The present invention relates to flexible tube structures and particularly to a tube structure the flexing of which may be controlled both to its extent and in its radius of curvature.

The present invention is particularly adapted for endoscopic devices which heretofore have been restricted in bending in only one direction and to a single extent and radius of curvature. In the use of the present day endoscope for viewing the walls of a cavity of the human body, it has been necessary to reposition the endoscope a number of times into the cavity in order to examine every portion of the cavity walls, all at great discomfort to the patient. Since the endoscopes currently being utilized have restricted flexing capabilities, complete viewing of the walls of the cavity has been impossible.

The flexible tube of the present invention is also capable of being utilized as a housing for an optical system for other purposes, such as, for viewing remote objects around corners or in other inaccessible places. When suitably encased with a plastic or rubber sheathing, the present invention may be adapted for underwater usage wherein movement of the submerged end may be effected by suitable controls located at the "dry" end. The present invention is also adapted to support a tool at its working end so that manipulation of the tool can be accomplished at the remote control end thereof.

In any of its many uses, the flexible tube structure of the present invention may be easily disassembled and reassembled if it is desired to lengthen or shorten the structure or to condition the structure for a predetermined radius of curvature. As a housing for any number of working tools such as an optical system for endoscopic use, the structure may be opened up, so to speak, for permitting any modification, removal or insertion of the optical system in part thereof. Various segments of the tube structure itself may be interchanged or replaced, added or removed. In its essence, the present tube structure is composed of various "building blocks" which may be "built up" in various arrangements for a number of purposes.

The primary object of the present invention is to provide a flexible tube structure the flexing of which is adapted to be controlled both as to extent and radius of curvature.

Another object of the invention is to provide a flexible tube structure which may be used for supporting working tools and for controlling manipulation thereof.

Still another object of the invention is to provide a flexible tube for endoscopic devices or other examining instruments which is simple in structure, economical to manufacture and maintain, and capable of being modified with a minimum amount of effort.

These and other objects and advantages reside in certain novel features of construction, arrangement and combination of parts as will hereinafter be more fully described, pointed out in the appended claims and will appear when taken in conjunction with the drawing wherein:

FIG. 1 is a side elevational view of one form of the flexible tube structure constructed in accordance with the invention;

FIG. 2 is a side elevational view of the details of the structure of FIG. 1, parts being in section for better illustration and showing various shapes that the structure may assume;

FIG. 3 is a cross-sectional view taken along line 3-3 of FIG. 2;

FIG. 4 is a fragmentary perspective view of a portion of the tube structure illustrating the manner in which the structure is assembled and arranged for receiving tools therein;

FIG. 5 is an exploded perspective view of one of the tube sections showing the component parts thereof in greater detail;

FIG. 6 is a side elevational view of another form of the flexible tube structure;

FIG. 7 is similar to FIG. 6 but illustrates some of the various shapes the tube structure may assume;

FIG. 8 is a cross-sectional view taken along line 8-8 of FIG. 6;

FIG. 9 is a side elevational view, parts being in section, of another modified form of the present invention;

FIG. 10 is an exploded perspective view of the structure shown in FIG. 9;

FIGS. 11 and 12 are similar to FIG. 9 but illustrate successive flexing of the tube structure; and

FIG. 13 is a plan view of a modified tube section.

Referring now to the drawings, and more particularly to FIGS. 1-5, there is shown a flexible tube structure generally indicated by the reference numeral 10 and comprising a plurality of tube sections 12 arranged in an end to end relationship. As shown in FIGS. 3 and 5, each of the tube sections 12 is composed of two identical semi-circular elements 14, 16, each of which is formed with a pair of axially spaced connecting lugs at one end and a single lug 20 at the other end. When the elements 14, 16 are joined together to form a single tube section, the lug 20 of each of the elements is retained between the two lugs 18 of the other element. The lugs 18 and 20 are suitably shaped so that when the elements are joined, the outer surface of the tube section 12 is unbroken and conforms with the surrounding circular surface. As shown in FIGS. 2 and 3, the lugs 18 and 20, when interlocked, form continuous transverse thickened portions or ridges which extend radially inwardly slightly from the circumference of the tube section and are diametrically opposed.

A similar pair of ridges 22 are formed on the inner wall surfaces of the tube sections and these are arranged in diametrically opposed positions at about a 90° displacement from the ridges formed by the lugs 18 and 20. Each of the ridges is formed with openings which in the present embodiment are in the form of apertures 24, 26, respectively, and in the case of the lugs 18 and 20, the apertures 24 extend in axial alignment when the elements 14, 16 are joined together, as shown in FIGS. 1 and 2.

The apertures 24 in each of the tube sections are adapted to accommodate a flexible cable 28 which extends through the length of the tube structure 10. Similarly, the apertures 26 are adapted to accommodate another flexible cable 30. It will be apparent that when the tube sections 12 are arranged in axial alignment as shown in FIG. 1, the apertures 24 of each of the tube sections are in axial alignment with the corresponding apertures in the preceding tube section and the apertures 26 of each of the tube sections are in axial alignment with the corresponding apertures in the preceding tube section.

One end of each of the cables 28, 30 may be directly secured to the terminal tube section 32 or connected indirectly thereto by means of suitable sleeves 34 which are made small enough to be swaged upon the ends of the cables and may be suitably welded to the section 32. The other ends of the cables 28 are similarly encircled by sleeves 36 with the ends swaged thereto. A coil spring 38 encircles each of the cables 28 and is held in com-
pression between the sleeve 36 and the adjacent tube section. The cables 30 may be connected together and held taut around a suitable control pulley, this structure being shown in FIG. 7 and will be described hereinafter.

A plurality of spacer annular elements 40 which may be in the form of washers or sleeves are positioned on the case between some of the tube sections and for purposes of this invention, such washers or sleeves are utilized in that portion of the tube structure where flexing thereof is desired. As shown in FIG. 1, the flexed portion of the tube structure 10 is provided with these annular elements.

To complete the structure of the embodiment of FIG. 1, the entire structure 10 may be suitable covered with a rubber or plastic sheathing 42 which would provide a smooth and continuous finish for the structure and permit the use of the structure in water or other moist surrounding without affecting the elements of the structure.

In operation, a pulling force exerted upon one of the cables 30 will produce flexing of the terminal portion of the tube structure, that is, the portion located in the right-hand portion of the structure of FIG. 1. The amount or extent of flexing is controlled by the amount of force exerted upon the cable 30 and it is possible to flex this end of the structure until the same assumes substantially the shape of a complete circle. A desired radius of curvature is determined by the axial length of the annular elements 40, and in the case of washers, this would be determined by the thickness thereof, and in the case of sleeves, by their length. If a large radius of curvature is desired, washers or sleeves having short lengths should be utilized, and in the event a sharp flexing, or one having a small radius, is desired, sleeves having relatively long lengths should be utilized. This relationship is illustrated in FIG. 2 wherein use of the larger sleeves 44 has permitted a sharp flexing of the tube structure and smaller sleeves 46 have permitted only a slight flexing. Any other desired shape of the flexed portion of the tube structure may be planned by simply using various sizes of spacer washers or sleeves.

Radii of curvature may also be varied by utilizing tube sections having other axial dimensions. In the embodiment of FIGS. 1–5, the tube sections are relatively wide, that is, their axial dimensions are long when compared to the embodiments shown in FIGS. 6–13. In FIG. 2, if the tube sections were replaced by ones having a smaller width, or in fact, by a tube section which is in the form of a plate, the flexing would even be sharper if the same number of tube sections are used. On the other hand, if a greater number of these plates or narrow tube sections are used, the radii of curvature are progressively increased. Therefore, the length of the tube sections, whether they be in the form plates or a size similar to that shown in FIG. 2, or the number of these tube sections utilized, will each contribute to the control of the radii of curvature.

For purposes of further description the cables 30 are considered as control cables while the cables 28 are to be treated as tying cables. A pulling force exerted upon either of the control cables 30 will flex the cable in the plane defined by both the cables 30 and the cables 28 will retain the tube sections to maintain the length of the tube structure 10, along its axis, which during flexing will assume the form experienced by the cables 28, substantially constant. During a flexing operation, the coil springs 38 serve as a coiled spring, and to assist in maintaining the length of the tube structure, along its axis, substantially constant. If the spacers 40 were perfectly rounded at their ends and of a predetermined radii of curvature thereof, the necessity for the coil springs 38 since, no matter what shape or form the tube structure assumes, its axial length would never vary and the anchor sleeves 34, 36 for the cables 28 would be sufficient for maintaining the length of the tube structure constant. However, since there is no need in the present invention for perfectly machined parts, the coil springs 38 cooperate with the anchor sleeve 36 to permit slight changes in the length of the tube structure if the occasion arises. Any change in length will be extremely small and will be caused solely by the inaccuracies of the various elements of the tube structure especially in the spacers 40. Thus, the tube sections are constantly held together during flexed or non-flexed conditions of the tube structure and the constant length of the tube structure may be attributed to the anchor sleeves 36 which are swaged to the ends of the cables 28 or to the use of the coil spring 38 in conjunction with the sleeve 36.

It will be apparent that the tube structure 10 is capable of moving the terminal section 32 in a relatively wide arc with the radius of curvature thereof from a point between the last tube section to the axis of the adjacent tube section which does flex, such point being illustrated in FIG. 1, at 48. For endoscopic use, this characteristic has the particular advantage in that different parts of a cavity under inspection may be viewed without the necessity of continual withdrawal of the tube structure and rotation thereof.

Another advantage of the present invention is the simplicity of assembly and the arranging of work tools within the tube structure. In FIG. 4, a portion of the tube structure is illustrated with one of the tying cables 25 removed and the individual tube sections "opened up," so to speak. To accomplish this, one of the cables 28 is disengaged from its anchor sleeve 34 and pulled through the lugs 18, 20, wherein one of the elements 14, 16 in each tube section is pivoted about the remaining tying cable 28. With all of the tube sections in this position, any desired optical system or other equipment may be installed, modified or replaced in the interior of the tube structure.

The present invention is also adapted to serve as a flexible control linkage for a tool which may be conveniently mounted at the terminal tube section 32 thereof. In an arrangement of this sort, the tube structure 10 would serve as a remote control linkage for the tool and would provide a flexible housing for any electrical wires, hoses, flexible shafts, etc. for the tool.

The embodiment of FIGS. 6–8 is similar to that of FIGS. 1–5 and differs therefrom only in compounding the various functions of the latter. The tube structure comprises tube sections 50, 52 which for purposes of illustration, are shorter in axial length than the sections shown in FIG. 1. The upper portion 54 of the tube structure includes the tube sections 50 of the same structure as the tube section illustrated in FIG. 3, however, the lower portion 56 includes the tube sections 52 having a structure of the cross-section as shown in FIG. 8.

Each of the sections 52 is provided with a pair of diametrically opposed apertures 58, 60 which are similar to apertures 24, 26, respectively, shown in FIG. 3. The tube sections 52 also include another pair of apertures 62 which are diametrically opposed with respect to each other but in close adjacency with the apertures 60. The sections 50, 52 also include the interlocking lugs which are provided on the tube sections 12 thus permitting easy assembly and "opening up" of the tube structure of FIG. 6.

A pair of tying cables 64 is threaded through the pairs of apertures 58, respectively, with one end of each of the cables secured to a terminal tube section of the upper portion 54 and the other ends secured to the walls of sleeves 66. Coil springs 68 are held in contact between the sleeves 66 and the adjacent tube section 70 and serve the same purpose as does the spring 38 in the embodiment of FIG. 1. As in the previous embodiment, annular elements 72 in the form of spacer washers or sleeves are provided between some of the tube sections for both upper and lower portions 54, 56, depending, as previously described, on the amount of flexing desired. In FIGS. 6 and 7, it will be noted that the lengths of
the sleeves for the upper portion are greater than those of the lower section. A pair of control cables 74 are threaded through the apertures 60, respectively, in the lower portion 56 and the ends of these cables are secured at 76 to the tube section 78 which is the terminal section for the portion 56. Another pair of control cables 80 are threaded through the apertures 62 and then extended through both portions 54, 56 of the tube structure. In FIG. 7, the terminal ends of the cables 80 are secured at 82 to the terminal section 84 of the portion 54.

The control cables 74 remote from its terminal ends are joined together and looped around a pulley 86 which is suitably connected to a control knob 88 by a shaft 90. Similarly, the ends of the control cables 74 remote from its terminal ends are joined together and looped around a pulley 92. A suitable knob 94 is rigidly connected to the pulley 92 for imparting rotation thereto.

In operation, rotation of the knob 88 in either direction will correspondingly impart a pulling force to one of the cables 80 and release, correspondingly, tension in the other cable. Such a pulling force will flex the upper portion 54 while the lower portion 56 remains straight. If it is desired to extend the terminal end of the tube structure at different radii of curvature, the knob 94 may be rotated in the same direction as the rotation of the knob 88, as shown in FIG. 7. The apparatus may assume other shapes or conditions of flexing depending upon the extent and manner desired. For example, from the condition shown in FIG. 7, the knob 94 may be rotated in order to straighten the upper portion 56 resulting in two straight sections separated by a flexed portion. The knob 88 may be rotated in the complete opposite extreme so that the upper portion is curved oppositely to that shown. In this case, the tube structure would assume an S-shape.

In the embodiment of FIGS. 9-13, the tube sections 100 are shown to be thin plate-like units as compared to the tube sections in the previous embodiments. It will be understood that this difference is merely for illustration purposes and that the tube sections for all of the embodiments may be of any desired length. Similarly, the tube sections 100 may be composed of two interlocking semi-circular ring elements, such as shown in FIG. 5. The advantage of the thin type of section is that in the use of a great number of the sections for a relatively short radius of curvature, the flexible tube structure will assume a more perfect smoothly curved structure rather than a many-sided arc which results when the tube sections are long, such as shown in FIG. 1.

Each of the tube sections 100 is formed with a pair of opposed openings 102 in the form of round apertures and a pair of opposed openings 104 in the form of slots. The apertures 102 receive a pair of control cables 106, respectively, and these may be suitably anchored on the terminal tube section (not shown). The other ends of the cables 106 may be connected together and arranged around a pulley in much the same fashion as in the previous embodiment.

The present embodiment differs from the previously described embodiments in the use of flexure strips, preferably of spring material, instead of tying cables and coil springs 38, 68. A pair of resilient flexure strips 108 having spaced notches or cut-outs 110 and spacer portions 112 therebetween is adapted to be received in the openings 104, respectively. To provide the tube structure with flush external and interior surfaces, the width of the strips 108 is made equal to the width of the tube sections and the depth of the openings 104 made equal to the portion of the strips above the notches 110 in which in turn will receive the portion of the tube sections below the flexure structure shown in FIGS. 9-12 may be encased in a rubber or plastic jacket or sheathing 114 which serves to maintain the flexure strips 108 in proper relationship with respect to the tube sections. It will be appreciated that the present embodiment is rather easy to assemble or disassemble, requiring only the holding of the tube sections and the insertion or removal of the strips 108 from their respective positions. The unique advantage in using a spring flexure strip instead of cables is that twisting of the tube structure is minimized or eliminated in the event that a relatively heavy tool is associated therewith either internally or mounted at the end.

The amount of flexing of the tube structure shown in FIGS. 9-12, depends upon the length of the spacer portions 112 and/or the length of the tube sections 106, such requirements being determined for the variance of flexing in the embodiments of FIGS. 1 and 6. If longer tube sections are to be utilized, the notches 110 would be correspondingly longer. In FIGS. 11 and 12 there is shown, in step sequence, the progress of flexing when a force is exerted upon one of the cables 106. This process would hold true for all of the embodiments of the invention. The force would initially flex the flexure strip portions between the two end tube sections until one end of the terminal tube section abuts the first succeeding section whereupon the continuing force will flex the flexure strip portions between the first succeeding section and the next succeeding section, and so on, until the desired amount of curvature is attained.

By having the notches 110 interlockingly engaged with a corresponding slot, the tube sections are held from displacement along the axis of the tube structure. Consequently, this engagement serves to retain the tube sections to maintain the length of the tube structure along its axis substantially constant. If a permanent arrangement is desired, a notched flexure strip may be dispensed with and one having continuous edges could be threaded through the slots 104. A weld may then be applied to every juncture of the strip with a tube section.

In FIG. 13, there is shown an oval tube section 120 having thickened portions on two sides thereof which may be substituted for the circular tube sections of the structure shown in FIG. 9. The advantage in the use of the oval tube section when the tying flexible element, whether it be a cable or flexible strip, is associated with the ends of the section having the greater diameter, is that there is less tendency for the tube structure to twist while being flexed, which may occur if the tying flexible elements are not sufficiently taut or the parts are loosely fitted. This has particular advantage for a device similar to the structure shown in FIG. 6 wherein there is a tendency for the structure to twist when a force is exerted on the cables 80. The twisting here would be occasioned because of the "off center" location of the openings 62 for the cables 80. Since one of the openings 62 is closer to one of the openings 56, a torque will be developed tending to twist the structure when the cable is pulled. In the use of an oval tube section, the tying flexible element has a greater moment arm, that is, the distance between the element and the axial center of the tube section, than the moment arm for the control cable. Therefore, the cable may be located off-center somewhat and its use thereof will not affect the alignment of the tube structure.

From the foregoing description, it will be appreciated that the present invention provides a flexible tube structure which may be flexed in a controlled manner, both as to extent and as to its radii of curvature. The flexible tube structure may be easily disassembled and reassembled, may be shortened or lengthened and may serve as a housing or a flexible support for various tools. While only specific assemblies are illustrated and described, it will be understood that this is for brevity only and that various other arrangements may be utilized. For example, the embodiment of FIG. 6 may be compounded into any number of individual flexing portions requiring only the addition of more openings and control cables for the additional portions. It will be understood that all of the tube sections in any of the embodi-
ments may be oval in cross-section. While not illustrated, the tube sections for any of the embodiments may include many openings in order to accommodate control wires, or cables for tools, housed within the tube structure or at the end thereof. These openings as well as those for the various flexible elements described may be tubularly thickened protruding portions of the tube sections such as those shown in FIGS. 3 and 8 or in the walls of the tube sections such as shown in FIG. 13. These and many more modifications and arrangements of the present invention may be made or employed without departing from the spirit or scope of the appended claims.

I claim:

1. A flexible tubular structure comprising, a plurality of tubular sections arranged in end-to-end relationship, spacer means defining longitudinal openings positioned diametrically opposed to each other and pivotally position- ing said tubular sections relative to each other, a plurality of openings in said tubular sections each of which is aligned with corresponding openings on the preceding tubular section to form at least two pairs of aligned openings extending longitudinally of the tubular structure, a first pair of cables extending through one of said pairs of openings, a second pair of cables extend- ing longitudinally through the second of said pairs of openings and said spacers associated therewith for tensioning said tubular sections, a second pair of flexible elements extending through a second pair of openings in said tubular sections, means for securing the first ends of said first pair of cables to the tubular section adjacent to the ends of said cables, means securing the other ends of each of said first pair of cables and one end of each of said second pair of cables to the tubular section adjacent said other ends of said first pair of cables, whereby a pulling force exerted upon either cable of said second pair of cables will produce a flexing of the tubular structure.

2. A flexible tubular structure comprising, a plurality of tubular sections arranged in end-to-end relationship, spacer means positioned diametrically opposed relative to each other and pivotally positioning said tubular sec- tions in spaced relation to each other, each of said tubular sections consisting of two semi-circular ring elements interlockingly connected at their respective ends, a plurality of openings formed in said tubular sections each of which is aligned with the corresponding openings of the preceding tubular section to form at least four series of aligned openings extending longitudinally of said tubular structure, two of said series of openings extending through connecting ends of said ring elements, said spacers positioned between adjacent ends of said tubular sections one at each of the connecting ends of the tubular sections in axial alignment with openings therethrough, a first pair of cable strung through the second of said series of two aligned openings, means securing the first ends of each of said first pair of cables to the tubular section adjacent said ends, means securing the second ends of each of said first pair of cables to the tubular section adjacent said other end of said first pair of cables, means for securing the first ends of said second pair of cables to the tubular section adjacent said ends, and means for securing the second ends of each of said second pair of cables to the tubular section adjacent said other end of said second pair of cables, thereby permitting flexing of the tubular structure upon exerting a pulling force upon one of said second pair of cables.

3. A flexible tubular structure comprising, a plurality of tubular sections arranged in end-to-end relationship, a plurality of spacer elements diametrically disposed, pivotally position said tubular sections in spaced relation, a plurality of openings in said tubular sections axially aligned with the corresponding openings of the preceding tubular section to form at least four series of aligned openings extending longitudinally of the tubular sections, a plurality of openings extending longitudinally through said spacer elements, said spacers positioned between the adjacent ends of said tubular sections in axial alignment with a pair of the openings therein, a first pair of cables strung through the series of openings which extend through said spacers associated therewith, a second pair of cables strung through the second two of said series of aligned openings, means securing the common ends of said cables to the section adjacent the ends of said cables, means preventing the opposing ends of said cables from forming a straight line and said spacers associated therewith, a plurality of openings in said tubular sections in spaced relation relative to each other, a first pair of cables extending through one of said pairs of openings and said spacers associated therewith for tensioning said tubular sections, a second pair of flexible elements extending through a second pair of openings in said tubular sections, means securing one of the ends of said second pair of flexible elements to the adjacent tubular section whereby a pulling force exerted on one of said second pair of flexible elements will produce a flexing of the tubular structure.

5. A flexible tubular structure comprising, a plurality of tubular sections arranged in end-to-end relationship, a plurality of openings extending longitudinally through each of said tubular sections each of which is aligned with the corresponding opening of the adjacent tubular section to form at least two pairs of aligned openings extending longitudinally of the tubular structure each of said ends being diametrically opposed, a first pair of flexible elements extending through said first pair of openings, a second pair of flexible elements extending through the second pair of axially aligned openings, spacer means positioned between adjacent ends of successive tubular sections and arranged in the plane defined by said first pair of flexible elements, said spacers pivot- ally positioning adjacent tubular sections relative to each other, means preventing movement of the portions of said flexible elements adjacent the end tubular section of the tubular structure, means preventing movement of the portions of said first pair of flexible elements adjacent to the end tubular section relative to said first end section whereby a pulling force exerted on either of said first pair of elements will produce a flexing of the tubular structure about the spacer elements.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,060,972

Gilbert J. Sheldon

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 1, line 15, for "of", second occurrence, read -- in --; column 3, line 13, for "suitable" read -- suitably --; line 49, for "plates" read -- plate --; line 52, after "form" insert -- of --; line 55, for "radius" read -- radii --; column 5, line 48, for "many-sided" read -- many-sided --; line 64, for "adapted" read -- adapted --; column 7, line 53, for "cable" read -- cables --.

Signed and sealed this 23rd day of April 1963.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

DAVID L. LADD
Commissioner of Patents
UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

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