

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
31 May 2007 (31.05.2007)

PCT

(10) International Publication Number
WO 2007/062066 A2

(51) International Patent Classification:
H01R 9/03 (2006.01)

(21) International Application Number:
PCT/US2006/045109

(22) International Filing Date:
22 November 2006 (22.11.2006)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/739,250 23 November 2005 (23.11.2005) US

(71) Applicant (for all designated States except US): **NEOGUIDE SYSTEMS, INC.** [US/US]; 104 COOPER COURT, Los Gatos, CA 95032 (US).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **SWINEHART, Charles** [US/US]; 1282 VINCI PARK WAY, San Jose, CA 95131 (US). **KERVER, Lawrence** [US/US]; 16361 MOZART AVENUE, Los Gatos, CA 95032 (US). **JULIAN, Chris** [US/US]; 546 WOODLAND RIDGE, Los Gatos, CA 95033 (US).

(74) Agents: **GLENN, W., Benjamin** et al.; SHAY LAW GROUP LLP, 2755 CAMPUS DRIVE, SUITE 210, San Mateo, CA 94403 (US).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

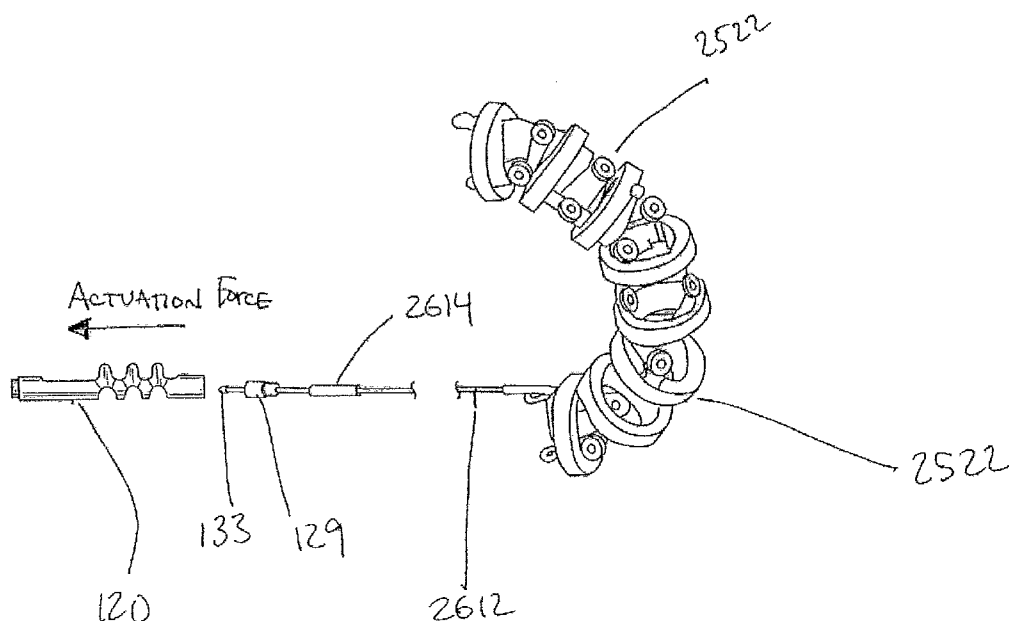
(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— without international search report and to be republished upon receipt of that report

[Continued on next page]

(54) Title: NON-METALLIC, MULTI-STRAND CONTROL CABLE FOR STEERABLE INSTRUMENTS



(57) Abstract: Embodiments of the invention provide methods for inserting a non-metallic multi-strand braid through a coil tube. Techniques for bonding one end of a lead line to one end of a multi-strand non-metallic braid are provided. There are also embodiments of steerable instruments described having a plurality of hinged segments; a multi-strand non-metallic braid connected distally to one segment of the plurality of segments and proximally to an actuator; and a steering controller adapted to control the actuator to move the hinged segment using the multi-strand non-metallic braid.

WO 2007/062066 A2



For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

NON-METALLIC, MULTI-STRAND CONTROL CABLE FOR STEERABLE INSTRUMENTS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 60/739,250 filed November 23, 2005, titled, "Improved Tendon For Steerable Instruments" which is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

[0002] One technique for transmitting actuation forces to the moveable segments of articulating instruments involves the use of a cable within a housing or a coil tube. This arrangement is commonly referred to as a Bowden cable and is similar in operation to a brake system on bicycle. This cable is used to transmit an actuation force from a control handle out to a steerable active segment. In some cases the forces needed to maneuver a steerable instrument can be large. In some cases, the large actuation force results from friction between the steel cable and the coil tube. It is desirable to reduce the amount of force the frictional forces in the cable/tube arrangement including the use of lubricants such as, for example, molybdenum disulfide.

[0003] However useful the lubricants may be, a number of practical challenges remain, such as, for example: (1) the molybdenum disulfide lubricant in powder form will eventually wear out with use of the scope causing degradation of scope performance; (2) the molybdenum disulfide lubricant is difficult to apply inside the coil and is messy during application; (3) the addition of any lubricant between cable and coil tube also causes lubrication issues between each of the coils of the coil tube allowing them to slip over each other under compressive loads. Coil tube buckling rapidly degrades endoscope performance and require expensive rebuilt of the scope coils.

[0004] What is needed is an improved way of overcoming the friction forces associated with transmitting actuation forces to the moveable segments of an articulating instrument.

SUMMARY OF THE INVENTION

[0005] One embodiment of the present invention provides a method for inserting a non-metallic multi-strand braid through a coil tube by bonding one end of a lead line to one end of a multi-strand non-metallic braid while maintaining the diameter of the bonded area the same

as or less than the diameter of either the non-metallic multi-strand braid or the lead line.

Next, advance the multi-strand non-metallic braid through a coil tube using the lead line. In one alternative, the lead line is altered before the bonding step to improve adhesion to the non-metallic multi-strand braid. In another alternative, the bonding step includes gluing one end of the lead line to one end of a multi-strand non-metallic braid. In another alternative, the bonding step includes thermally bonding one end of the lead line to one end of a multi-strand non-metallic braid. In one aspect, a strand of the multi-strand braid is cut before the bonding step. In another embodiment, before the bonding step, placing one end of the lead line and one end of the non-metallic multi-strand braid into a fixture. In one aspect, the diameter of one end of the lead line or one end of the non-metallic multi-strand braid is reduced before bonding the lead line and the non-metallic multi-strand braid. In one aspect, the lead line is formed from the same material as the non-metallic multi-stranded braid.

[0006] In another aspect, the end of the multi-strand non-metallic braid is terminated. In one aspect, terminating includes forming a knot in the multi-strand non-metallic braid. In another aspect, the multi-strand non-metallic braid is passed through a threaded element before the terminating step. Termination may be accomplished by applying an adhesive to the knot formed in the multi-strand non-metallic braid, gluing a ball within the multi-strand non-metallic braid, securing a crimp to the multi-strand non-metallic braid or forming a loop in one end of the multi-strand non-metallic braid.

[0007] In another embodiment, there is provided a steerable instrument having a plurality of hinged segments; a multi-strand non-metallic braid connected distally to one segment of the plurality of segments and proximally to an actuator; and a steering controller adapted to control the actuator to move the hinged segment using the multi-strand non-metallic braid. In one aspect, a connector assembly couples the multi-strand non-metallic braid to the actuator. In another aspect, there is a carriage assembly in the connector and attached to one end of the multi-strand non-metallic braid. In another aspect, the multi-strand non-metallic braid passes through a coil tube extending between the connector assembly and the segment. In one alternative, the ratio of the clearance between the multi-strand non-metallic braid and the interior surface of the coil tube to the inner diameter of the coil tube is less than or equal to 15%. In one embodiment, the multi-strand non-metallic braid comprises ultra high molecular weight polyethylene (UHMWPE). In one aspect, the multi-strand non-metallic braid is connected distally to one segment of the plurality of segments by terminating the multi-strand non-metallic braid at the desired segment. In another aspect, there is a threaded element on

the one end of the multi-strand non-metallic braid to attach the one end of the multi-strand non-metallic braid to the carriage assembly. In another aspect, there is a knot formed in the multi-strand non-metallic braid positioned between the threaded element on the one end of the multi-strand non-metallic braid and the carriage assembly. In one embodiment, there is a knot formed in the multi-strand non-metallic braid. In one aspect, there is an adhesive applied to the knot. In another aspect, the adhesive contains a pigment that provides a visual indication that the adhesive is present.

INCORPORATION BY REFERENCE

[0008] All publications and patent applications mentioned in this specification are herein incorporated by reference to the same extent as if each individual publication or patent application was specifically and individually indicated to be incorporated by reference.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The novel features of the invention are set forth with particularity in the claims that follow. A better understanding of the features and advantages of the present invention will be obtained by reference to the following detailed description that sets forth illustrative embodiments, in which the principles of the invention are utilized, and the accompanying drawings of which:

[0010] FIGs. 1A, 1A1 and 1B illustrate various views of a fixture used to bond a leader to an braid structure.

[0011] FIG. 2 illustrates altering the end of a braid prior to bonding.

[0012] FIG. 3A and 3B illustrate different altered leaders.

[0013] FIG. 4 illustrates the fixture of FIGs. 1A-1B in a vise during a bonding operation.

[0014] FIG. 5 illustrates a strand bonded to a leader being removed from a fixture.

[0015] FIG. 6 illustrates the diameters of the leader, the braid and a bonded area.

[0016] FIGs 7A and 7B illustrate a cross section view of a braid in a coil tube.

[0017] FIG. 8 illustrates a braid connected to a segmented, hinged instrument.

[0018] FIG. 9 illustrates using the braid to articulate the instrument in FIG. 8.

[0019] FIG. 10 shows a schematic view of a system for articulating a controllable article or bendable instrument.

[0020] FIG. 11 is a perspective view of a connector assembly.

[0021] FIG. 12 illustrates an embodiment of a segmented endoscope.

[0022] FIG. 13 illustrates an embodiment of a system used with an instrument of the invention;

[0023] FIG. 14 shows a partial schematic representation of a single UHMWPE tendon connected to a segment and an actuator.

DETAILED DESCRIPTION OF THE INVENTION

[0024] The use of braided Ultra-High Molecular Weight Polyethylene (UHMWPE) is proposed as replacement for conventional stainless steel control cables. UHMWPE force transmissions cables may be used without additional lubrication. Our testing has demonstrated that the use of UHMWPE without additional lubrication reduces frictional forces as compared to the use of other cable material types such as steel. As a result, the reduced frictional load on the UHMWPE/coil tube configuration translates into a substantial reduction of the actuation forces required to steer the endoscope. In addition, the interior of the cable housing or coil tube may also be made of or have a coating of material to further reduce the friction between the UHMWPE cable and the housing.

Replacement of steel cables with braided UHMWPE

[0025] Through extensive testing of various materials, it was found that braided UHMWPE purchased under the trade name of either Spectra® made by Honeywell in the United States or Dyneema® made by DSM in the Netherlands could substantially reduce the forces required to actuate the steerable segments of an endoscope. Additional details of the physical properties of UHMWPE are available in commercial references. Additional details are available via the Honeywell and DSM websites. The lubricity of the material allows it to be used without the need for lubrication in the coil tube resulting in more reliable force transmission elements with longer intervals between required servicing as compared to conventional steel cables. The resulting lower force also solves the problem of buckling the coil tubes. The construction of the pre-stretched, high denier braid of UHMWPE contributes to minimizing the lost motion in the system.

Method of threading braided UHMWPE through coil tubes

[0026] One challenge to overcome when attempting to use a braided material to replace the conventional steel cable is the means of threading the limp braid through a coil tube. In some cases the coil tube may be as long as 110 inches and have an inside diameter of 0.025 inch.

[0027] This problem was solved in a novel way by first joining a lead line onto the braid. The addition of the lead line allowed the braid to be maneuvered through the coil tube. The method included bonding one end of a lead line to one end of a multi-strand non-metallic braid while maintaining the diameter of the bonded area the same as or less than the diameter of either the non-metallic multi-strand braid or the lead line. Once bonded with a diameter small enough to traverse the coil tube without undue friction, the lead line was used to advance the multi-strand non-metallic braid through the coil tube.

[0028] The lead line could be anything joined to the braid to assist in threading the braid structure into the tube. In one case, the lead line to assist in braiding was a monofilament line joined to the end of the UHMWPE braid. In one embodiment, the lead line is formed from the same material as the non-metallic multi-stranded braid.

[0029] This monofilament line could then be threaded through the coil tube and used to pull the UHMWPE braid through as well. This method required bonding the monofilament line to the braid without allowing the diameter of the bond to be larger than the inner dimension of the coil tube being used. Maintaining the size of the diameter of the bonding area may be accomplished by reducing the diameter of one end of the lead line, reducing the diameter of the non-metallic multi-strand braid or both before bonding the lead line and the non-metallic multi-strand braid. FIG. 6 illustrates how the diameter of the braid (D_b) and the diameter of the leader (D_l) are the same as the diameter of the bonding area 155. Additionally, bonding channels 120 may also be sized and dimensioned to maintain the diameter of each of these parts of the bonded structure so that will pass through a coil tube 2614. In one specific embodiment where the coil tube had an inner diameter of 0.025 inch and the diameter of the bonding area 155 was maintained at a diameter less than approximately 0.024 inch.

Additional details of this challenge are detailed below with regard to FIG. 7A and 7B.

[0030] FIGs. 1-5 will now be used to illustrate one proposed bonding solution involving a bonding fixture was designed out of blocks of PTFE (i.e., Teflon®). Fabricating the fixture out of PTFE or other material that will not bond to the leader or the braid allows the bonding of the leader to the braid while being able to control the diameter of the bonding area. FIGs. 1A, 1A1 and 1B illustrate various views of the bonding fixture 105 made from complementary blocks 108A and 108B having a plurality of bonding channels 120. FIG. 1A is an exploded view of the components. FIG. 1A1 illustrated the assembled fixture 105. FIG. 1B illustrates the assembled fixture with a view of the opening 113. The blocks are secured together using conventional means such as a bolt 110 passed through opening 113 and

secured by nut 112. The blocks may also or alternatively be secured using a vise 103 as shown in FIG. 4.

[0031] As shown in FIG. 2, a multi-strand non-metallic braid 2612 is shown inserted into an assembled fixture 105. This is the first step in the placing one end of the lead line and one end of the non-metallic multi-strand braid into a fixture before bonding the leader to the braid.

[0032] Next, the end of the braid may be cut to help bond to the leader and also aid in keeping the size of the bonded area small. In one embodiment, there is a step of cutting a strand of the multi-strand braid before the bonding step. Alternatively, all but one strand of the braid was trimmed approximately $\frac{1}{4}$ inch from the end using a razor blade prior to assembling the braid in the fixture. The remaining strand is used to bond to the leader. This cut end 128 is shown sticking up from the fixture 105 in FIG. 2. The next step is gluing one end of the lead line to one end of a multi-strand non-metallic braid. This may be accomplished with a drop of cyanoacrylate glue (such as commercially available Loctite 420) placed on the end of the braid 128.

[0033] Thereafter, the braid 2612 is pulled down into the fixture 105. The leader line 150 is then placed into the same bonding channel 120 as the braid 2612 as shown in FIG. 4. The leader 150 is advanced to meet the braid 2612 and any excess glue is wicked away. As shown in FIG. 3A, the leader 150 may have a reduced or shaped end 152 to aid in bonding to the braid while also keeping the bonded area diameter appropriately sized. Alternatively, as best seen in FIG. 3B, the leader 150 may have a reduced shape and a textured surface 154 to aid in bonding to the braid. As can be seen, the method includes altering one end of the lead line before the bonding step to improve adhesion to the non-metallic multi-strand braid.

[0034] After the glue dries, the braid 2612 with the attached leader 150 (i.e., the monofilament line in this example) is removed from the 2-piece fixture as shown in FIG. 5.

[0035] Once the monofilament leader is fixed to the end of the braid as best seen in FIG. 5, it can then be readily threaded through multiple lengths of coil tube 2614. Each time, the end of the braid 2612 can be cut to length and the assembly (i.e., the leader bonded to the braided structure) used to thread additional coils 2614. For example, the monofilament line 150 can be bonded to a 55 foot spool of braided UHMWPE that can be used to thread more than 50 feet of coil tubes 2614. The ability to make large lengths of the braided/tube assembly will greatly simplify the fabrication process used to make steerable instruments articulated using the non-metallic braid structure.

[0036] Alternatively, bonding the leader to the braid may be accomplished using other known bonding techniques such as thermal bonding or other techniques known to those of ordinary skill in the art to join the material type of the leader onto the UHMWPE braid. One of ordinary skill will appreciate that the bonding technique will depend on the types of material to be joined. The Beahm Split Die Thermal Bonder 220-B is a commercially available unit that may be well suited to a thermal bonding technique. As such, the bonding step may also include thermally bonding one end of the lead line to one end of a multi-strand non-metallic braid.

Method of terminating the braided UHMWPE

[0037] While useful in reducing friction in articulation forces, the lubricity of the UHMWPE braid makes it difficult to terminate the ends of the braid in a precise location.

[0038] One solution to the termination challenge was the realization that the braided UHMWPE can be terminated by simply knotting it off, or using other techniques known for securing braids of this type. As such, terminating an end of the multi-strand non-metallic braid may include forming a knot in the multi-strand non-metallic braid.

[0039] Alternatively, the knotted end could be further secured by gluing the braid together or other techniques to terminate the end of the line. As such, terminating the braid may include applying an adhesive to the knot formed in the multi-strand non-metallic braid. One cyanoacrylate used was Loctite® brand 420 series adhesive. Alternatively, for ease of manufacturing, a pigment may be added to the adhesive to provide a visual sign whether glue was applied to each knot 133. This is an improvement over clear glue that is difficult to tell if it has been applied to each knot. In an alternative embodiment, the adhesive applied to the terminated end is an ultraviolet cured adhesive such as an epoxy.

[0040] One exemplary technique is the use of a stopper knot soaked in a low viscosity, high wicking cyanoacrylate glue. The stopper knot, also known as a double overhand knot, as well as other suitable knots are described in a number of references.

[0041] FIGs. 7A and 7B illustrate a braid 2612 within a coil tube 2614 having a clearance 190 between the braid and the interior surface of the coil tube. The inner diameter of the coil tube and the diameter of the coil tube are also indicated. Maintaining the appropriate inner diameter clearance 190 was another challenge solved using the methods of the invention. If the clearance 190 is too small, then the friction forces on the braid are high leading to the need for increased actuation forces. If the clearance is too large, the pulling on the braid to

actuate a segment may cause the coil tube to buckle. Maintaining the proper clearance 190 is important to ensuring acceptable force transmission function. Consider the following specific examples for coil tubes having an inner diameter of 0.040 inch. A clearance of 0.001 inch will result in too much friction. A clearance of more than 0.007 inch results in buckling and herniation. The acceptable range of force transmission is between greater than 0.001 inch and less than 0.007 inch. Coil tubes in the size range are typically needed given the number of control cables 2612 used in the controllable instruments described below (i.e., up to 64 control cables used to control a fully articulated instrument). Numerous manufacturing challenges related to maintaining a small bonding area while working with small diameter braids have been solved by the methods described herein. As such, we have found that the ratio of the clearance between the multi-strand non-metallic braid and the interior surface of the coil tube to the inner diameter of the coil tube is less than or equal to 15%.

[0042] An exemplary UHMWPE cable is shown with an articulating instrument in FIGs. 8-14. As best seen in FIG 8, a standard 2-56 set screw 129 was drilled through allowing the braided UHMWPE 2612 to be passed through the screw 129 and terminated using the stopper knot 133. The screw 129 could then be inserted in the end of a threaded carriage assembly 120 that is part of a rack or connector (further described in U.S. Patent Application Publication US 2006/0052664). The UHMWPE cable 2612 is pulled with an actuation force to activate each segment individually as described below.

[0043] As detailed above, the multi-strand non-metallic braid is connected distally to one segment of the plurality of segments by terminating the multi-strand non-metallic braid at the desired segment. Alternate termination methods include:

1. Full strength loop manufactured in one end of the braided cable.
2. Steel crimp of adequate length, with "toothed" or rough interior capable of holding the UHMWPE securely in place. Alternatively, a brass crimp with a smooth interior may be used.
3. Metal ball placed inside the hollow braid, then glued in place to terminate.

Steerable Instruments and System Using UHMWPE

[0044] There are a number of steerable instruments available. Examples of steerable instruments, various control, and force transmission systems are described in, for example, U.S. Patent 6,468,203; U.S. Patent 6,858,005 and U.S. Patent Application Serial No. 10/988,212 filed 11/12/2004, now U.S. Patent Application Publication US 2006/0052664,

titled "Articulatable Connector Device for Endoscopes " each of which is incorporated herein by reference in entirety. The application and patents listed above are commonly assigned with this application.

[0045] FIGs. 8 and 9 illustrate a plurality of hinged segments 2522 and a multi-strand non-metallic braid 2612 connected distally to one segment of the plurality of segments (i.e., via knot 175) and proximally to an actuator as described below. In this illustrative portion of the system, the braid 2612 is terminated proximally at knot 133. The screw 129 is threaded into the rack or connector 120 so that the knot is maintained between the threaded connector and the rack. Not shown in this figure but described below is a steering controller adapted to control the actuator to move the hinged segment 2522 using the multi-strand non-metallic braid 2612. Application of an actuation force (shown by arrow in FIG. 9) to the rack 120, pulls the braid 2612 to bend the segment 2522 as shown. Additional details of the use of the non-metallic braided structures described herein will be appreciated through reference to FIGs. 10-14.

[0046] FIG. 10 illustrates a schematic view of a system 1000 for moving a controllable article 1100. A force generator under control of one or both of a user input device 1140 and a system controller 1145 generates forces that are used to move the controllable article 1100. The forces generated by the force generator are transmitted to the controllable article using force connecting elements 1135 and a connector assembly 1120. The controllable article may also be an articulating instrument or a bendable instrument.

[0047] A connector assembly 1120 completes the transmission of power generated by the force generator 1110 and applied to the controllable article 1100. The two portions 1125, 1130 of the connector assembly 1120 are disengagably coupled. The connector portion 1125 is the first connector portion or the force generation side connector. The connector 1130 is the second connector portion or the controllable article side connector portion. When the connector portions 1125, 1130 are in a coupled condition, the force transmission elements 1135 are joined and force generated by the force generator 1110 is applied to the controllable article 1100. When the connector portions 1125, 1130 are not coupled, the connector portion 1130, force transmission elements. 1135 and the controllable article 1100 may be removed, in some embodiments as a single integrated unit, from the connector portion 1125, force transmission elements 1135 and the force generator 1110 or actuators 1115. The force transmission element 1135 may be a non-metallic braided cable such as the UHMWPE cable described herein.

[0048] The connector assembly 1120 provides the ability to quickly connect and disconnect the two portions 1125, 1130 allows a single force transmission portion to be used with multiple controllable articles. Currently, articulating instruments such as, for example, endoscopes typically have only 4 cables to provide limited control at the tip of the endoscope. Moreover, the connector provides compact organization and efficient coupling of numerous force transmission elements used by highly maneuverable controllable articles. The controllable articles described herein may use 16 or more UHMWPE control cables or 4 UHMWPE control cables per segment and 4 or more segments. In one embodiment, there are 32 UHMWPE cables used to control a fully segmented controllable instrument. In another embodiment, there are 64 UHMWPE cables used to control a fully segmented controllable instrument.

[0049] FIG. 11 illustrates a perspective view of a connector assembly 110 according to one embodiment of the present invention. The connector assembly 110 includes a first connector portion 112 (not shown but within housing 109) and a second connector portion 114. The first connector portion 112 is within the housing 109. The second connector assembly 114 includes a plurality of guide ways 118 each containing a carriage assembly 120. Each carriage assembly contains one or more than one engaging feature 122. Engaging features 122 on carriage assemblies 120, in the second connector portion 114 are adapted to engage with the engaging features 122 on carriage assemblies 120 of the first connector portion 112. One end of the carriage assemblies is connected to force transmission elements or UHMWPE cables 130. In the illustrated embodiment, the cables are Bowden cables. The cables run through a slack area 116. The slack area 116 allows added space for cable slack that may build up during controllable article movement. Thereafter, the UHMWPE cables are terminated and connected as desired to a specific segment of the controllable article.

[0050] The housing 109 provides a structural base for supporting the connector assembly 110. In this embodiment, the first connector portion 112 (not shown) is secured within the housing 109. The first connector portion and its carriage assemblies are connected via force transmission elements 130 to actuators 105. While four actuators 105 are illustrated, it is to be appreciated that more actuators may be used to drive a corresponding number of carriage assemblies. The housing 109 also provides an opening 107 configured to receive the second connector portion 114. Optionally, either one or both of the opening 107 or a portion of the second connector portion 114 may be keyed to ensure correct orientation prior to connection. When the second connector portion 114 is placed within the opening 107, the first and second

connector portions 112, 114 are brought into engagement using an appropriate quick release mechanism, such as for example a cam actuated lever or other engagement device as known to those of ordinary skill in the art. When the first and second connector portion 112, 114 are engaged, forces generated by actuators 105 are transmitted to the controllable article.

[0051] FIG. 12 shows an embodiment where the controllable instrument is a tendon driven endoscope 2510. The endoscope 2510 has an elongate body 2512 with a manually or selectively steerable distal portion 2516, an automatically controlled portion 2520, and a flexible and passively manipulated proximal portion 2514, which may be optionally omitted from the device. The steerable distal portion 2516 can be articulated by hand (i.e., using mechanical force of a conventional endoscope manual controls adapted to articulate segments) or with mechanical assistance from actuators pulling on UHMWPE cables. In addition, some embodiments allow a user to input steering commands (i.e., via a joystick 2544 or other input device) into a controller that translates the steering commands into endoscope segment movement.

[0052] The automatically controlled portion 2520 is segmented, and each segment is capable of bending through a full range of steerable motion. The distal portion 2516 is also a controllable segment. A more detailed description on the construction and operation of the segmented endoscope may be found in U.S. patent application Ser. No. 10/229,577 filed Aug. 27, 2002, which is incorporated herein by reference in its entirety. Additional details of the arrangement of components are illustrated in FIG. 13 that illustrates an actual embodiment of a computer controlled endoscope and system described herein.

[0053] Returning now to FIG. 12, the selectively steerable distal portion 2516 can be selectively steered or bent up to, e.g., a full 180 degree bend in any direction 2518, as shown. A fiber optic imaging bundle 2534 and one or more illumination fibers 2532 may extend through the body 2512 from the proximal portion 2514 to the distal portion 2516. Alternatively, the endoscope 2510 may be configured as a video endoscope with a miniaturized video camera, such as a CCD or CMOS camera, positioned at the distal portion 2516 of the endoscope body 2512. The images from the video camera can be transmitted to a video monitor by a transmission cable or by wireless transmission where images may be viewed in real-time and/or recorded by a recording device onto analog recording medium, e.g., magnetic tape, or digital recording medium, e.g., compact disc, digital tape, etc. LEDs or other light sources could also be used for illumination at the distal tip of the endoscope.

[0054] The body 2512 of the endoscope 2510 may also include one or more access lumens 2528 that may optionally be used for illumination, fibers for providing a light source, insufflation or irrigation, air and water channels, and vacuum channels. Generally, the body 2512 of the endoscope 2510 is highly flexible so that it is able to bend around small diameter curves without buckling or kinking while maintaining the various channels intact. When configured for use as a colonoscope, the body 2512 of the endoscope 2510 may range typically from 135 to 185 cm in length and about 13-19 mm in diameter. The endoscope 2510 can be made in a variety of other sizes and configurations for other medical and industrial applications.

[0055] The controllable portion 2520 is composed of at least one segment 2522, and preferably several segments 2522, which are, controllable via a computer and/or electronic controller 2540 located at a distance from the endoscope 2510. Each or at least a majority, of the segments 2522 may have UHMWPE force transmission elements or tendons mechanically connected to force generators or actuators to allow for the controlled motion of the segments 2522 in space. The actuators driving the UHMWPE tendons may include a variety of different types of mechanisms capable of applying a force to a tendon, e.g., electromechanical motors, pneumatic and hydraulic cylinders, pneumatic and hydraulic motors, solenoids, shape memory alloy wires, electronic rotary actuators or other devices or methods as known in the art. The linear translation of the actuators within the controller may be configured to move over a relatively short distance to accomplish effective articulation depending upon the desired degree of segment movement and articulation. The movement of the actuators may be measured using sensors to provide input to the control system.

[0056] Each segment 2522 preferably defines at least one lumen running throughout to provide an access channel through which wires, optical fibers, air and/or water channels, various endoscopic tools, or any variety of devices and wires may be routed. A polymeric covering, or sheath, 2530 may also extend over the body of the endoscope 2512 including the controllable portion 2520 and steerable distal portion 2516. This sheath 2530 can preferably provide a smooth transition between the controllable segments 2522, the steerable distal portion 2516, and the flexible tubing of proximal portion 2514.

[0057] A handle 2524 may be attached to the proximal end of the endoscope. The handle 2524 may include an ocular connected to the fiber optic imaging bundle 2534 for direct viewing. The handle 2524 may otherwise have a cable 2552 for connection to a video monitor, camera, e.g., a CCD or CMOS camera, or a recording device 2550. The handle 2524

may be connected to an illumination source 2536 by an illumination cable 2538 that is connected to or continuous with the illumination fibers 2534. Alternatively, some or all of these connections could be made at the controller 2540. luer lock fittings 2526 may be located on the handle 2524 and connected to the various instrument channels.

[0058] The handle 2524 may be connected to a motion controller 2540 by way of a controller cable 2542. A steering controller 2544 may be connected to the motion controller 2540 by way of a second cable 2546 or it may optionally be connected directly to the handle 2524. Alternatively, the handle may have the steering control mechanism integrated directly into the handle, e.g., in the form of a joystick, conventional disk controllers such as dials, pulleys or wheels, etc. The steering controller 2544 allows the user to selectively steer or bend the selectively steerable distal portion 2516 of the body 2512 in the desired direction 2518. The steering controller 2544 may be a joystick controller as shown, or other steering control mechanism, e.g., dual dials or rotary knobs as in conventional endoscopes, track balls, touch pads, mouse, or sensory gloves. The motion controller 2540 controls the movement of the segmented automatically controlled proximal portion 2520 of the body 2512. This controller 2540 may be implemented using a motion control program running on a microcomputer or using an application specific motion controller.

[0059] The actuators applying force to the tendons may be included in the motion controller unit 2540, as shown, or may be located separately and connected by a UHMWPE control cable. The UHMWPE tendons controlling the steerable distal portion 2516 and the controllable segments 2522 extend down the length of the endoscope body 2512 and connect to the actuators. FIG. 3 shows a variation in which the UHMWPE tendons may pass through the handle 2524 and connect directly to the motion controller 2540 via a quick-release connector 2554. In this embodiment, quick release connector 2254 could be any of the above described connector or engagement assemblies. In this variation, the UHMWPE tendons may be part of the control cable 2542, although they could independently connect to the actuators, so long as the actuators are in communication with the controller 2540.

[0060] An axial motion transducer (also called a depth referencing device or datum) 2548 may be provided for measuring the axial motion, i.e., the depth change, of the endoscope body 2512 as it is advanced and withdrawn. The depth referencing device 2548 can be made in many possible configurations. For example, the axial motion-transducer 2548 in FIG. 3 is configured as a ring 2548 that may surround the body 2512 of the endoscope 2510. The axial motion transducer 2548 is preferably attached to a fixed point of reference, such as the

surgical table or the insertion point for the endoscope 2510 on the patient's body. Depth referencing device 2548, and different examples thereof; as well as segment articulation and cable operation are described in further detail in U.S. patent application Ser. No. 10/229,577 filed Aug. 27, 2002, which is incorporated herein by reference in its entirety.

[0061] FIG. 14 shows a partial schematic representation of a single UHMWPE tendon coupled to a segment. For clarity, the other parts of a complete endoscope, including other tendons and segments, have been omitted from FIG. 4. Tension applied to a UHMWPE cable is transferred across the entire segment, resulting in bending. The Bowden cable 2610 has a coil tube 2614 attached to the base 2622 of the segment 2601 and also fixed at the proximal actuator end 2603. The UHMWPE cable 2612 is connected to the actuator 2605 and the distal segment end 2630. By applying tension to the UHMWPE cable 2612, only the intended segment 2601 is bent, and more proximal segments are unaffected. The UHMWPE cable 2612 is placed in tension by the actuator 2605, which is shown in this variation, as a motor pulling on the UHMWPE cable 2612.

[0062] While numerous embodiments of the present invention have been shown and described herein, one of ordinary skill in the art will appreciate that such embodiments are provided by way of example only. Numerous variations, changes, and substitutions will now occur to those skilled in the art without departing from the invention. It should be understood that various alternatives to these embodiments of the invention described herein may be employed in practicing the invention. It is intended that the following claims define the scope of the invention and its methods and structures within the scope of these claims and their equivalents be covered thereby.

WHAT IS CLAIMED IS:

1. A method for inserting a non-metallic multi-strand braid through a coil tube, comprising:
bonding one end of a lead line to one end of a multi-strand non-metallic braid while maintaining the diameter of the bonded area the same as or less than the diameter of either the non-metallic multi-strand braid or the lead line; and
advancing the multi-strand non-metallic braid through a coil tube using the lead line.
2. The method according to claim 1 further comprising:
altering the one end of the lead line before the bonding step to improve adhesion to the non-metallic multi-strand braid.
3. The method according to claim 1 wherein the bonding step comprises gluing the one end of the lead line to the one end of a multi-strand non-metallic braid.
4. The method according to claim 1 wherein the bonding step comprises thermally bonding the one end of the lead line to the one end of a multi-strand non-metallic braid.
5. The method according to claim 1 further comprising:
cutting a strand of the multi-strand braid before the bonding step.
6. The method according to claim 1 further comprising:
placing the one end of the lead line and the one end of the non-metallic multi-strand braid into a fixture before the bonding step.
7. The method according to claim 1 further comprising:
terminating an end of the multi-strand non-metallic braid.

8. The method according to claim 7 wherein terminating includes forming a knot in the multi-strand non-metallic braid.
9. The method according to claim 7 comprising:
passing the multi-strand non-metallic braid through a threaded element before the terminating step.
10. The method of claim 8 further comprising applying an adhesive to the knot formed in the multi-strand non-metallic braid.
11. The method of claim 8 wherein terminating an end of the multi-strand braid comprises gluing a ball within the multi-strand non-metallic braid.
12. The method of claim 8 wherein terminating an end of the multi-strand non-metallic braid comprises securing a crimp to the multi-strand non-metallic braid.
13. The method of claim 8 wherein terminating an end of the multi-strand non-metallic braid comprises forming a loop in one end of the multi-strand non-metallic braid.
14. The method of claim 1 further comprising reducing the diameter of the one end of the lead line or the one end of the non-metallic multi-strand braid before bonding the lead line and the non-metallic multi-strand braid.
15. The method according to claim 1 wherein the lead line is formed from the same material as the non-metallic multi-stranded braid.
16. A steerable instrument, comprising:
a plurality of hinged segments;
a multi-strand non-metallic braid connected distally to one segment of the plurality of segments and proximally to an actuator; and
a steering controller adapted to control the actuator to move the hinged segment using the multi-strand non-metallic braid.

17. The steerable instrument of claim 16 further comprising:
a connector assembly to couple the multi-strand non-metallic braid to the actuator.
18. The steerable instrument of claim 16 further comprising:
a carriage assembly in the connector and attached to one end of the multi-strand non-metallic braid.
19. The steerable instrument of claim 16 wherein the multi-strand non-metallic braid comprises ultra high molecular weight polyethylene (UHMWPE).
20. The steerable instrument of claim 18 further comprising:
a threaded element on the one end of the multi-strand non-metallic braid to attach the one end of the multi-strand non-metallic braid to the carriage assembly.
21. The steerable instrument of claim 20 further comprising:
a knot formed in the multi-strand non-metallic braid positioned between the threaded element on the one end of the multi-strand non-metallic braid and the carriage assembly.
22. The steerable instrument of claim 16 further comprising:
a knot formed in the multi-strand non-metallic braid.
23. The steerable instrument of claim 22 further comprising:
an adhesive applied to the knot formed in the multi-strand non-metallic braid.
24. The steerable instrument of claim 23 wherein the adhesive applied to the knot comprises a pigment that provides a visual indication that the adhesive is present.
25. The steerable instrument of claim 16 wherein the multi-strand non-metallic braid passes through a coil tube extending between the connector assembly and the segment.

26. The steerable instrument of claim 23 wherein the ratio of the clearance between the multi-strand non-metallic braid and the interior surface of the coil tube to the inner diameter of the coil tube is less than or equal to 15%.

27. The steerable instrument of claim 16 wherein the multi-strand non-metallic braid is connected distally to one segment of the plurality of segments by terminating the multi-strand non-metallic braid at the desired segment.

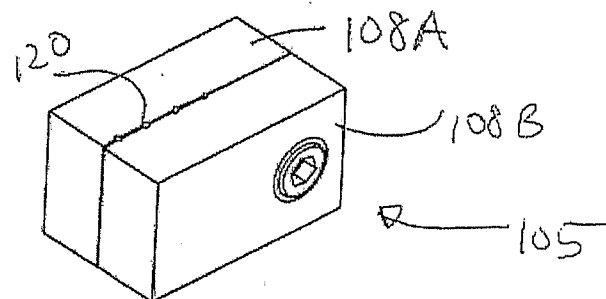
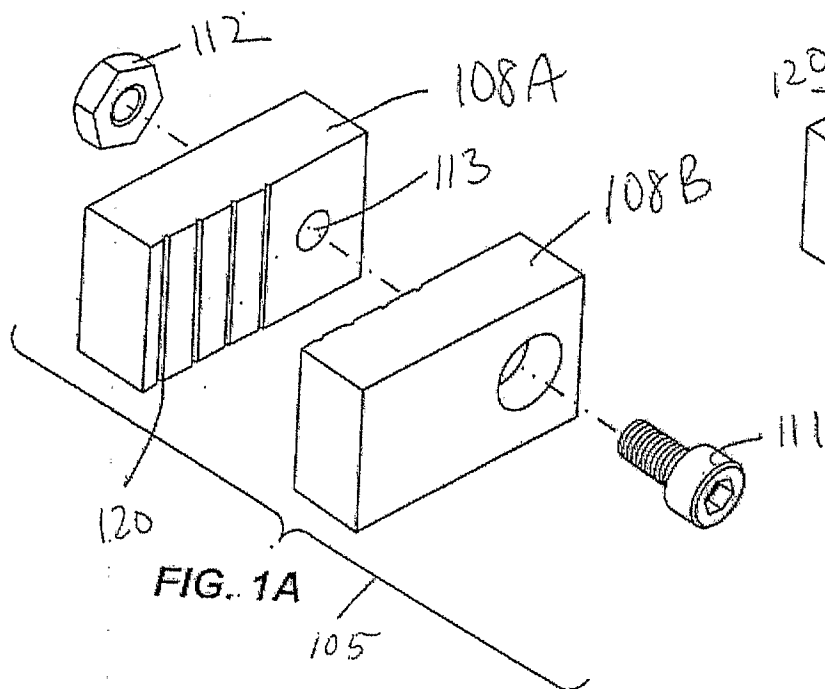


FIG. 1A1

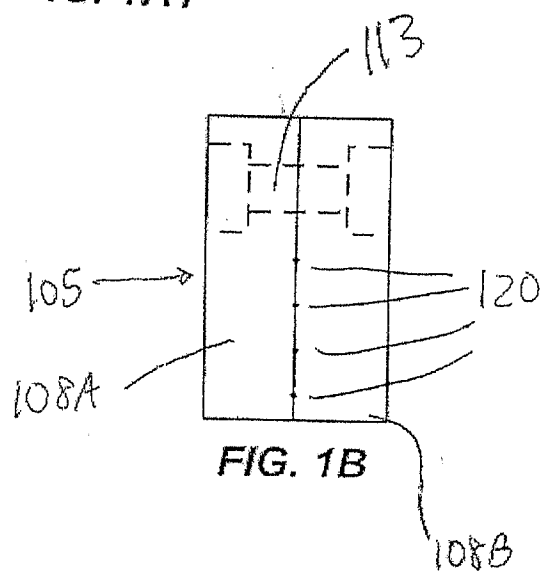


FIG. 1B

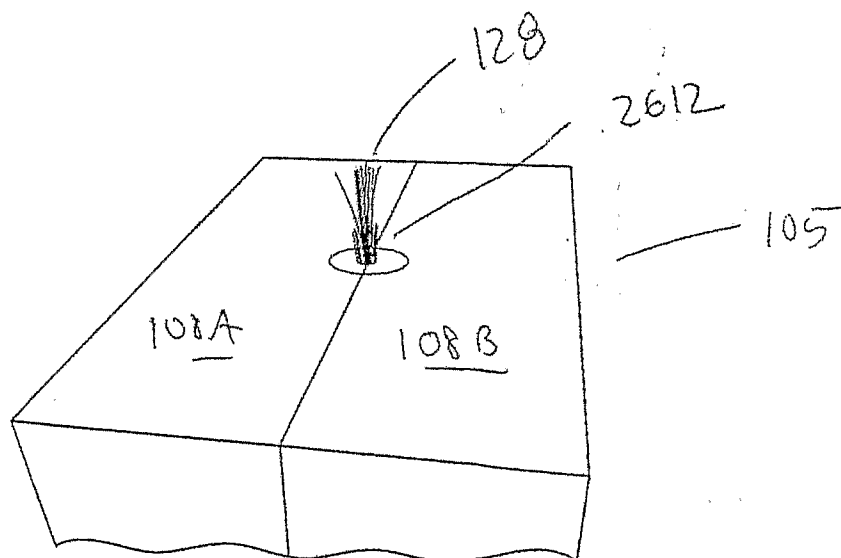


FIG. 2

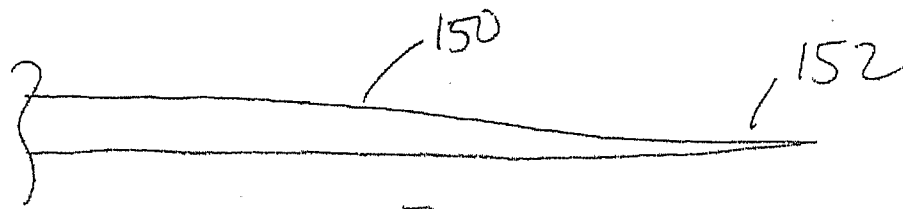


FIG. 3A

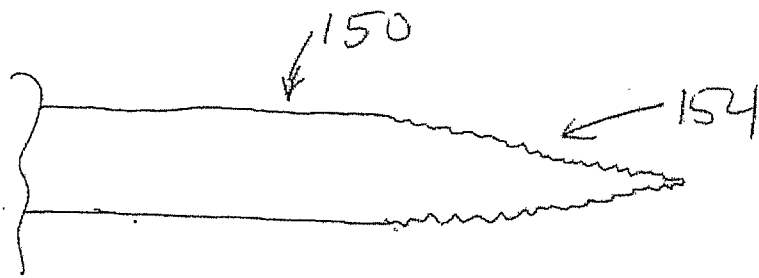


FIG. 3B

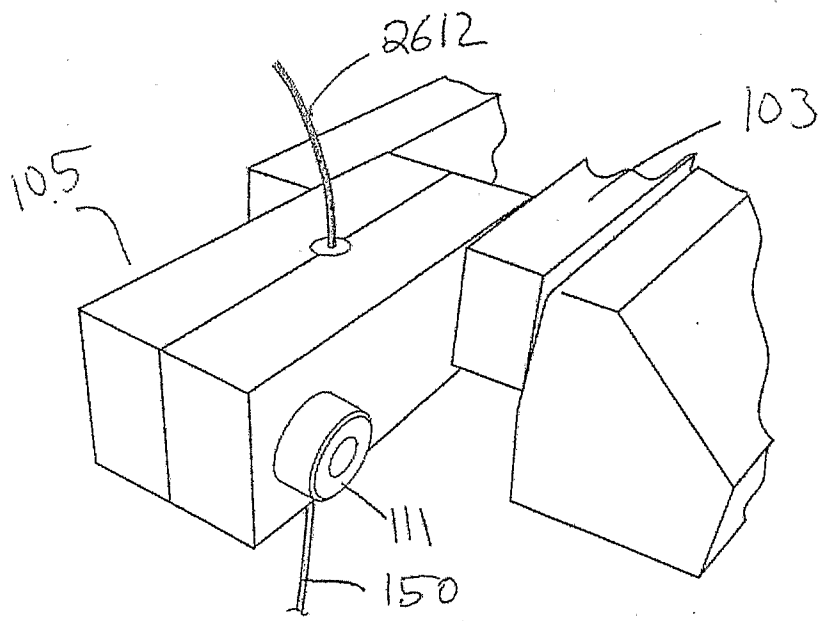
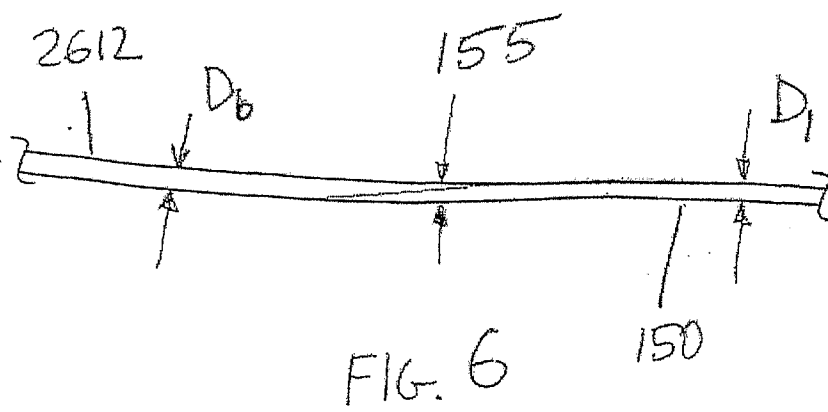
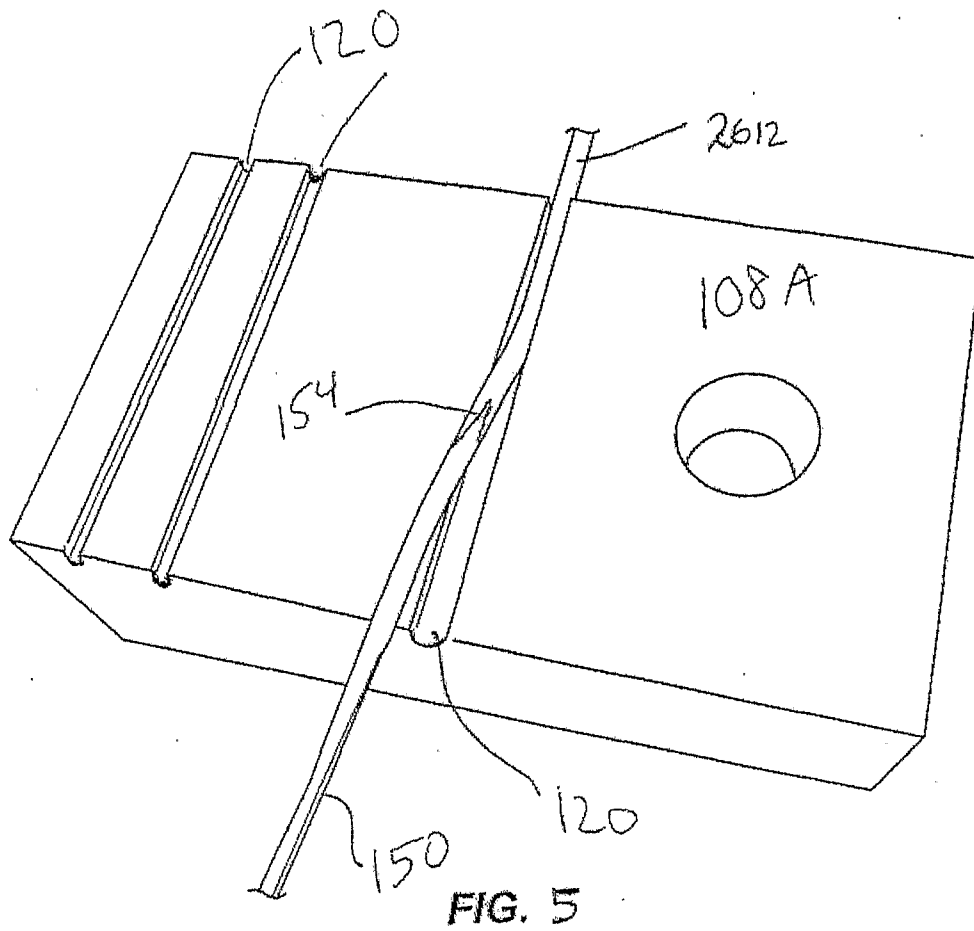


FIG. 4



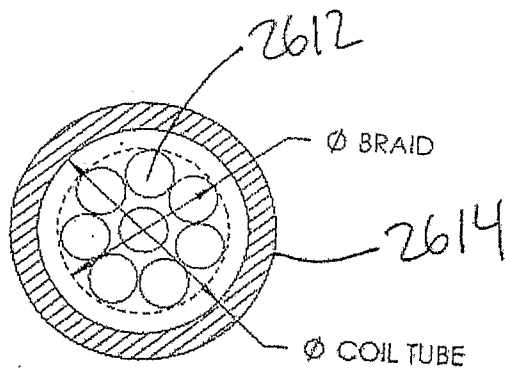


FIG. 7A

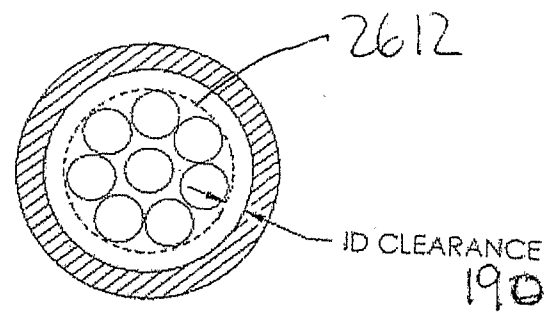
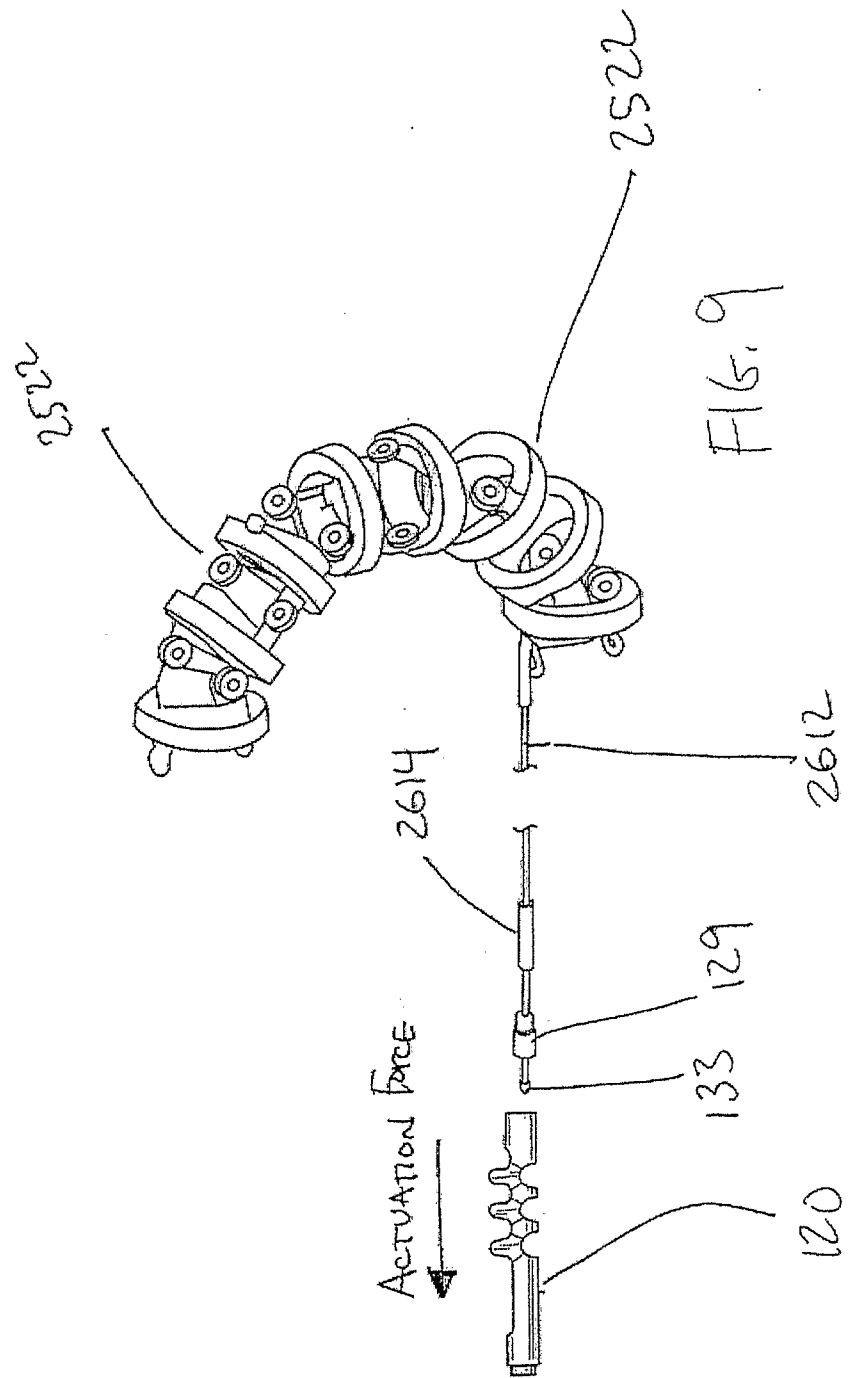
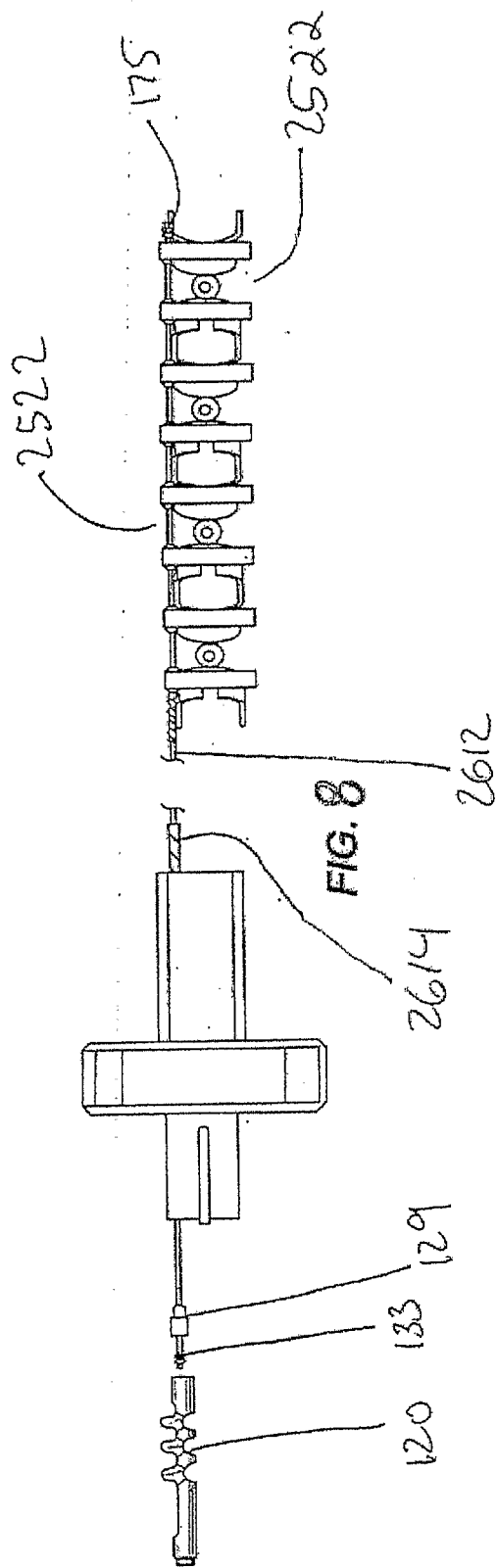


FIG. 7B



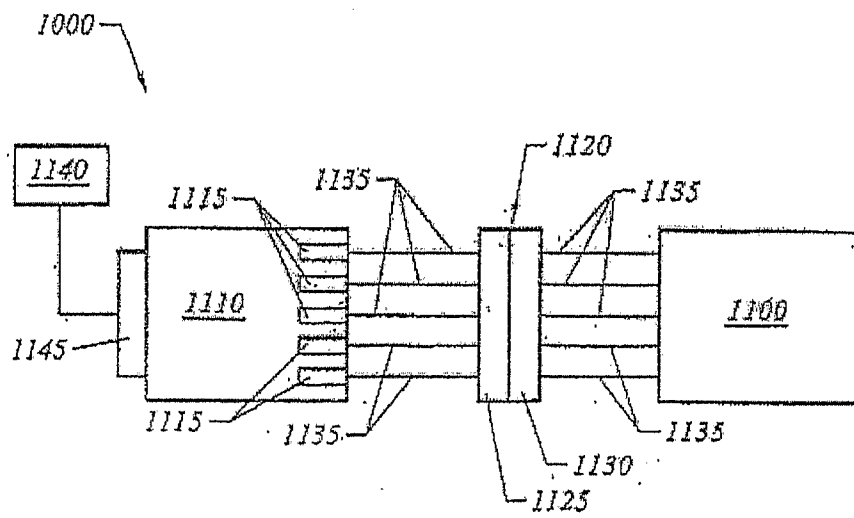


FIG. 10

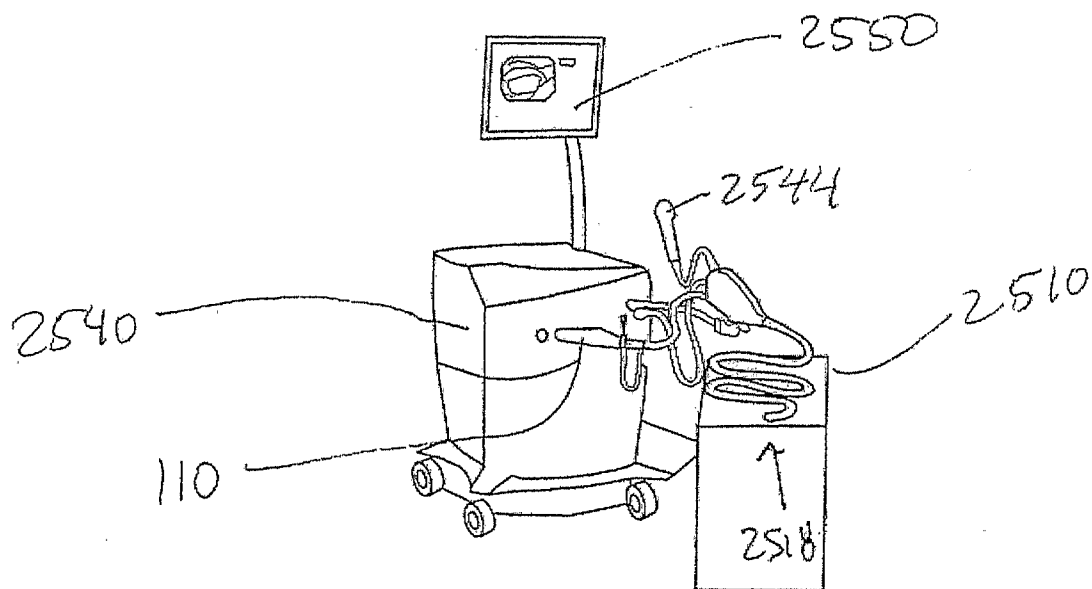
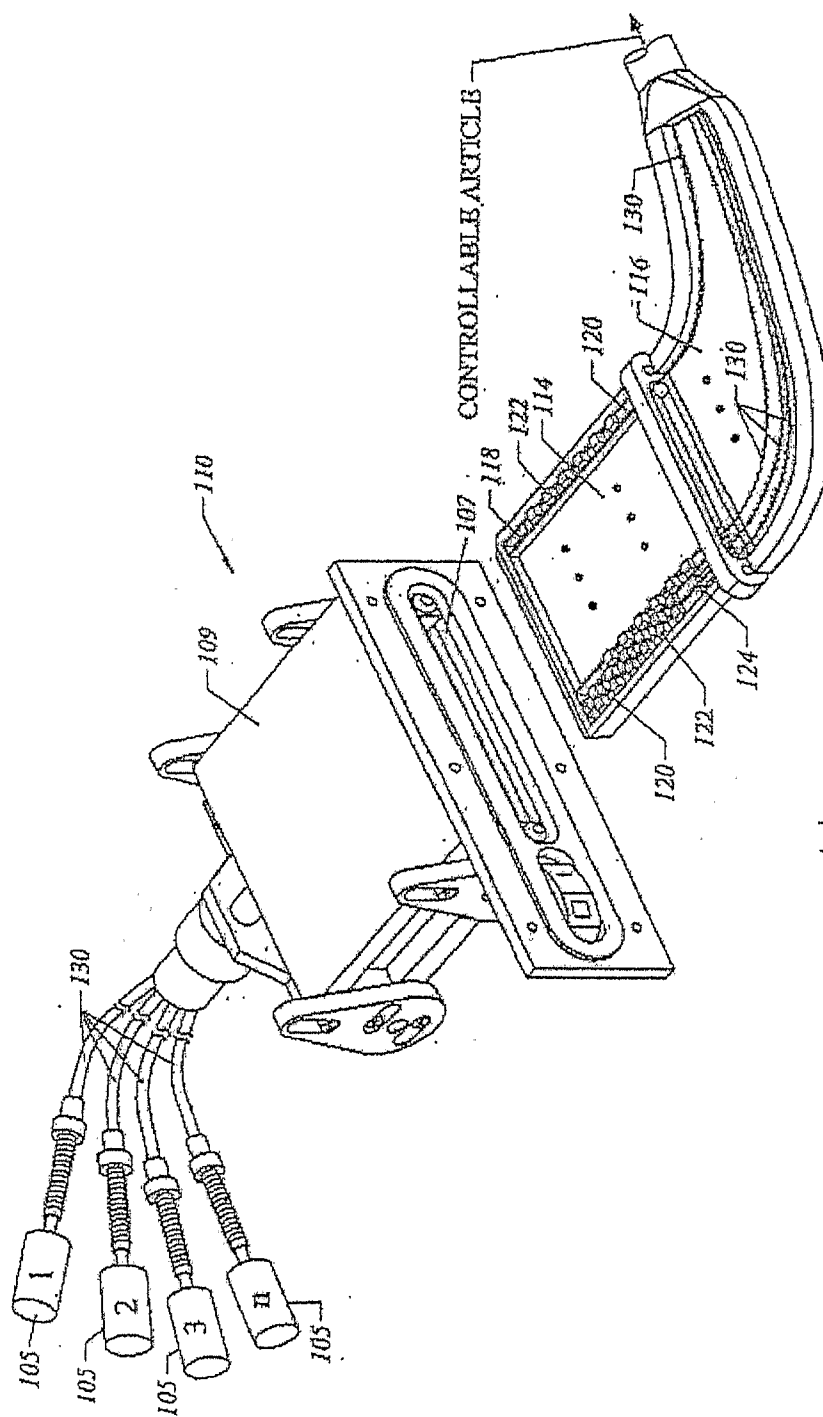


FIG. 13



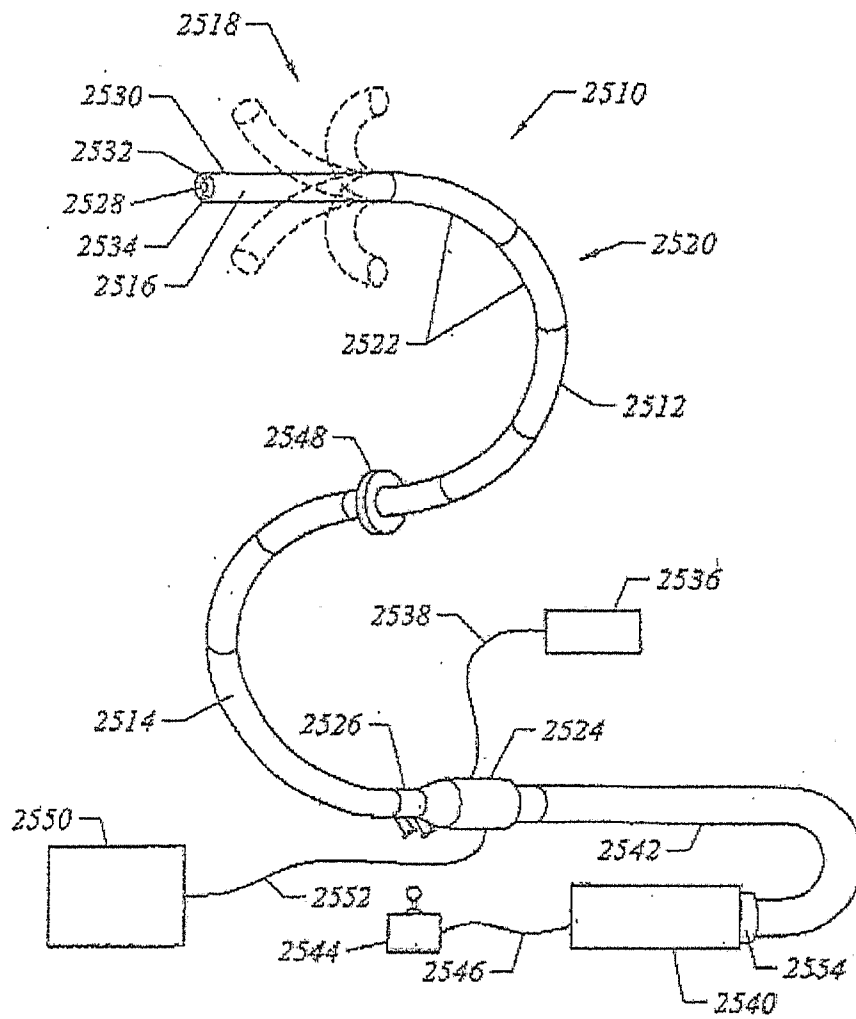


FIG. 12

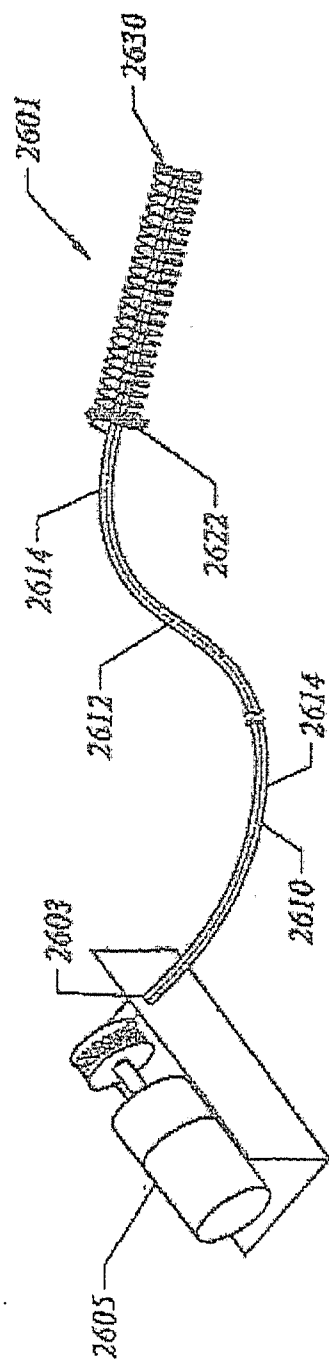


FIG. 4