deploying mechanisms and gravity gradient stabilization rods in space satellites. For details of construction and methods of use of the known devices, reference may be made to United States Patents 3,144,215, 3,144,104 and 3,243,132, all of which have been assigned to the assignee in the present application.

It is the compactness of these devices that has gained their acceptance for use in space satellites and for certain ground applications requiring extensible and/or retractable booms, actuators, antennas and the like. This compactness is primarily due to the use of very thin strip materials but is also due to the general compactness of the storing and deploying mechanisms as a whole. One of the factors governing the overall compactness of the devices is the ploy length of the extensible member. The ploy length is defined as the axial distance necessary for the extensible member to change from the flat to the tubular condition. It has been found that extensible members that are formed of single or multiple strips using conventional overlapped cross sections have ploy lengths which must be fairly long for efficient deployment and it has been recognized that if this ploy length could be reduced, the overall compactness of the devices could be considerably improved.

It is, therefore, a primary object of this invention to

provide a device involving a storable tubular extensible member having a relatively short ploy length as compared to devices known heretofore whereby to improve the overall compactness of the device through reduction in package length.

It is a further and related object of the invention to provide a device of the above type having a relatively small package width as compared to devices known heretofore whereby improved package compactness as a whole is gained through reduction of package width as well as length.

Another disadvantage of an extensible tubular member formed of a single overlapped strip is that, when extended, it invariably assumes a somewhat curved configuration. This is a particularly serious drawback when the extensible member is used to deploy an instrument, or to act as an actuator to perform work in the form of a force directed along its longitudinal axis, or as a gravity gradient stabilization rod which depends on rod straightness for system accuracy. The curved characteristic tends to cause buckling of the member.

It is therefore, a further object of this invention to provide a device involving a tubular storable extensible member wherein the extended member is relatively straight as compared with the members of the devices known heretofore.

The above and further objects of the invention are gained by forming the extensible tubular member of at least two strips, each of which, when extended, takes the form of a partial tube with the concave surfaces of the strips facing each other with sufficient overlap between the strips as to hold the strips together as a tube.

It is a further object of the invention to provide devices incorporating storable extensible tubular members which include storing and extending mechanisms which avoid problems encountered in similar mechanisms known heretofore due to the continually changing rate of delivery of strip material as the coiled strip is uwound from a coil of continuously decreasing diameter. The improved storing and deploying mechanism of the invention is particularly adapted to use with the type of tubular member defined above which is formed of two strips of material but it may also be used to good advantage in storing and deploying tubular members formed of conventional overlapped single or multiple strips.

The invention will be more thoroughly understood from the following description of several preferred embodiments as read in conjunction with the accompanying drawings.

In the drawings:

FIG. 1 is a cross-sectional view through a first and preferred embodiment of a storable tubular extensible member in accordance with the invention as it is shaped in its extended condition;

FIG. 2 is perspective view, partly broken away, of a device in accordance with the invention incorporating a storable extensible tubular member and illustrating the construction of the mechanism for storing and for extending the tubular member;

FIG. 3 is a cross-sectional view taken along the line 3—3 of FIG. 2 to illustrate the tubular member of the embodiment of the invention shown in FIG. 1 in the form it assumes at the outlet guidance orifice of the device of FIG. 2;

FIG. 4 is a cross-sectional view taken along the line 4—4 of FIG. 2 and showing the tubular member of FIGS. 1 and 3 in its flattened condition as it is wound on the storage drum of the storage device;

FIGS. 5 to 8 are schematic cross-sectional views through several alternative embodiments of the extensible member of the invention;

FIG. 9 is a schematic perspective representation of a device such as shown in FIG. 2, and

FIG. 10 is a schematic side view of an alternative embodiment of the storing and extending mechanism of the invention.

Referring to FIG. 1, the preferred tubular member of the invention consists of two strips **10** and **12** which together form the tubular member **14**. Each strip **10** and **12** constitutes a partial tube in the sense that it is a tube having a longitudinally extending slot or open section along one side. It is in this sense that the expressions "partially tubular" or "partial tube" are used in the following specification and appended claims. For the purpose of defining the amount of overlap between the two strips, the width of the "slots" or open sections is defined by the angle A, which is an angle having its apex at the centre of the member. Each strip is formed of springy material of considerably greater length than width which is pretreated in the manner discussed in the aforementioned patent specifications so that the strip will revert to a partially tubular formation whenever free to do so, i.e. when deployed from its coiled storage configuration. The strips can be any thickness provided the critical thickness to diameter ratio for the material used is not exceeded. Commonly used thicknesses at present range from 0.001 inch to 0.030 inch although larger or smaller thicknesses might be used in the future. The material of which the strips are formed can vary depending upon the intended use of any particular device. By way of example, the material may be 1095 carbon steel, 301 stainless steel, beryllium copper, certain titanium alloys or fiber composites such as fiberglass.

As is apparent from FIGS. 1 and 3, the deployed partially tubular elements are positioned with their concave surfaces facing one another. As the terminology developed heretofore with respect to tubular extensible members of this type has applied the term "front" to the concave surface of an element and the term "back" to the convex surface, the characteristic form of the tubular member of the present invention is defined as a front to front relationship. Heretofore, while tubular members formed of two or more strips have been developed, these have been mounted in a front to back relationship so that the effect has merely been to reinforce the tubular member by using two or more coaxial tubes whereby to increase the strength of the tubular member as a whole. It is to be understood, therefore, that to be consistent with the terminology developed with respect to tubular members of this type in the prior art, the tubular member of the present invention is defined as consisting of two or more partial tubes positioned front to front.

One of the chief advantages of the double strip front to front tubular member of the invention is that it has been found that the "ploy" length is considerably shorter than the ploy length of known tubular members consisting of an overlapped single strip or multiple overlapped strips mounted in front to back relationship. As a matter of fact, it has been found that the ploy length of the tubular member of the invention is only 55% of the ploy length of an equivalent tubular member of the prior art devices. This reduced ploy length permits a reduction in the storage and deploying mechanism as a whole as is explained hereinafter.

FIG. 2 illustrates a preferred mechanism for storing and deploying the tubular extensible member of the invention. It should be clearly understood, however, that other and/or known mechanisms could be used for storing and extending the double strip member of this invention. The illustrated mechanism is particularly useful for storing and extending members up to 50 feet in length. For members longer than this a good mechanism would be the one shown in our co-pending U.S. patent application 387,163, now Patent No. 3,371,453. Other adaptable mechanisms are shown in the aforementioned U.S. patent specifications.

As is described below, the particular mechanism illustrated also has advantages when used in storing and deploying even the known type of extensible members consisting of a single overlapped element or a number of front to back overlapped elements. The mechanism essentially consists of a rectangular-shaped box having a pair of side walls **16** and **18**, a rear wall **20** and a smaller front wall **22**. Cover plates may also be used to enclose the top and bottom of the mechanism but as illustrated the top and bottom are left open. Positioned towards the rear of the mechanism is a rotatable drum **24** having a pair of end flanges so that the drum takes the form of a spool and it is hereinafter referred to as storage spool **24**. The two strips **10** and **12** forming the preferred extensible tubular member of the invention are fixed at their inner ends to the surface of the spool so that as the spool is rotated in the direction of arrow B, the extensible member is wound tightly thereon so that the extensible member is eventually brought to its fully retracted position as shown in FIG. 2. Motive power for both extending and retracting the tubular member is provided by a suitable electric motor **26** which in most applications will draw its power from a portable current producer such as a battery or a fuel cell but for certain applications, AC current might be used. The output shaft **28** of the motor carries a bevel gear **30** which engages a similar gear **32** fixed to the shaft **34**. The latter shaft extends through side wall **18** and carries at its outer end a gear **36** engaging, in accordance with the invention, both a first gear **38** fixed to the axle **40** of spool **24** and to a second gear **42** fixed to the axle of a drive roller **44**. It can be seen, therefore, that as the motor rotates it positively drives both the spool **24** and the drive roller **44**. The latter roller carries a number of friction rings **46** which are formed of neoprene or the like. Alternative to the friction rings it would be possible to use spring biased metal rollers or sprockets working in suitable perforations in the strips. Positioned beneath the drive roller **44** is a second roller **48** so that retraction and extension of the elements **10** and **12** is achieved by a pinching action between rollers **44** and **48**.

While the mechanism shown in the drawing and as described above is a motorized unit, it will be appreciated that the motive power may be gained through a hand crank. In either case, the gears **36, 38** and **42** are so selected as to match the peripheral velocity of the drive roller **44** to the delivery velocity of the stored extensible member from the storage pool **24** in a particular manner. This relationship is defined as follows:

$$\frac{\text{diameter full spool} - \text{diameter empty spool}}{2} = \text{average diameter}$$

$$\frac{\text{diameter drive roller (44)}}{\text{average diameter}} = \frac{\text{number of teeth drive roller gear (42)}}{\text{number of teeth storage spool gear (38)}}$$

The above selected relationship between the size of the drive roller, the storage spool and the number of teeth of their gears overcomes a problem encountered with all deploying mechanisms resulting from the fact that the diameter of the coiled extensible member continuously changes as the member is being extended. The manner in which the selected relationship achieves this object is as follows.

During the typical extension cycle (starting with full storage spool), the storage spool tends to supply more extensible member than that demanded by the drive roller. This "surplus" member is stored in the form of a loose spiral on the storage spool. At the point when the average diameter of the storage spool is reached, the amount of the member demanded by the drive roller is equal to the amount given away by the storage spool. Past this point, the drive roller requires more member than the storage spool is supplying and this demand is satisfied by the originally created "surplus" member. Thus, at the time when the last bit of extensible member is extended, all the "surplus" extensible member has been used up and full extension is achieved with no extensible member remaining on the storage spool. During the rewind or retraction cycle, the process is reversed.

The above described deploying mechanism is equally adapted to the deploying of an extensible member consisting of a single strip and/or members formed of a number of strips in the known front to back arrangement. Further, it can be used even if the extensible member of the present invention, i.e, consisting of two strips in front to front relationship, is used but with the modification that the two strips are stored on separate storage spools. In this latter case, of course, both of the storage spools are driven through the geared connection to gear **36**. A schematic representation of a double storage spool mechanism is illustrated in FIG. 10.

A further advantage of the double strip extensible member of this invention is that the guidance system required to efficiently support the strips in the ploy area is greatly simplified relative to the guidance system required to assure proper deployment and formation into a tube of the overlapped single or multiple strip extensible members of the prior art. Indeed, it has been found that the only guidance required is to extend the strips through a generally oval-shaped opening in the forward wall **22**. The shape of this opening can best be appreciated from FIG. 3 which shows the strips as they emerge from the opening.

Common with most of the deploying mechanisms of the prior art, the mechanism of the present invention also includes an automatic shut-off feature to interrupt current to the motor **26** when the member has been fully extended. As illustrated, this automatic shut-off feature may be gained through a simple limit switch type of lever **50** which is fixed to a spring biased rotatable rod **52** so that its lower end moves inwardly as the extensible member is extended and eventually trips a switch **54** to cut off current to the motor. The mechanism might be further provided with a retraction limit switch of similar construction or of the known type which is tripped by a detent or the like carried by the member. Further, other desirable limit switches might be included, e.g., a stop-start switch for halting movement of the member during extension or retraction at any desired intermediate position or positions.

As previously mentioned, a major advantage of the extensible member of this invention is that the overall package dimensions relative to the known packages are considerably reduced. To illustrate this package size reduction, reference is made to FIG. 9. This figure illustrates the meaning of the various symbols employed in the following equations which relate the overall package size to such things as strip width, strip thickness and ploy length. In these equations the symbol b is the strip width, d is the diameter of the extended member, D is the diameter of the storage spool, D_1 is the diameter of the storage spool plus the stored extensible member, t is the strip thickness, L is the full extended length of the extensible member, L_1 is the ploy length (the axial distance necessary for the extensible member to change from the flat to the tubular condition) while k_1 and k_2 are constants. The symbol x is the overlap factor while A is the angle A shown in FIG. 1 and defines the amount of overlap between the strips as a function of the size of the "slots" previously mentioned.

The equations are:

$$b=x\pi d \tag{1}$$

$$x=\left(L-\frac{A}{2\pi}\right) \tag{2}$$

$$D=1.5d \tag{3}$$

$$D_1=\left[\frac{4(L-L_1)t}{\pi}+2.25d^2\right]^{1/2} \tag{4}$$

$$t=k_1d \tag{5}$$

$$L_1=k_2b \tag{6}$$

In accordance with the invention, the angle A can vary between the limits 10° to 170° but preferably is in the order of 40°. Thus, to give an example, with an angle A of 60° the overlap factor X equals 0.833, while in conventional extensible member formed of a single strip of material which overlaps itself to form the tube, the equivalent overlap factor is normally in the order of 1.5. Thus, it can be seen that the strip width in accordance with this invention will be approximately 55% the strip width of the prior art devices, and as the width of the package is closely related to the strip width, it follows that the package for storing an extensible member of this invention is approximately 55% the width of a storage package of a prior art device. As previously mentioned, and as apparent from FIG. 9, the package length is a function of the ploy length (L_1) and the overall storage spool diameter (D_1). From Equation 6, it follows that the ploy length is proportional to strip width; hence the poly length of the extensible member of this invention will be approximately 55% that of the poly length of one of the prior art extensible members.

However, as the extensible member of this invention employs two strips, the overall storage spool diameter will be somewhat greater than the equivalent dimension of the prior art devices. For example, from Equations 3, 4 and 5, a 0.5" diameter extensible member of the prior art, 0.002" thick and 50 ft. long will have a storage spool diameter of:

$$D_1=1.45''$$

while for the equivalent extensible member of the present invention

$$D_1=1.9''$$

This diameter increase is insignificant, as in the above example, L_1 is reduced from approximately 15" to 8" by the use of a double strip extensible member in accordance with the invention. Thus, for the example used, the overall package length will be approximately 60% that of a package length of an equivalent extensible member device of the prior art.

The package depth is closely related to the overall storage spool diameter so that the depth of the package for storing and deploying the double strip type of extensible member of the invention will be somewhat larger than the depth of packages for storing and extending extensible members of the prior art of equivalent size.

In general, the net effect of using the double strip extensible member of the invention is to change the shape of the storage and deploying package by considerably reducing its length and width while somewhat increasing its depth. The reduced length is of extreme importance in spacecraft applications as the package is usually mounted with its long axis at right angles to the thrust of the launch vehicle and this dimension is generally severely limited. The reduced length is also important in ground applications such as when endeavoring to minimize the silhouette of a vehicle.

The overall weight of a device employing the double strip extensible member of the invention is also considerably less than the weight of a prior art device for deploying an extensible member of equivalent diameter and length. While each of the strips in accordance with the invention are approximately 55% the width of a conventional single strip extensible member so that the weight per unit length of a member of the invention is somewhat heavier than the equivalent length of a prior art member by approximately 10%, the increase in the weight in the member itself is more than offset by the reduction in the deployment mechanism weight, resulting, primarily, from the reduction in the mechanism length and width.

The double strip extensible member of this invention also has improved bending strength characteristics relative to equivalent size extensible members of the prior art. Particularly where angle A is in the order of 60° or less, the moment of inertia of the cross-section of a member of the invention is greater than the equivalent prior art member cross-section. This results in the double strip member of the invention being able to withstand a bending moment approximately 20% higher than a conventional single strip member. To reduce the deployment mechanism length of a conventional member unit, it has been common practice to terminate the member guidance system before the member has formed into a full round section. Thus, only a partial utilization of the full bending strength of the member is realized due to the resulting open section. The double strip extensible member of this invention does not suffer from this factor and hence it can develop full bending strength with a guidance much shorter than heretofore possible. This feature, coupled with the reduction in deployment mechanism length previously described, results in a deployment mechanism which is at least 65% shorter than the length of the deployment mechanisms of the prior art for extensible members of lengths up to 50 ft. and having equivalent member diameter.

As previously mentioned, conventional single strip extensible members have a distinctive curvature which is due to stress distribution in the member as it changes from the flat to the round condition. These stresses are composed of those induced naturally by flattening the member and those imposed by the guidance system. The double strip extensible member of this invention, however, has an inherently straight ploy, since the two elements are "front to front," and the stresses oppose and cancel one another. In addition, as previously mentioned, conventional single strip extensible members have a distinctive curvature which is due to stress distribution in the member beyond the ploy region. These stresses are introduced during the manufacturing process of the member and cannot be fully relieved. As in the case cited above for the ploy region, the double strip extensible member of this invention is inherently straight beyond the ploy region since the two elements are front to front and the stresses oppose and cancel one another.

The natural straightness of the double strip extensible member of the invention is a great advantage where the member is used as an actuator to perform work in the form of a force directed along its longitudinal axis, or as a gravity gradient stabilization rod which depends on rod straightness for system accuracy.

It has further been found that the double strip extensible member of the invention is torsionally stiffer than the conventional single strip members of the prior art and is also more repeatable in terms of angular position. This results from the more positive strip fixations at the tip and root with the double strip member of the invention. Provided the value of angle A is not excessively large, the configuration of the double strip extensible member of the invention produces significantly smaller thermal deflections due to solar radiation than those associated with a conventional extensible member of the prior art. This is due to the outer element shielding the inner one and the inner one acting as a heat reservoir.

The extensible member of the invention is suited to the three normal types of operation, namely motorized extension and retraction, self extension using the stored spring energy in the extensible member where there is no requirement for retraction, and manual extension and retraction. The application in use, therefore, is potentially very broad and is particularly suited to applications requiring the ability to support large loads.

While the foregoing specification has referred to an extensible member formed of two strips arranged in front to front configuration, it should be understood that it is within the scope of this invention to form the member of more than two strips provided, of course, the same front to front configuration is employed. In other words, the known principle of using a plurality of elements to gain greater strength in any particular extensible member can be equally applied to the front to front arrangement of the extensible member of the invention. As previously mentioned, it is also within the scope of the invention to deploy the two strips from separate storage spools and it is further contemplated that should it be desired to strengthen one or both of the strips by other strips, the latter might also be deployed from separate storage spools.

FIGS. 5 to 8 illustrate the above variations but it should be understood that in the case of FIGS. 7 and 8, the illustrated storage spools would, in practice, be larger than shown and they are included solely to illustrate their relative positions.

Referring to FIGS. 5 and 6, the members shown therein are each formed of four strips but with somewhat different arrangements of the open sections or "slots." The members of FIGS. 5 and 6 can be deployed from either a single or multiple storage spools because the "slots" are aligned. In the FIGS. 7 and 8 embodiments, multiple storage spools must be employed as the "slots" are positioned at 120° or 90° to one another respectively. In this regard it should be understood that other angular orientations of the "slots" are possible and it should also be understood that while the illustrated cases employ two, three or four strips it would be within the scope of the invention to use more than four strips. Still further there might be occasion for the use of three strips in a manner other than that shown in FIG. 7, for example, by forming three strip members essentially consisting of the FIGS. 5 or 6 format but without the outermost strip.

It is also to be understood that the term "tubular" as used herein includes other than circular cross-sections e.g. elliptical, oval or the like. Indeed, for certain applications requiring particular strength characteristics an extensible member which is elliptical in cross-section in its extended form would be preferable to a circular cross-section. In all cases, however, the characteristic arrangement of the invention is used, namely, a front to front arrangement of at least two strips and without either or any of the strips overlapping upon itself. With respect to this lack of overlap, it should be understood that the lower limit of the angle A, namely, 0° is primarily selected as being indicative of this lack of overlap since an angle A of 0° suggests an absence of a "slot" or open section.

What I claim is:

1. An apparatus comprising, in combination, a storable, tubular, extensible member and means for storing and extending said tubular member, said tubular member including a plurality of strips, each of said strips being formed of springy material and pretreated to assume, when free to do so, a partially tubular form and each of said strips having a concave surface and two longitudinal edges spaced from each other to form a longitudinal slot therebetween, and said strips being disposed one within another when said tubular member is extended such that said concave surfaces face one another and said longitudinal slots are spaced from one another.

2. An apparatus as claimed in claim **1** wherein said tubular member includes four partially tubular strips with the longitudinal slots thereof being spaced 90 degrees from one another.

3. An apparatus as claimed in claim **1** wherein said tubular member includes three partially tubular strips with the longitudinal slots of said strips being spaced 120 degrees from one another.

4. An apparatus as claimed in claim **1** wherein the material from which said strips are formed is selected from the group consisting of steel, copper alloy, titanium alloy, nickel alloy and fiber composites.

5. An apparatus as claimed in claim **4** wherein said strips are formed of 1095 carbon steel.

6. An apparatus as claimed in claim 4 wherein said strips are formed of 301 stainless steel.

7. An apparatus as claimed in claim 4 wherein said strips are formed of beryllium copper.

8. The apparatus as recited in claim 1 wherein said longitudinal edges of said strips are spaced 10 to 170 degrees apart with respect to an angle having its apex at the center of said tubular member.

9. The apparatus as recited in claim 1 wherein said longitudinal edges of said strips are spaced 40 degrees apart with respect to an angle having its apex at the center of said tubular member.

10. The apparatus as recited in claim 1 wherein said plurality of strips included in said tubular member includes first, second, third and fourth strips and said first, second, third and fourth strips are disposed one within another when said tubular member is extended such that the longitudinal slots of said first and second strips are diametrically spaced from the longitudinal slots of said third and fourth strips.

11. The apparatus as recited in claim 10 wherein said first strip is disposed within said second strip, said second strip is disposed within said third strip and said third strip is disposed within said fourth strip.

12. The apparatus as recited in claim 10 wherein said first strip is disposed within said third strip, said third strip is disposed within said second strip and said second strip is disposed within said fourth strip.

13. The apparatus as recited in claim 1 wherein said plurality of strips included in said tubular member includes first and second strips and said first and second strips are disposed one within another when said tubular member is extended such that the longitudinal slot of said first strip is diametrically spaced from the longitudinal slot of said second strip.

14. Apparatus comprising storable tubular extensible

member means having a stored state and an extended state; and means for storing said tubular member means and extending said tubular member means; said tubular member means including a plurality of strips, each of said strips being formed of springy material and pretreated to assume a partially tubular form when said tubular member is in said extended state and each of said strips having a concave surface and two longitudinal edges spaced from each other to form a longitudinal slot therebetween when said tubular member means is in said extended state, said strips being disposed one within another when said tubular member means is in said extended state such that said concave surfaces face one another and said longitudinal slots are spaced from one another, said strips being disposed such that said concave surfaces are adjacent to and face one another when said tubular means is in said stored state, and said means for storing and extending said tubular member means including a spool for winding and unwinding said tubular member means in said stored state.

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WILLIAM S. BURDEN, *Primary Examiner.*

U.S. Cl. X.R.

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