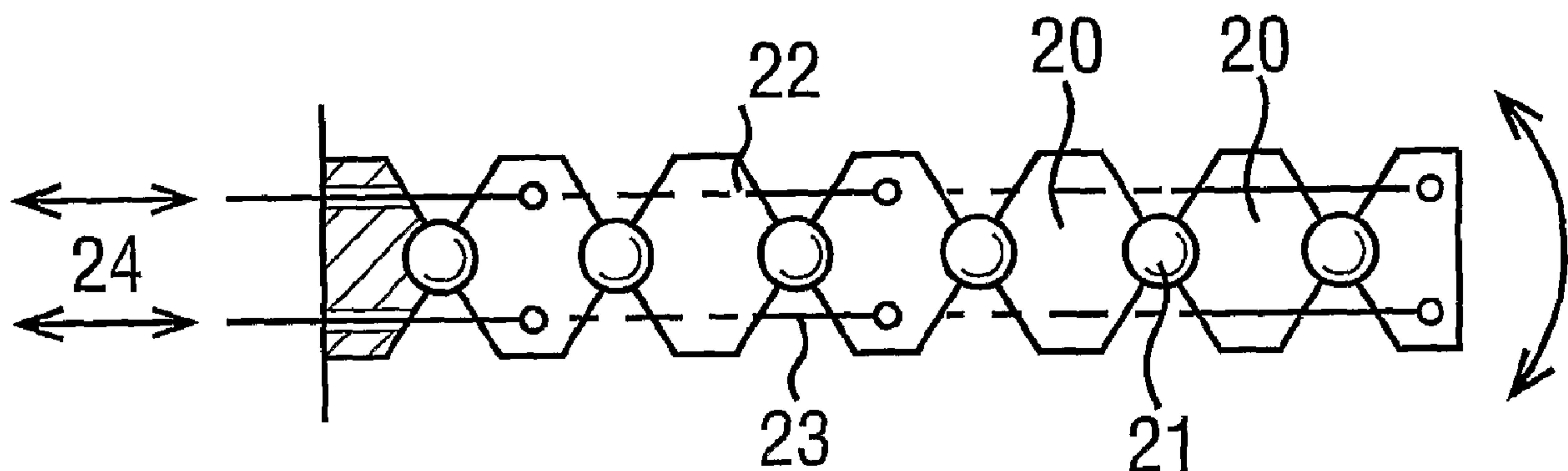




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(72) Inventeurs/Inventors:
BUCKINGHAM, ROBERT OLIVER, GB;
GRAHAM, ANDREW CRISPIN, GB
(73) Propriétaire/Owner:
OLIVER CRISPIN ROBOTICS LIMITED, GB
(74) Agent: RIDOUT & MAYBEE LLP

(54) Titre : SYSTÈME AMÉLIORÉ DE POSITIONNEMENT ROBOTIQUE D'UN OUTIL OU D'UN DETECTEUR
(54) Title: IMPROVEMENTS IN AND RELATING TO THE ROBOTIC POSITIONING OF A WORK TOOL OR SENSOR



(57) Abrégé/Abstract:

This invention relates to redundant robotic apparatus and methods of deploying them. The specification teaches the methodology and construction of a robotic arm device capable of accessing machinery and equipment, which is otherwise difficult to access for maintenance and repair, and is particularly useful in the aeronautical, turbine and nuclear industries. In particular the invention includes apparatus which comprises a support arm comprising a plurality of longitudinal segments each capable of movement one with respect to the other to define a serpentine path or shape, work head carrying means at or towards the distal end of said arm and adapted to carry a work and or examination tool and control means for at least some of said segments to permit control of the shape of the associated segment so that different segments constituting the arm may assume different shapes whereby the arm may advance longitudinally along a predetermined access path to present said tool at said site. The use of a combination of segments, each comprising a plurality of links with separate control means for each segment allows inter alia such a device to extend longitudinally into a restricted space or pathway.



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(71) Applicant (for all designated States except US): **OLIVER CRISPIN CONSULTING** [GB/GB]; 5 Fallodon Way, Henleaze, Bristol BS9 4HR (GB).

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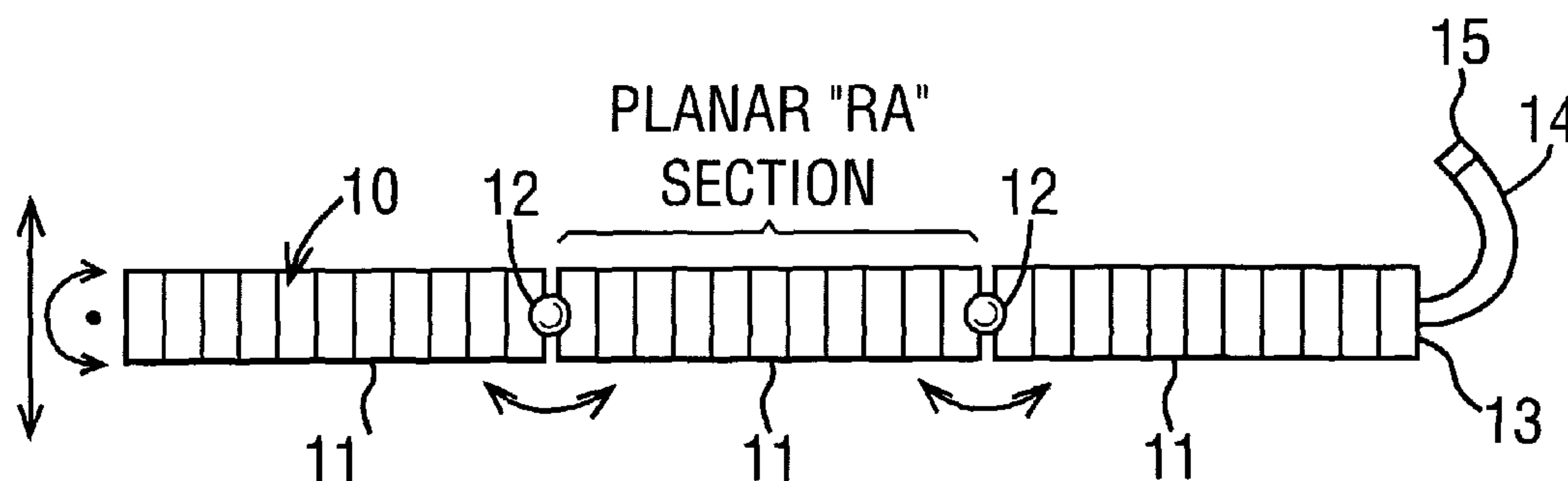
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(72) Inventors; and
(75) Inventors/Applicants (for US only): **BUCKINGHAM, Robert, Oliver** [GB/GB]; 5 Fallodon Way, Henleaze, Bristol BS9 4HR (GB). **GRAHAM, Andrew, Crispin** [GB/GB]; 5 Fallodon Way, Henleaze, Bristol BS9 4HR (GB).

(74) Agents: **EVANS, David, Charles** et al.; fJ Cleveland, 40-43 Chancery Lane, London WC2A 1JQ (GB).

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(54) Title: IMPROVEMENTS IN AND RELATING TO THE ROBOTIC POSITIONING OF A WORK TOOL OR SENSOR



(57) Abstract: This invention relates to redundant robotic apparatus and methods of deploying them. The specification teaches the methodology and construction of a robotic arm device capable of accessing machinery and equipment, which is otherwise difficult to access for maintenance and repair, and is particularly useful in the aeronautical, turbine and nuclear industries. In particular the invention includes apparatus which comprises a support arm comprising a plurality of longitudinal segments each capable of movement one with respect to the other to define a serpentine path or shape, work head carrying means at or towards the distal end of said arm and adapted to carry a work and or examination tool and control means for at least some of said segments to permit control of the shape of the associated segment so that different segments constituting the arm may assume different shapes whereby the arm may advance longitudinally along a predetermined access path to present said tool at said site. The use of a combination of segments, each comprising a plurality of links with separate control means for each segment allows inter alia such a device to extend longitudinally into a restricted space or pathway.



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IMPROVEMENTS IN AND RELATING TO THE ROBOTIC POSITIONING OF
A WORK TOOL OR SENSOR

The present invention relates to an improvement in the
5 robotic positioning of work tools and sensors and relates
in particular to improved mechanical and software tools for
positioning a work tool or sensor and to control algorithms
for effecting control of such equipment.

10 Traditionally, mechanical equipment such as engines and
machines encased by a housing have been maintained by
regular maintenance schedules. In the event of a
malfunction, an operative or engineer will run the machine
or engine through a series of test functions in a
15 trouble-shooting programme and note the reaction of the
machine or engine to each test function. From observation
of the action or reaction of the machine or engine to a
given function, it is possible to diagnose, at least in
part, the general area of malfunction of the machine.
20 Thereafter the machine is dismantled to an extent
sufficient to examine the possible malfunction and to
repair the fault.

Such activity is time-consuming and on many occasions the
25 trouble-shooting programme or the number of available
diagnostic functions for the machine is insufficient to
pin-point with accuracy the precise location of the fault.
On many occasions a machine or engine will need to be
partially dismantled involving much wasted effort,
30 particularly when the trouble-shooting regime or programme
gives an false indication of a fault.

Hitherto, detailed inspection of machines or engines has involved the determination of changes in sound, the use of ultrasound examinations for cracks and breaks in equipment and also for x-ray analysis of particular components. In each case, however, these techniques only serve to assist in diagnosis of faults. Where the components concerned are readily accessible or where the machine has been partially dismantled, only then can examination of individual suspect components be undertaken.

10

In complex machines such as steam or gas turbine engines and the like, there is a need to determine faults in machine and to locate, with precision, the area of the fault before commencing stripping of the engine to examine the faulty component(s) closely for repair/replacement.

In medical science, it has, for many years, been the practice to use endoscopes to examine body cavities sometimes at quite significant distances from the point of access. An endoscope may typically have an examination light source and an optical receiving device at the distal end of a flexible support arm. It is entered into a body orifice and entry is continued until examination of the desired area of disease/damage is reached for internal examination. The flexible support arm is capable of adopting a serpentine path to follow the path of the body orifice. Thus, the walls of the body orifice serve to guide the endoscope and assist the endoscope in following its serpentine path. The use of endoscopes for the examination of machines and engines has been used with some degree of success. A major difficulty of such devices, however, is the problem of controlling the endoscope within the machine and arranging for the light and optical sensor to be

disposed in the correct area of the machine for examination. Where the point of examination of the machine is near an access port then endoscopes have been fairly successful in the internal examination of complex
5 machinery. Likewise, where the repair is similarly located near an access port and is a simple repair, for example, such as tightening a screw or grinding a metal surface then a working device such a borescope may be used.

10 A typical prior art proposal is set out in British Patent Specification No 2033973 which relates to a method of inspecting a gas turbine engine, which latter has a casing provided with at least one access aperture to allow inspection of engine components located within the casing
15 the method comprising inserting guide means into the access aperture locating one end of the guide means being external of the casing and the other end of the guide means being located adjacent the engine component to be inspected fixing the guide means in said location and inserting a
20 flexible endoscope or other remote viewing inspection apparatus into the guide means. In this case the guide means serves as the guide for the flexible endoscope rather in the manner of the body orifice described above.

25 In European Patent Specification No 0907077 there is described and claimed a method and apparatus for inspecting in situ a turbine engine blade in a stage of a gas turbine engine by using eddy currents, which examination is effected from a remote location. The engine includes a
30 casing about the stage of the engine to be examined and a borescope hole which extends through the casing and into the stage in which the turbine blade in question is located. The turbine blade may be inspected by inserting

the apparatus through the borescope hole in the turbine casing. In this case the essence of the invention is the use of the sensor probe means for holding eddy current coils and for sensing imperfections in the structure
5 detected by induced eddy currents within the component, such as a turbine blade, being examined.

United States Patent Specification No 5644394 relates to a system for repairing damaged airfoils for gas turbine
10 engines including a plurality of rigid attachment tools. Each attachment tool is individually shaped to access a leading edge of a damaged airfoil of a particular stage of a gas turbine engine. The attachment tools enable repair of damaged airfoils without disassembling the gas turbine
15 engine. In this case, however, the tools are rigid and are designed to operate juxtaposed the borescope opening into the engine housing.

British Patent Specification No 2154335 relates to a
20 technoscope for internal inspection of a power plant such as an aircraft power unit equipped with noncircular preferably cornered, e.g. square, wall ports comprising a first rigid guide shaft of non-circular cross-section insertible into one of the wall ports and having a lateral
25 distal outlet and a guiding element which passes through said first guide shaft and has a flexible distal portion an intermediate portion of its cross section matches that of the first guide shaft and a proximal control system for control deflection of said flexible distal end the guiding
30 element is used to guide a flexible endoscope shaft to the desired site within the plant to be inspected. Again, a rigid guide shaft is used for insertion into a wall port and serves to provide support for a flexible guiding

element which passes through said guide shaft as a sliding fit.

United States Patent Specification No 5803680 also relates
5 to an instrument such a technoscope for machining the
surfaces of engine blades in normally inaccessible cavities
having a machining tool able to be simultaneously observed
at a machining location with an optic comprising an
instrument shank to which the head is distally coupled,
10 said head carrying the tool and being pivotable relative to
the longitudinal axis of the instrument shank. In order to
create the possibility of being able to measure damage to
the surface to be machined with this instrument, a
measuring tool with a measuring template is attached to the
15 instrument head and when this instrument head is pivotable
into the field of view of the optic the measuring tool may
be attached to the head of instrument in a simple manner
instead of a machine tool.

20 From the foregoing, therefore, it will be appreciated by a
person skilled in the art, that there is a need for an
internal examination and repair function without
disassembling the machine or engine. It will be obvious to
the person skilled in the art that maintenance carried out
25 in this way has the considerable advantage of saving of
time effort and cost by being able to effect a repair or an
inspection without dismantling the engine or machine into
its component parts.

30 The prior art, however, all suffers from the problem that
in order to work on or examine a component or part, the
area to be worked upon or the site to be observed, needs to
be near the access port for the technoscope, borescope or

endoscope as the case may be, or guide means must be provided to support the endoscope/borescope during its passage to the area of work/examination.

- 5 There is, therefore, a need for apparatus to inspect and/or work on a component of an engine which is more remote from the access port and where the access path is convoluted.

The present invention, therefore, seeks to overcome this
10 problem of accessibility to remote parts of an engine by providing apparatus which is capable of following a convoluted path from an access port in an engine or machine to a work place or inspection site within the machine. The invention further seeks to provide apparatus which can be
15 controlled by an appropriate algorithm for control of such equipment remotely whereby the work tool and/or optic may be guided to a work site by computer control of the support arm. The invention further provides apparatus on the form of an arm capable of extending longitudinally along a
20 convolute path within the machine or engine from an access port to a work site.

The advantage of such apparatus is that it enables tools, inspection and test equipment to be carried deep inside an
25 engine or machine to sites which would not normally be accessible without dismantling. A particular feature is that the invention does not need, although it may make use of, guidance or support intermediate the access port and the work/examination site. This permits for example,
30 ultrasound examination of components such as, turbine blades to be carried out in situ with access to the leading or trailing edge and without the need to access the blade tip.

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United States Patent Specification No 4,900,218 discloses a flexible robot arm structure utilising and elongate skeletal frame member which can be controlled to assume any of a number of curved shapes as the performance of automated operations requires. The arm functions somewhat like the body of a snake or an elephant/. The skeletal frame defines a plurality of similar elemental segments disposed in the form of disk like structures as well as turns in a helical loading configuration.

United States Patent Specification No 3,284,964 discloses a flexible beam structure comprising a central longitudinal and extending flexible call member, is a plurality of longitudinal space radially extending members fixed through said call member and at least three longitudinal expandable in contract will fluid pressure elements between each pair of radially extending members space circumferential leaks about said call member and fluid pressure means for selectively controlling the fluid pressure instead pressure elements to expand or contracts are element selectively. The specification discloses the possibility of using a plurality of elements in a longitudinal arm.

According to one aspect of the present invention, therefore, there is provided a method for inspecting or working on an engine or machine in which the
5 work/inspection site is remote from an access point, which method comprises

defining an access path within the engine or machine to said work/inspection site,

10

mounting a work/examination tool at a distal end of a support arm having a plurality of articulated elements

providing control means for at least some of said
15 articulated elements, and causing or allowing said arm to enter said engine or machine and to advance longitudinally of itself to follow said access path to present the tool at the work/inspection site.

20 In another aspect of the present invention there is provided Apparatus for inspecting or working on an engine or machine by the method of the invention, which apparatus comprises

25 a support arm comprising a plurality of longitudinal segments each capable of movement one with respect to the other to define a serpentine path or shape,

work head carrying means at or towards the distal end
30 of said arm and adapted to carry a work and or examination tool

and control means for at least some of said segments to permit control of the shape of the associated segment so that different segments constituting the arm may assume different shapes whereby the arm may advance
5 longitudinally along a predetermined access path to present said tool at said site.

In one particular aspect of the present invention the articulation between the segments in the arm are maintained
10 under tension in order to provide rigidity of each articulation point. By maintaining the articulation of the links under tension in this way the spatial positioning of each articulation can be controlled precisely with time to
15 enable the arm to follow a convoluted path to guide the work tool into the machine.

In a further aspect of the present invention each segment may be separately controlled. The separate control may
20 comprise servo motor means. The servo motor means may be mounted on each segment or they can be remote from the segment with the segments themselves controlled or driven by wires. The motors may be hydraulic or pneumatic motors. The apparatus used in accordance with the present invention
25 could be provided with a datum for a particular engine or machine and the algorithm for the control means may be provided to enable presentation of the work head to a particular position or location within the machine relative to that datum.

30

In a particular aspect of the present invention, each segment comprises a plurality of links, each link being capable of relative movement in at least two dimensions one

with respect to another. The links may be a two-dimensional segment capable of operating in a single plane or may be a three-dimensional segment. Each link may be articulated with respect to its neighbour and the articulation means
5 may comprise a roller in the case of the 2-D segment or ball in the case of the 3-D segment.

In a further aspect of the invention the articulation of the links in a segment may be maintained under tension by
10 wires. This has the advantage of maintaining a stiffness of the joint and enables the segment to adopt a bent configuration with a degree of rigidity and control which would enable a force to be applied by the work head at the work site. Individual links in a segment may be "stiffened"
15 to improve the load capacity and positional determinancy of each joint in the segment. This is important when determining the position of the arm in relation to its datum and for applications where a significant mass is to be supported at the end of the arm.

20

The stiffening may take the form of a spring or springs located in the gap between each link. The springs may be sized with two factors in mind; (1) the compressive force on the spring(s) will be slightly less than the total
25 control wire tension, and (2) the "rocking" stiffness will be selected to give a specific bending stiffness to each joint.

The compressive force has the benefit of reducing the
30 compression on the link ball joint, reducing the friction in the joint even with high wire tension. The bending stiffness introduces a tendency for the segment to conform to a curve of an arc (even with large loads carried by the

arm) and reduces the negative effect of carrying services of unpredictable stiffness through the centre of the apparatus.

5 The stiffened device (stiffened by springs or by a flexible skin or housing or some other technique) is less affected by gravity, but the tension in the wires required to change the shape of the stiffened device is considerably higher. By varying the stiffness in combination with wire tension
10 the device can be made to behave in different ways to produce the desired configuration.

The link disposition within a segment may be controlled by wires. At least two wires may be provided for each link
15 whereby adjusting one wire with respect to another controls the attitude of one link member with respect to the next thereby causing or allowing the segment to "bend". The operating means may include drive means for operating through the length of the support arm and for operating a
20 work piece attached to said work head. The control of the segment, the articulations between the links, and the spatial disposition may be controlled by computer means operating through one or more servo motors provided throughout the device.

25

In one embodiment of the present invention, each segment may comprise a plurality of links capable of allowing the segment to bend in two dimensions only. This enables the tension in of the control means to be flat ribbons or
30 strips of material typically 25 micron or 50 microns spring steel strip. This approach enables banks of strips to be used in juxtaposition and simplifies the design features for each link since only one slot would be required for an

entire ribbon stack for the control of a plurality of segments. In a typical embodiment, therefore, each link may comprise a guide path having arcuate edges or surfaces about which the strip (s) may bend while at the same time
5 constrained in the extent of bending. Thus we have a single guiding element either side of an entire bundle of control ribbons that produces a simpler construction, which would, in the longer term, tend to be more reliable and cheaper.

10 It will be appreciated by the person skilled in the art that the contact pressure over a surface will be considerably lower than in the case of an equivalent wire. This allows improved lubrication with resultant frictional and wear reduction. Furthermore, in situations where access
15 is required into a narrow but tall space, the design can be biassed towards such an arrangement. An additional advantage is that electrical conduit(s) may be included with the strip to provide additional control to actuators spaced lengthways along the arm. Thus, for example, it
20 would be possible to provide a rotational joint between a pair of segments so that part of the arm may be oriented to bend at a plane different to the rest of the arm.

In a further embodiment of the invention, by providing the
25 link axes offset from the centre line of the link in each case, or incline one slightly with respect to its adjacent neighbour, it is possible to create spiral behaviour to assist entering a convoluted space.

30 The control means may comprise redundant robot control means. In this connection, a robot is said to be redundant when a manipulator can reach a specified position with more than one configuration of the links.

The algorithm for control for said control means may comprise trajectory planning techniques and may further comprise a potential field algorithm which may typically be
5 based on an adaptation of the Laplace equation.

The control means may be further adapted to move an arm to present a work head at a work site without contact with obstacles in the machine. In another aspect of the
10 invention the control means may include an algorithm for taking into account moving obstacles within the machine during investigation and analysis.

In a typical aspect of the invention there is provided a
15 multi-link planar redundant robot in which the links are servo controlled with set point data being provided from either real time or off-line calculation using a trajectory planning technique. In this way the robot may move to pre-determined goal points without hitting obstacles or by
20 following the interstices between components within the machine or engine.

Apparatus in accordance with the present invention is capable of inspection and repair of turbine blades and
25 other internal features of gas turbine and like engines while gaining access via the normal air path that is to say by gaining access to the internals of the engine are accessed through the interstices of the blades along the air flow path. The apparatus allows access to the internal
30 features of an engine or machine along a non-straight path.

Apparatus in accordance with the present invention would be of interest in surgery for example in colonoscopy and ventriculoscopy.

- 5 Apparatus in accordance with the present invention could also be used in bomb disposal for cutting a hole in a bomb and then for access to the internals of the bomb to wash out and remove the explosives and/or to defuse the bomb.
- 10 The invention further envisages the use of multiple devices to do parallel inspections and work tasks simultaneously on an engine or machine and also conduct co-ordinated tasks such as grinding, waste removal and viewing.
- 15 In a further aspect of the present invention the support arm comprises a hyper redundant snake robot control path borescope which is made up of a plurality of segments. Between each segment, there is a joint and each segment is individually controlled with respect to the preceding
- 20 segment. The segment length and the maximum angle between the segments is a function of design and may depend on the task for which the arm to be employed. The motion of the device may be controlled by computer so that the device can follow its nose along a specified path. These devices can
- 25 operate in 2-D or 3D depending upon the task and can within reason have any length. The cross-section of the device can vary along its length and the device can also be hollow and have channels for tools and services and the like. In one aspect of the invention the control motors can be mounted
- 30 in each segment or each motor can be connected remotely by wires.

The tools that may be carried by the work head include vision, ultrasound, or eddy currents sensors and these could be changeable. The work head may also incorporate expansion means for clamping the work head relative to
5 fixed components in the machine thereby to provide a basis for operation of a tool in the work head relative to a datum provided by the positioning of the clamp.

In a particular embodiment of the invention the control
10 means includes computer control means operational in response to an algorithm to operate in combination with a CAD model of the engine so that known positions of the access path can be calculated off-line. This will enable apparatus in accordance with the invention to be deployed
15 to a given engine and for the arm to extend into the engine by a predetermined path in accordance with a pre-set algorithm for that particular engine based on CAD modelling. This enables more rapid deployment of the apparatus to its operational position.

20

The following is a description by way of example only and with reference to the accompanying informal drawings of methods of carrying the invention into effect.

25 In the drawings:-

Figure 1 is a diagrammatic view of part of a multisegment arm in accordance with the present invention;

30 Figure 2 is a diagrammatic view of part of a segment of Figure 1 showing individual links;

Figure 3a is a side view of a two-dimensional segment of Figure 2;

Figure 3b is a plan view of 3a;

5

Figure 3c is a detail of 3b;

Figure 4a is a side view of a three-dimensional segment of Figure 2;

10

Figure 4b is a plan view of Figure 4a;

Figure 4c is a cross-section on line iv-iv of Figure 4b;

15 Figure 5 is a longitudinal section along the line v-v of Figure 3b;

Figure 6a is a diagrammatic representation of a work head in its operative position;

20

Figure 6b is an alternative embodiment to 6a;

Figure 7a is a diagrammatic representation of distal end clamping means to locate the work head relative to the work site;

25

Figure 7b is a further embodiment of Figure 7a.

Figure 8 is a perspective view of a 2-D arm in accordance with the present invention.

30

Figure 9 is a top view of the device of Figure 8.

Figure 10 a section through the device of Figure 9

Figure 11 is a detail of portion 'Z' in Figure 10.

- 5 Figure 12 is a diagram showing the installation of a control strip for ribbon in of the segment of Figure 8

Figure 13 is flow sheet for the operation of an arm in accordance with the present invention.

10

One aspect of the invention comprises a longitudinally extending multi-segment arm part of which is indicated generally at 10. The arm comprises a plurality of individual links 11 each of which is articulated one to another by articulated joint 12. The distal end 13 of the arm carries a further segment 14 as hereinafter described terminating in a work head 15. Each segment 11 is a multi-link section comprising a plurality of individual links 20 each interconnected by a connecting element 21 about which link 20 is capable of limiting arcuate movement. The arrangement is such that each link 20 alternates with an element 21 the arrangement being such that the links of a segment are capable of deflecting about an arc in at least one plane. Each link 20 is connected by means of control wires 22, 23 to control means 24 for applying tension to said wires. In the rest position with the segment extended as shown in Figure 2, the wires are maintained under equal tension in a leftward direction. This maintains each of the elements 21 under a degree of kinetic stability. To enable bending, the individual wires to each link are subjected to increasing tension in one direction and a relaxation of tension in the other. Thus, as shown in Figure 2 an increase in tension of the upper

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wires indicated generally at 22 and a corresponding relaxation of tension of the lower wires 23 would result in a flexing or bending of the segment arrangement in a upward direction.

5

In a two-dimensional segment, each of the elements 21 is generally cylindrical extending transversely of the axis of the segment, each element also having a central transverse diametric bore 26 substantially longitudinally of the segment 11. The element 21 is provided on one side with a lip 25 extending along a surface of the element and embracing bore 26. Each link 20 extends the width of the segment and is contoured in cross-section to provide, as shown in Figure 5, a central body portion 31 provided with a central bore 32 and outer portions 50 defining an outer surface 30 and having inclined faces 34 to allow adjacent links to "bend" about an element 21 without interference between the surfaces of adjacent links. The central body portion of each link has a face 33 and is provided with a central transverse groove 40 which is adapted to accommodate the arcuate surface of cylindrical connecting element 21 the arrangement being such that the cylindrical connecting element 21 is disposed relative to its adjacent contiguous link 20 such that the central bore of element 21 is substantially coaxial with the bore of its adjacent links 20 when the links are maintained in a "straight" configuration. The longitudinal lip 25 on each element 21 serves to limit relative rotation between each link and its adjacent element.

30

Each of the outer portions 50 of each link is provided with a longitudinal through cavity 51 in substantially spaced parallel relationship with the axis of bore 32. Cavity 51

is intended to accommodate one or more control wires 22, 23 for the purpose of controlling the link array.

Another embodiment of a two-dimensional device in accordance with the present invention is illustrated in figure 8. In figure 8, each link 71 is substantially elongated and provided with a nose portion 72 at each end. One end of each link portion is recessed and 73 and is adapted to receive the projecting nose portion 72 of an adjacent link the arrangement being such that adjacent links 71 and 71' -- (see figure 9) are capable of limited pivotal movement one with respect to the other in a two-dimensional plane. Each link 71 is provided with a central body portion indicated generally and 75 see figure 11, which body portion carries a pair of upstanding guide members 76 and 77 respectively. Each of guide members 76 and 77 is provided with an arcuate in a surface 78, 79 for the purpose of engaging with a control ribbon passing thereover. As shown in figure 11, a plurality of control ribbon elements 80 are applied and passed through the spacing between guides 76 and 77 respectively as a stack of ribbons. Each of links 71 is manufactured in two parts as shown in figure 12. This enables the individual components of each link to be separated so that in assembly, the ribbon stack 80 is inserted within the space between guides 76 and 77 of each link of the segment and when positioned satisfactorily, the "upper" part of each link is then applied in mating relationship with its neighbour. The two halves of each link are secured together to encase the ribbon stack between each pair of guides 76 and 77 respectively. This design provides for a considerable amount of lumen space between the ribbon guides 76 and 77 to permit, in addition, the supply of services such as

electricity or compressed air through the lumen space without significant interruption by the control ribbons.

Where a control function needs to be exerted on a particular link, the outer ribbon may be bent back about the outer guide 77 as shown in figure 11 and the extremity 82 may be secured to the outer surface 83 of outer guide 77 either by pins or screws or by use of a suitable adhesive.

10 It will be appreciated by the person skilled in the art that there are fewer design features in each link and since any tension in each ribbon is spread over a considerable surface area of the guide members 76, 77, the frictional loading is much reduced in each case. This allows for improved lubrication, significant frictional reduction and the corresponding reduction of wear over a period of time. In a variant of the embodiment described above, the pivots 90 between each link may be offset or skewed one with respect to another by perhaps as much as a degree or two thus providing a twisting or spiralling effect to the arm. The ribbons are able to accept this slight shift in the pivot axis and the device is able to follow a spiral path to correspond with a desired path within the given environment of use for the device.

25

The three-dimensional segment differs from the two described above with regard to Figure 5 in that each of the connecting elements 21 is generally spherical and permits movement of a link over a limited arc in any direction relative to the adjacent link. In this case the links themselves need to be generally spherical and profiled in section as before with the sloping faces 34. In this case, however, at least three wire receiving apertures 51 are

provided to permit control of the segments in all three dimensions - see Figure 4c.

A central through passage 32 provided through the elements 5 21 and the links 20 serve to provide a passageway for control or power supply means to a work head 15.

The work head may be provided at the distal end of usually a three-dimensional segment 14 as shown in Figure 1. To 10 allow for varying angular profiling, for example, provision may be provided for a shaped work head 80 having a profiled work surface 81. Thus, a differing angle of work may be applied at the work site 82 by moving the work head 80 longitudinally with respect to the distal end 83 of segment 15 14.

In a particular embodiment of the present invention the segment 14 may be provided at its extremity with an expandable element 90. When following its serpentine path 20 into an engine, the expanded portion 90 is collapsed and forms part of the distal segment 14. When entered between a pair of turbine blades 100 for example, and positioned along the length of each thereof at the appropriate position, the expanded portion 90 may be actuated to expand 25 against the blades 100 to clamp the distal end 83 of segment 14 relative thereto to enable the work piece 15 to operate on an appropriate portion of the work site 82.

Such an arrangement together with the ability to move the 30 work head 15 longitudinally and laterally with respect to expanding portion 90 enables a limited amount of blade indexing and/or stripping rotation to take place at the distal end of the arm.

A flow sheet giving a description of the action of a typical arm in accordance with the present invention is set out in some detail in figure 13 of the drawings
5 accompanying this specification. It will be appreciated by the person skilled in the art that the detail of each step in the flow sheet will be dependent upon the nature of the tasks that the arm is required to perform.

10 From the foregoing, therefore, it will be seen that the arm, the control mechanism and algorithm in accordance with the present invention permits an arm in accordance with the present invention to extend into an engine or like machine without the need for intermediate guide means. The distal
15 end and work head 15 can be entered into an engine orifice and the various segments of each link can be controlled so that the device can find its way around various obstacles within the engine leading with the work head 15. The extent to which the device can enter the internals of the engine
20 is almost unlimited depending, of course, upon the extent of the arm and the level of control over the individual segments or groups of segments within each link. The motors for each link may be carried on the links themselves or may be provided remotely as described above. The need to fix
25 guide means to guide endoscopic components within the engine is much reduced although the use of guides can be provided to assist in achieving a further reach into the internals of the machine being examined.

30 It will also be appreciated that with turbines in particular it will be possible to enter the machine via the normal air flows/steam passages within the turbine and that, certainly for examination purposes, separate access

ports within the engine will not be a necessity. This has the advantage that it retains the strength and integrity of the engine casing so that in the event of the engine failure at high speed components within the engine can still be contained as part of the containment strategy within the design of the engine without a possible weakening thereof by the inclusion of access ports around the periphery of the engine.

10 The apparatus in accordance with the present invention and as described above can also be used in conjunction with systematic engine monitoring systems. Proposals have been put forward for the routine monitoring of engine exhausts particularly of gas turbine engines by sensing the ionic
15 component in exhaust gases. By maintaining a record of the ionic emissions of the engine during service it is possible to build up a picture of the where the wear and/or problems within the engine are likely to occur. Combining this information with an algorithm for access to various parts
20 of the engine would enable, in the event of an unacceptable series of measurements of ionic components from engine exhaust monitoring, substantially automated inspection of likely areas of wear.

25 Such activities would cut and indeed almost eliminate servicing down-time on engines and would ultimately lead to much greater efficiency of operation of such engines and machines and gas turbine engines in particular.

CLAIMS:

1. A robot arm (10) comprising a plurality of links (20, 71) each of which is articulated with an adjacent link by means of a joint comprising a connecting element (21) and is capable of relative movement in at least two dimensions with respect to said adjacent link, control means (24) for imparting a bending movement to said links, and a work-head carrying means (14) at, or towards, a distal end of the arm (10),
characterised in that
 - 10 (a) the arm (10) comprises a plurality of segments (11) each segment comprising a plurality of the links;
 - (b) the control means (24) comprises tensioning means (22, 23, 80) adapted to act on a selected one of the links (20, 71) of each segment (11) to move each selected segment independently of the other
15 segments;
 - (c) means being provided for maintaining said joints under load so that the control means can manipulate the shape of the segments to enable the arm (10) to be advanced along a predetermined path; and
 - (d) wherein the connecting element (21) between individual links
20 (20, 71) in a segment (11) are stiffened to improve the load capacity and positional determinancy of each link in the segment, such that the links are capable of deflecting about an arc.
2. A robot arm according to claim 1, further characterised in that the
25 segments (11) are provided along the entire length of the arm from a proximal end of the arm (10) to the distal end of the arm (10).
3. A robot arm according to claim 1 or claim 2, wherein the connecting elements (21) are shaped and positioned to define a surface on which
30 each link (20, 71) is capable of sliding arcuate movement relative to the connecting element (21).
4. A robot arm according to claim 1 or claim 2, wherein the tensioning means (22, 23, 80) are connected to selected links (20, 71) and operate
35 on them to apply a load on the links that imparts rigidity to each joint

between a link and a connecting element (21), and imparts stiffness and kinetic stability to each connecting element (21).

5 5. A robot arm according to any one of claims 1 to 4, wherein the control means (24) is operable to apply to the joints and connecting elements (21) a load sufficient to render the arm (10) self-supporting without external support means and therefore enable the arm (10) to be capable of supporting a mass at a distal end of the arm (10), and to apply a load to selected links (20, 71) sufficient to control the spatial positioning of each link (20, 71), segment (11), joint (12), and connecting element (21) to enable the arm (10) to be advanced longitudinally along a predetermined convoluted path.

15 6. A robot arm as claimed in claim 1, wherein each segment (11) has separate control means (24).

7. A robot arm as claimed in claim 6, wherein said separate control means (24) comprises servo motor means.

20 8. A robot arm as claimed in claim 7, wherein the servo motor means is mounted within each segment (11).

25 9. A robot arm as claimed in claim 7, wherein the servo motor means is remote from the segment (11).

10. A robot arm as claimed in any one of claims 7 to 9, wherein the servo motors are hydraulic or pneumatic motors.

30 11. A robot arm as claimed in any one of claims 1 to 10, wherein the tension means are wires (22, 23, 80).

35 12. A robot arm as claimed in any one of claims 1 to 11, wherein the control means (24) incorporates a datum for a particular workpiece and further includes an algorithm to enable presentation of a workhead (15) to a particular position or location relative to that datum.

13. A robot arm as claimed in any one of claims 1 to 12, wherein the links (20, 71) of a segment (11) are articulated in a single place to allow for movement of the segment (11) in two dimensions.
- 5 14. A robot arm as claimed in any one of claims 1 to 13, wherein the links (20, 71) of a segment (11) are articulated to allow movement in three dimensions.
- 10 15. A robot arm as claimed in claim 13, wherein the connecting element (21) is a roller.
16. A robot arm as claimed in claim 14, wherein the connecting element (21) is a ball.
- 15 17. A robot arm as claimed in any one of claims 1 to 16, wherein the stiffening of the connecting element (21) is by a spring or springs.
18. A robot arm as claimed in claim 17, wherein each spring or springs is/are such that the compressive force on the spring will be slightly less
20 than the total tensioning means (22, 23, 80) tension, and will be selected to give a specific bending or rocking stiffness to each joint (12).
19. A robot arm as claimed in any one of claims 1 to 18, wherein the tensioning means comprises at least two wires (22, 23, 80) for each link
25 (20, 71) of a segment (11) whereby adjusting one wire (22, 23, 80) with respect to another controls the attitude of its respective link with respect to an adjacent link thereby causing or allowing the segment to bend.
20. A robot arm as claimed in any one of claims 1 to 19, wherein the
30 control means (24) includes a drive means for operating through the length of the arm for operating a work-piece (15).
21. A robot arm as claimed in any one of claims 1 to 20, wherein the control means (24) includes computer means for control of each segment
35 (11), the articulations (21) between the links (20, 71), the articulations

(12) between the segments, and the spatial disposition of the links and articulations (12, 21).

22. A robot arm as claimed in any one of claims 1 to 21, wherein at least one segment comprises a plurality of links (71) capable of allowing the segment to bend in two dimensions only, and wherein the tensioning means comprises flat ribbons (80) or strips of material.

23. A robot arm as claimed in claim 22, wherein the flat ribbons (80) or strips are spring steel having a thickness of typically 25 micron or 50 microns.

24. A robot arm as claimed in any one of claims 1 to 23, wherein rotational joint means (12) is provided between pairs of segments (11) so that part of the arm (10) is oriented to bend at a plane different to the rest of the arm.

25. A robot arm as claimed in any one of claims 1 to 24, wherein at least some of the links (20, 71) are offset from the centre line of the segment (11) in each case, or inclined one slightly with respect to its adjacent link, thereby permitting spiral articulation of the arm.

26. A robot arm as claimed in any one of claims 1 to 25, wherein the control means (24) comprises redundant robot control means (24).

27. A robot arm as claimed in any one of claims 1 to 26, wherein said control means (24) includes an algorithm for implementing trajectory planning techniques.

28. A robot arm as claimed in any one of claims 1 to 27, wherein the control means (24) includes a potential field algorithm based on an adaptation of the Laplace equation.

29. A robot arm as claimed in any one of claims 1 to 28, wherein a workhead (15) for the arm (10) includes clamping means for clamping the

workhead to surrounding structure within the work environment to steady or locate the workhead relative to a workpiece.

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RIDOUT & MAYBEE LLP
Toronto, Canada
Patent Agents

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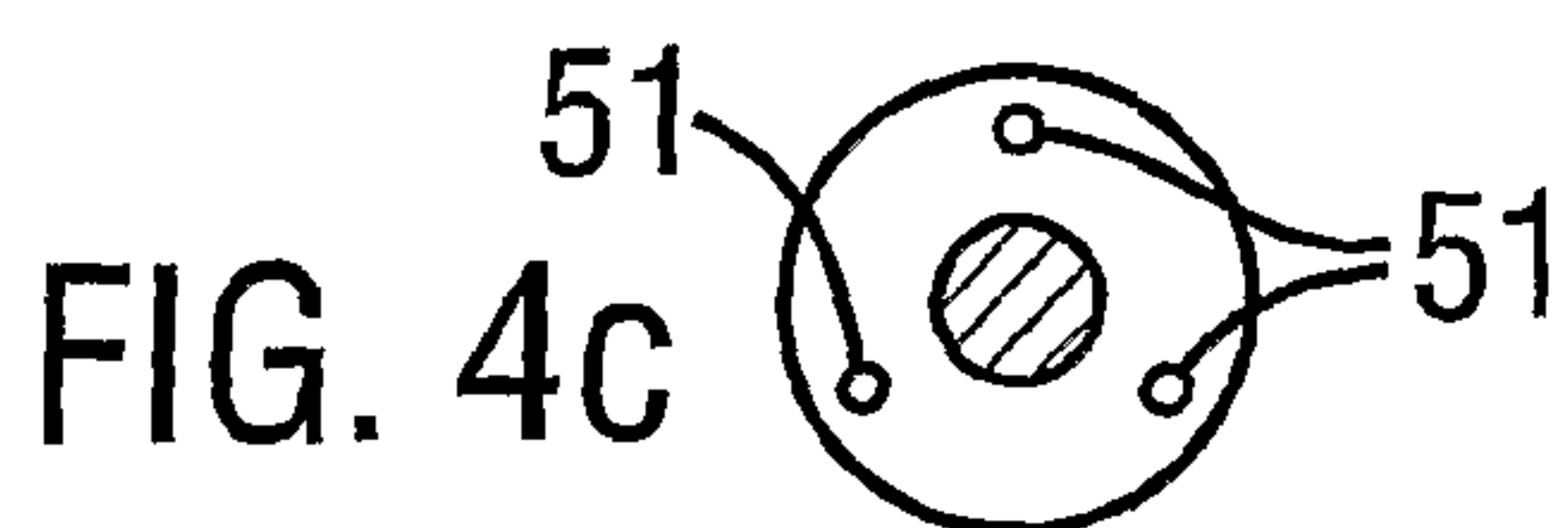
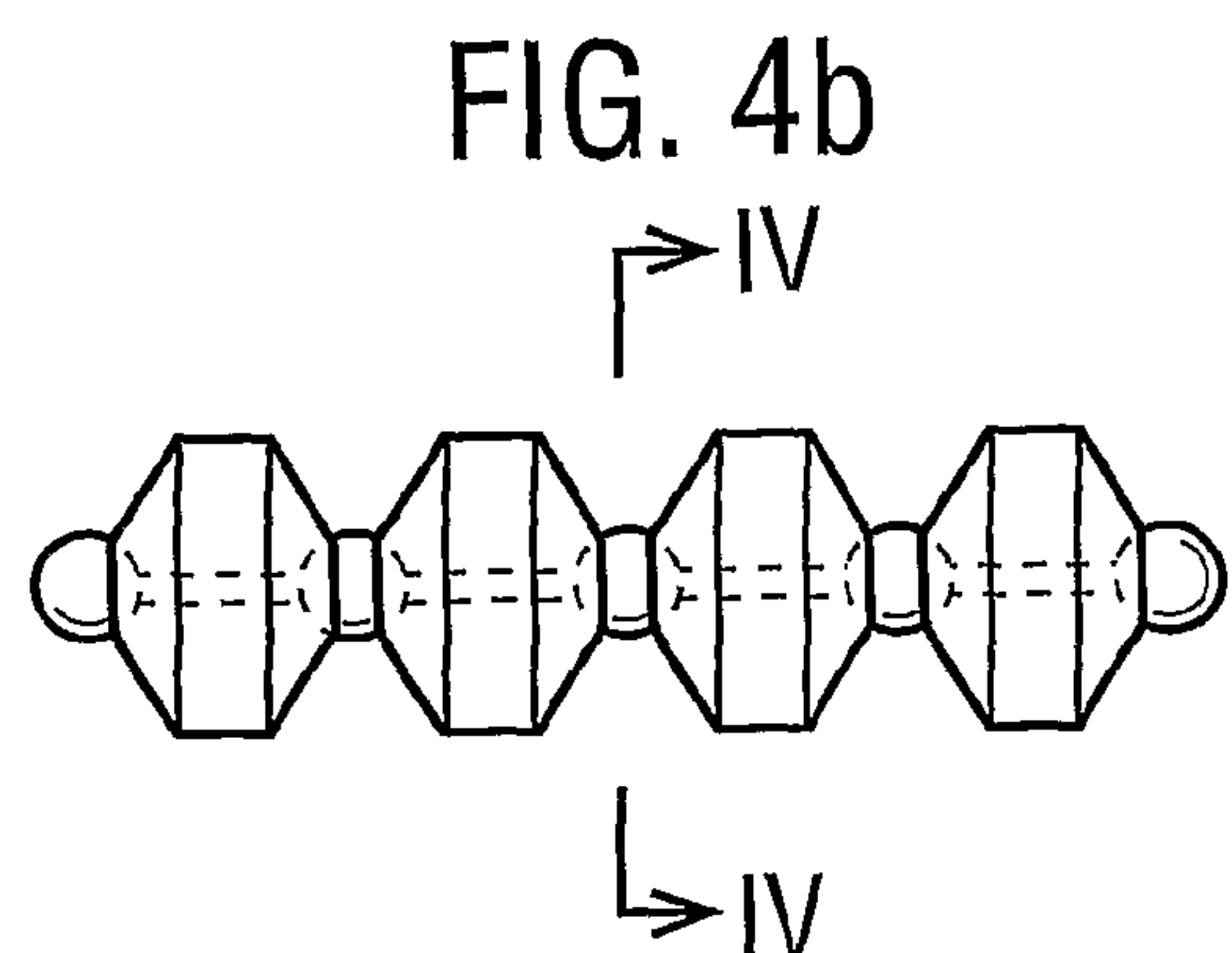
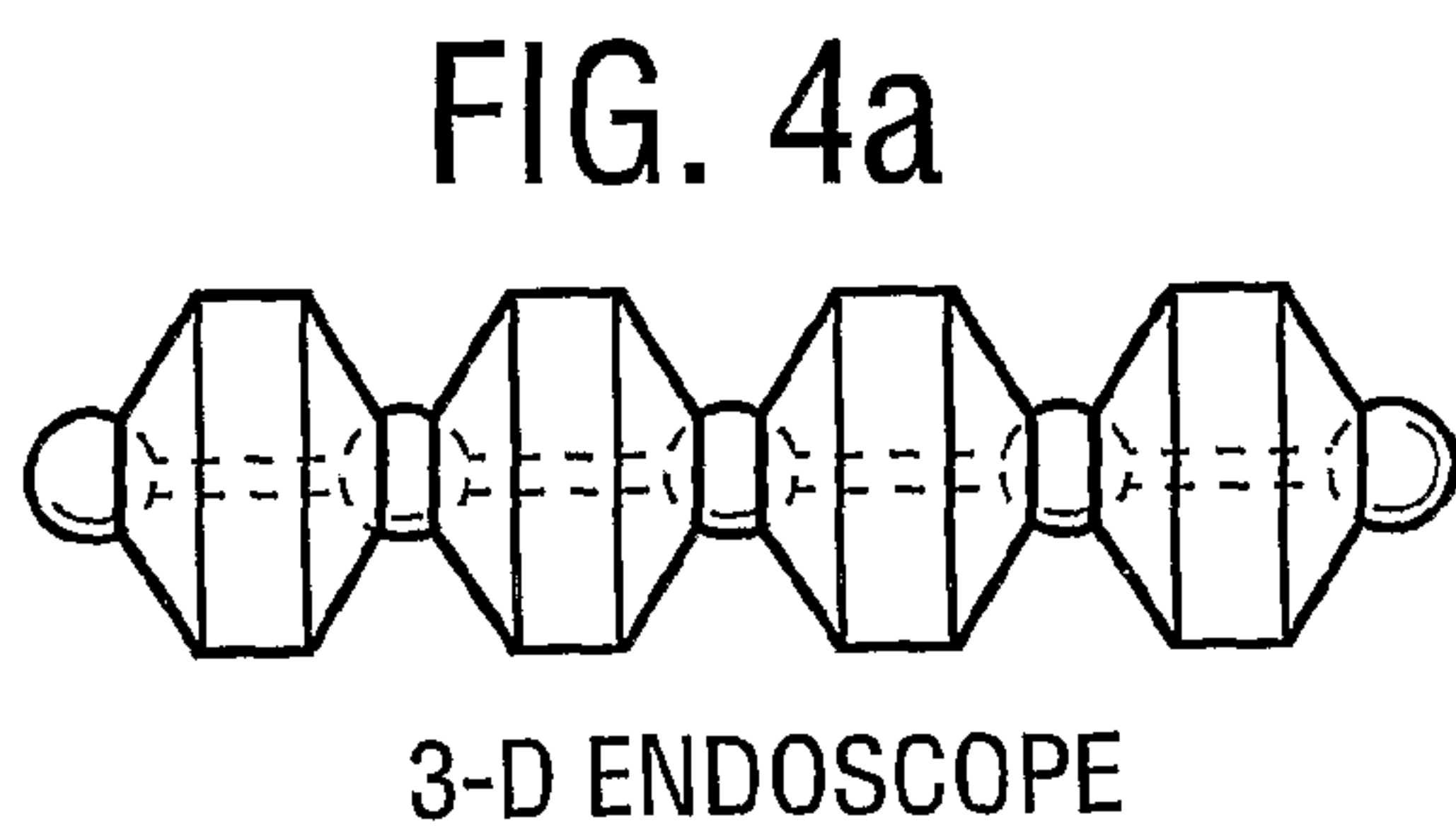
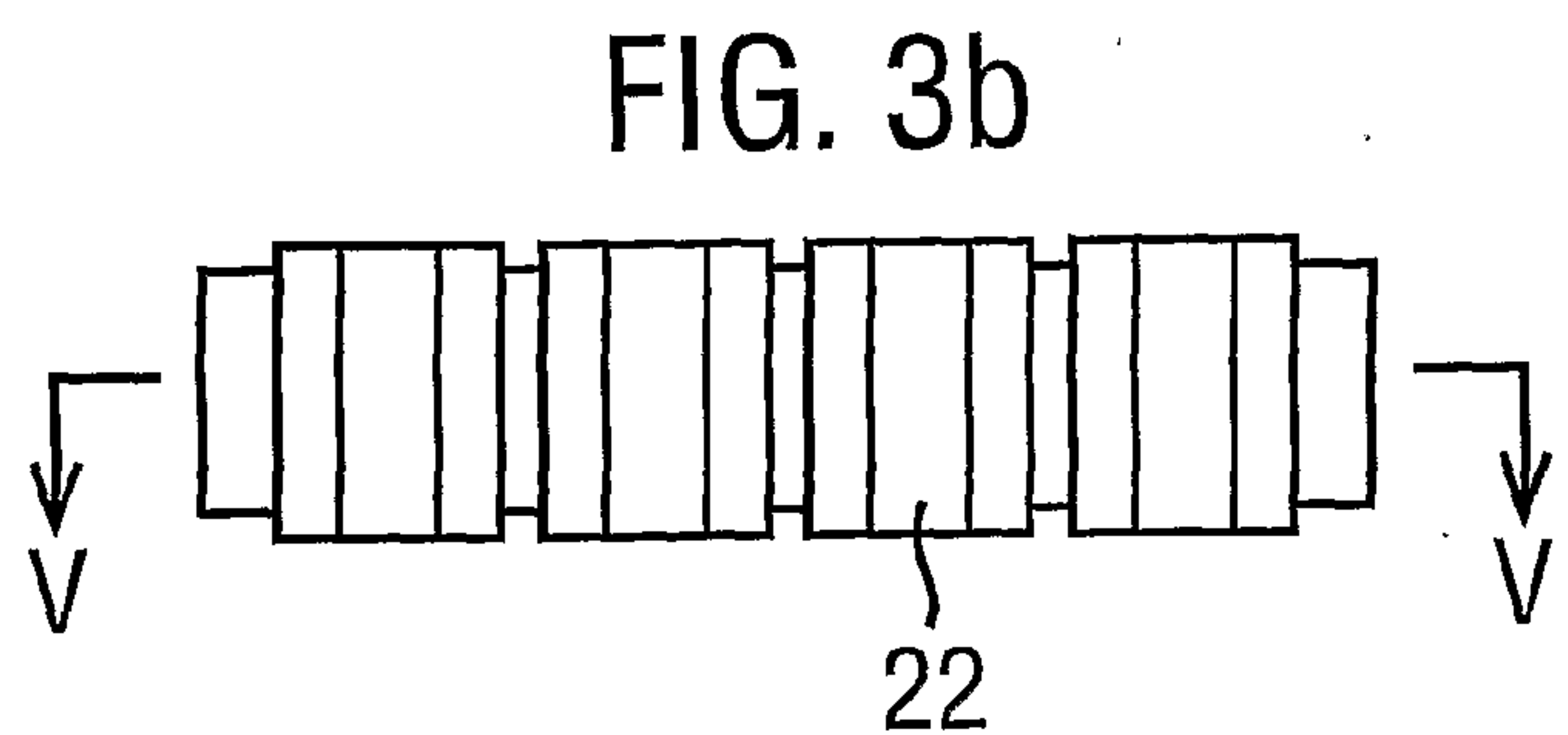
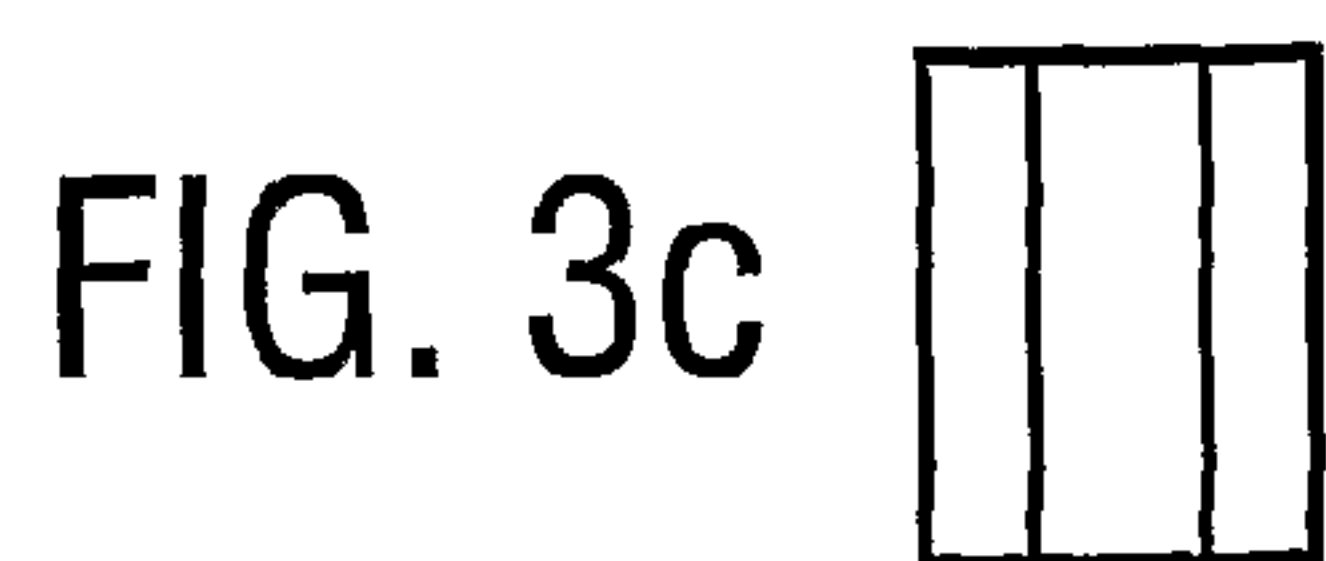
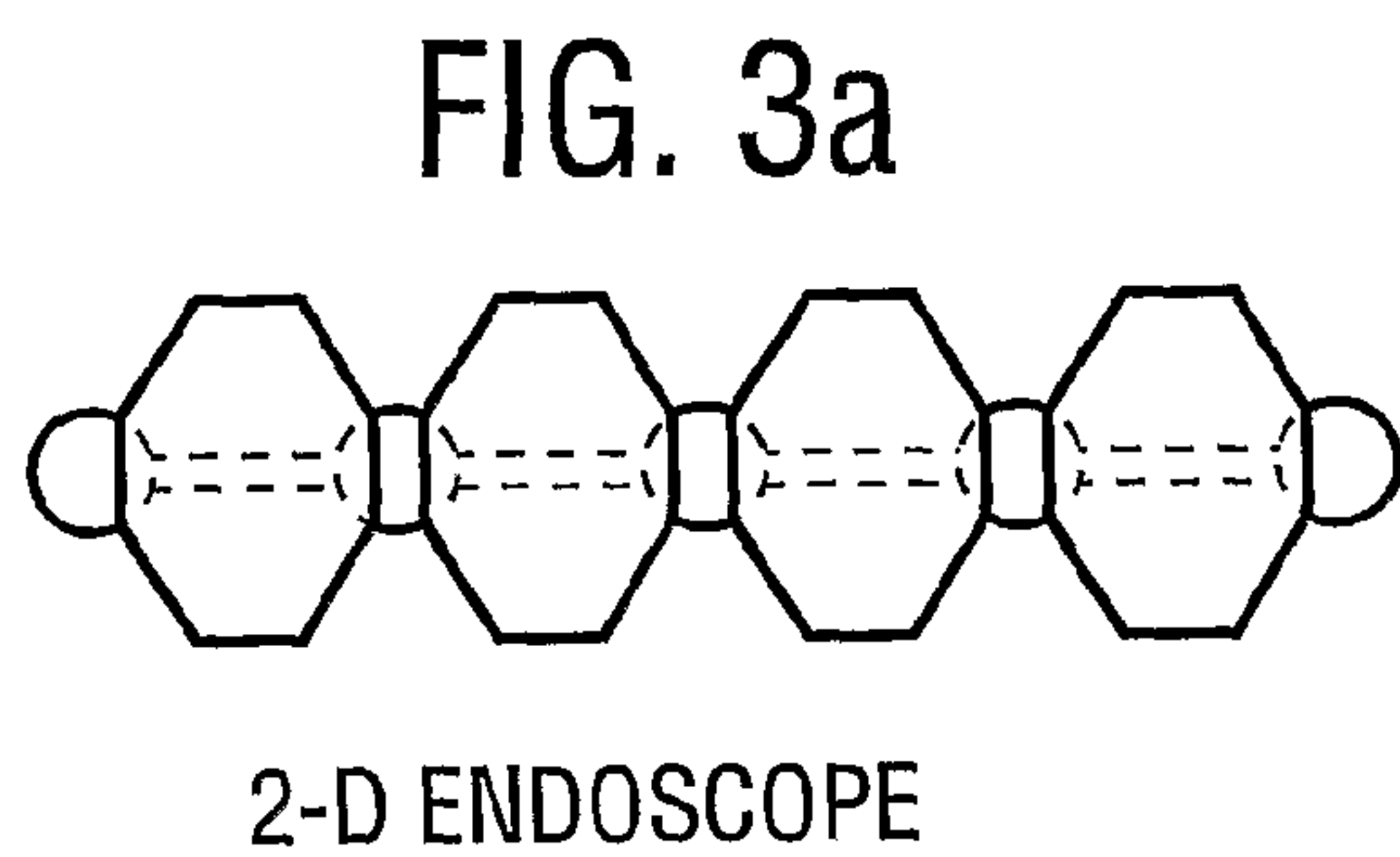
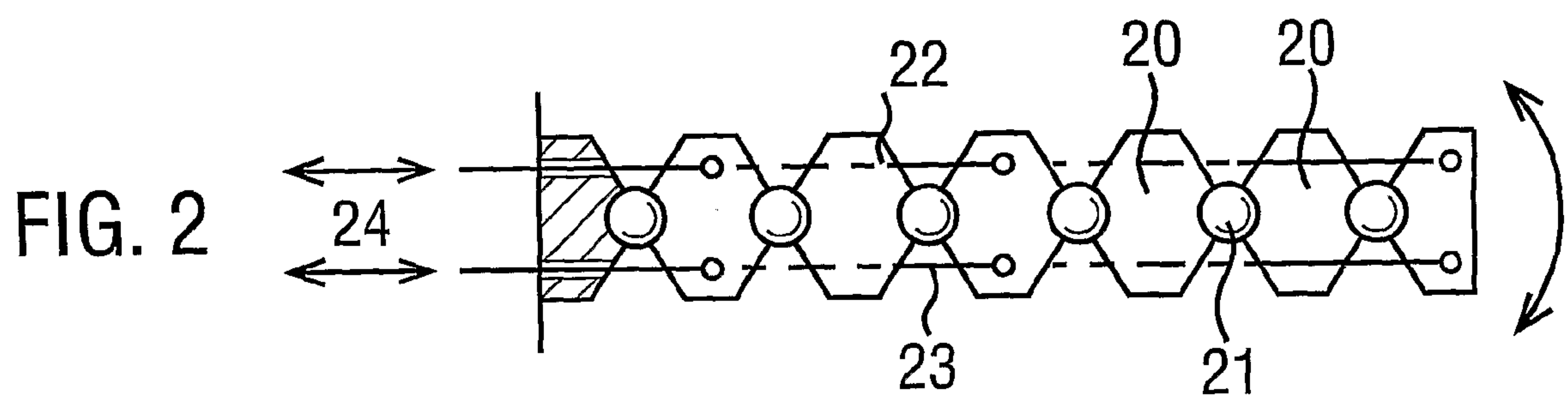
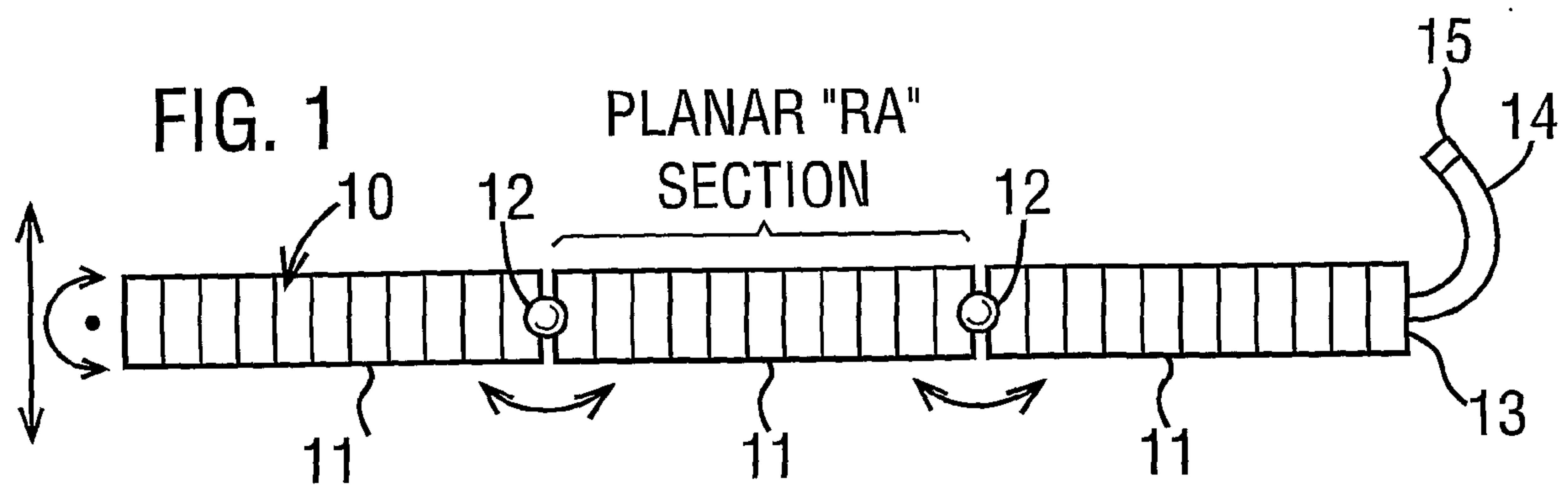
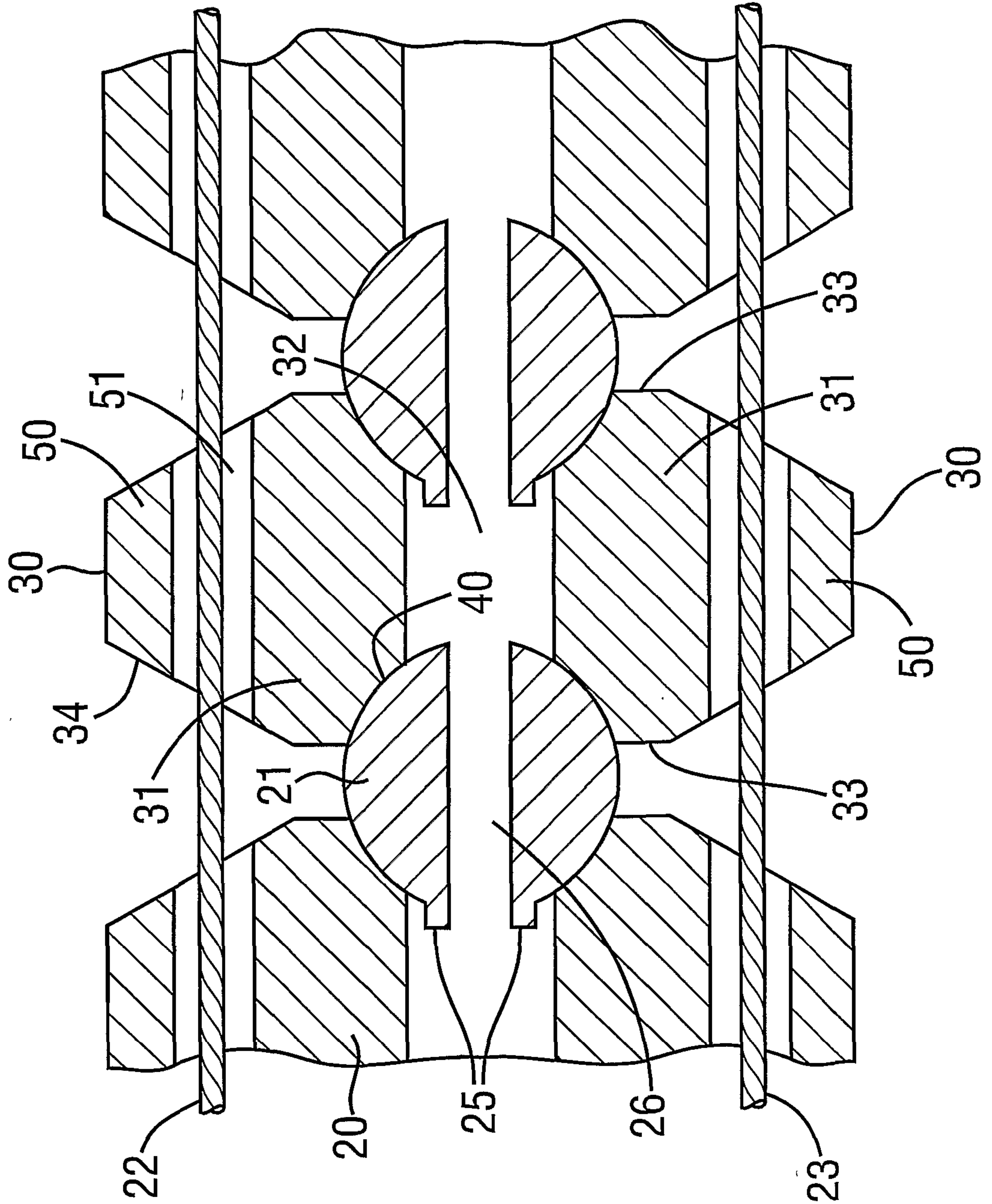


FIG. 5



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FIG. 6a

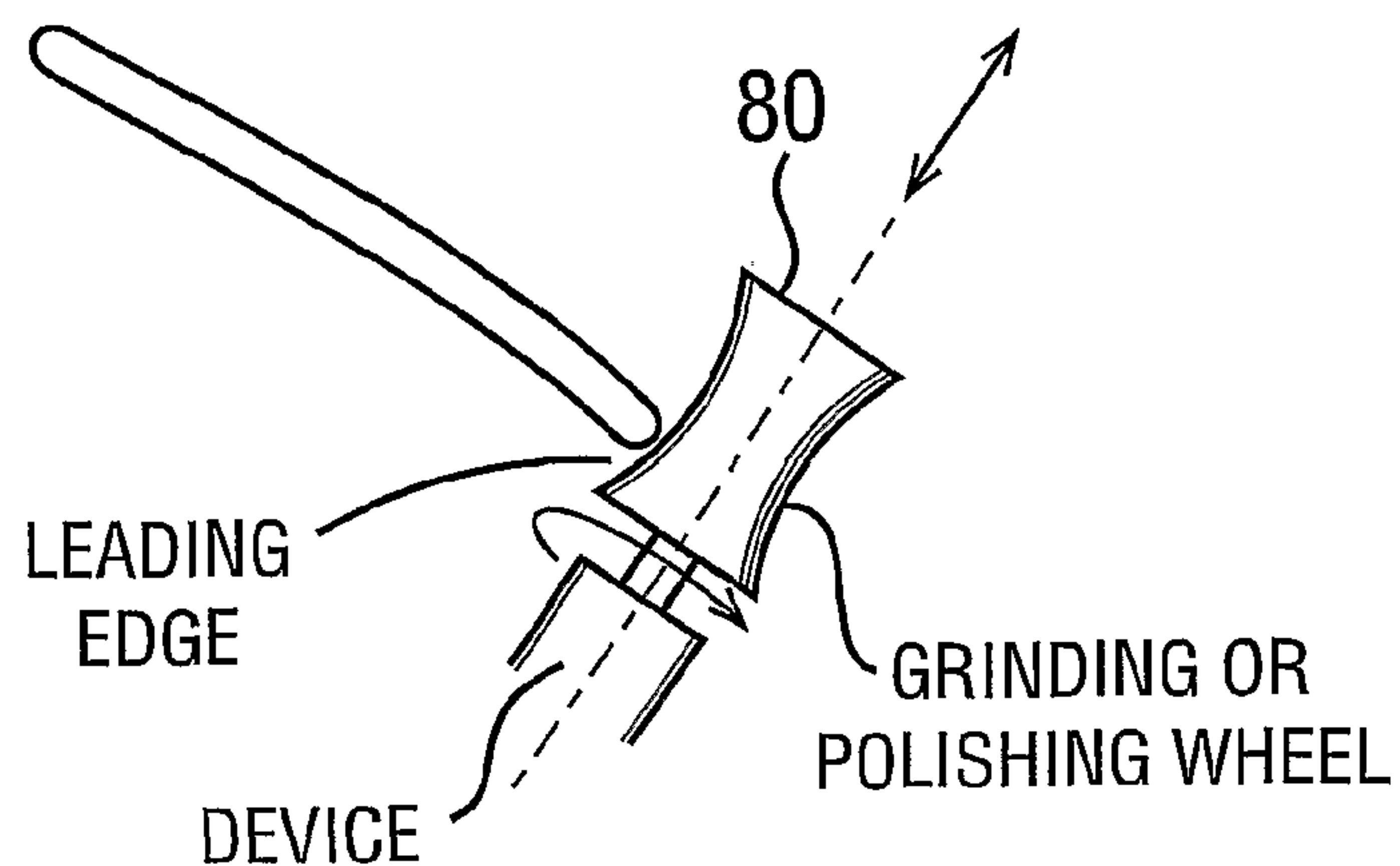


FIG. 6b

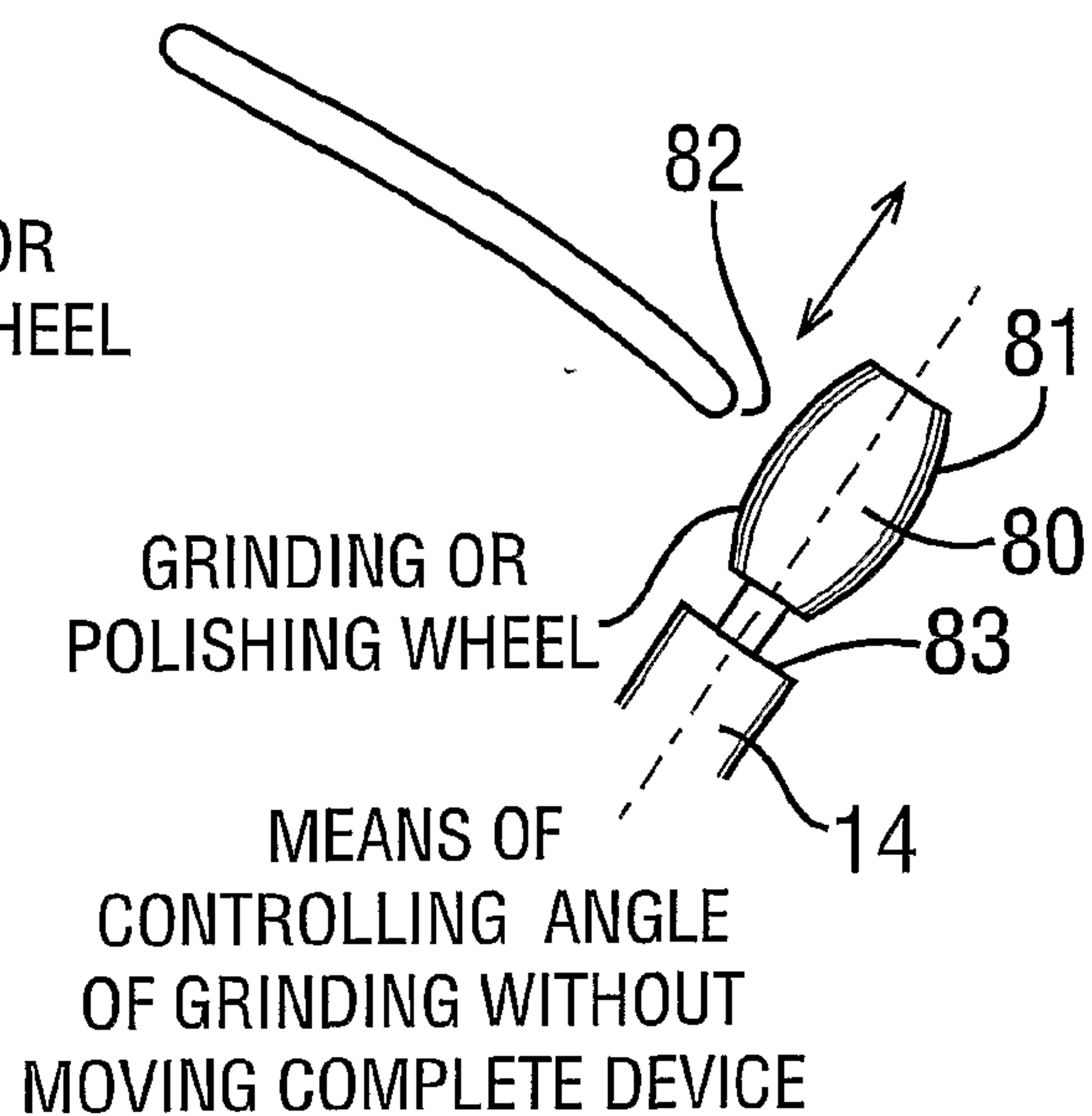


FIG. 7a

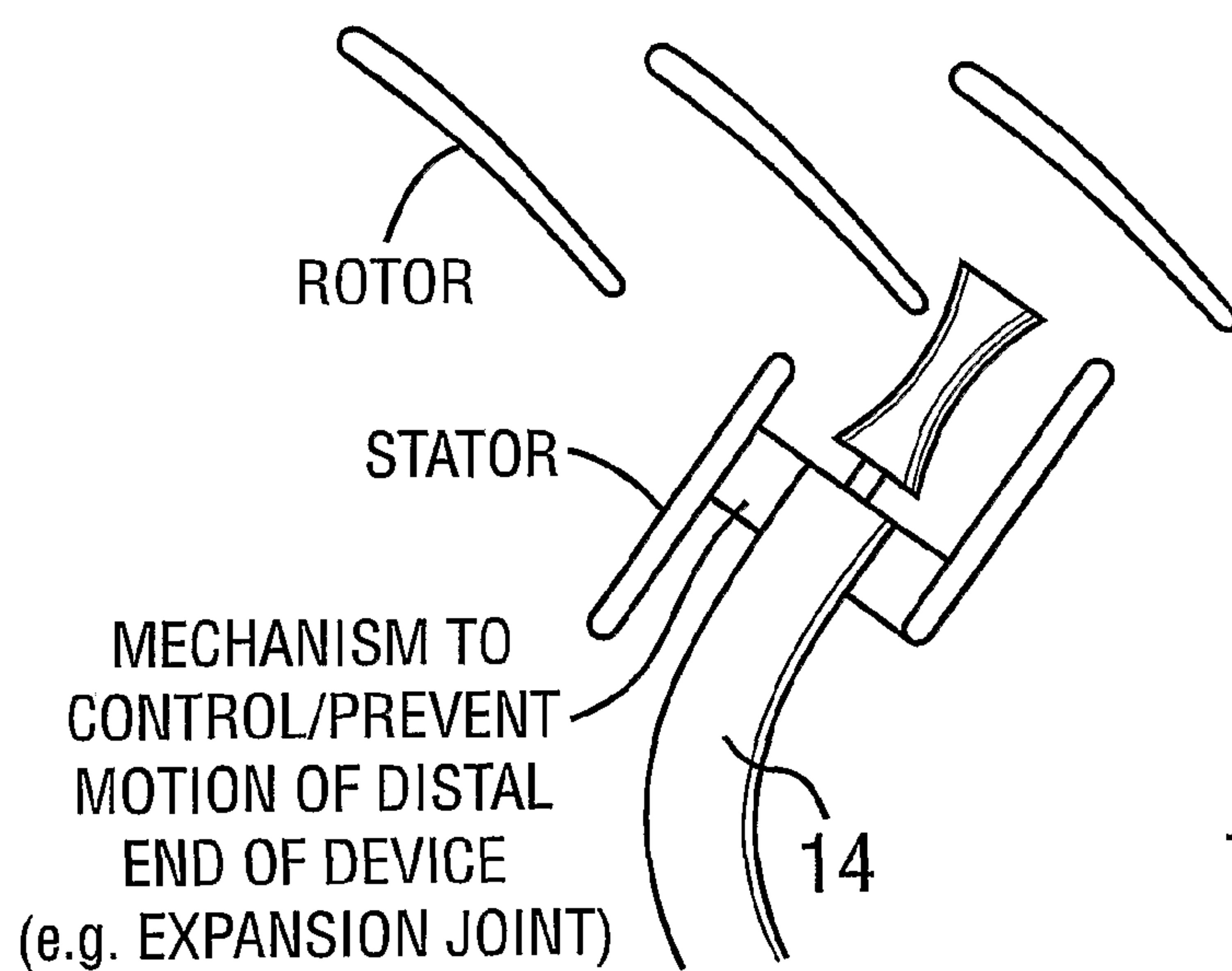
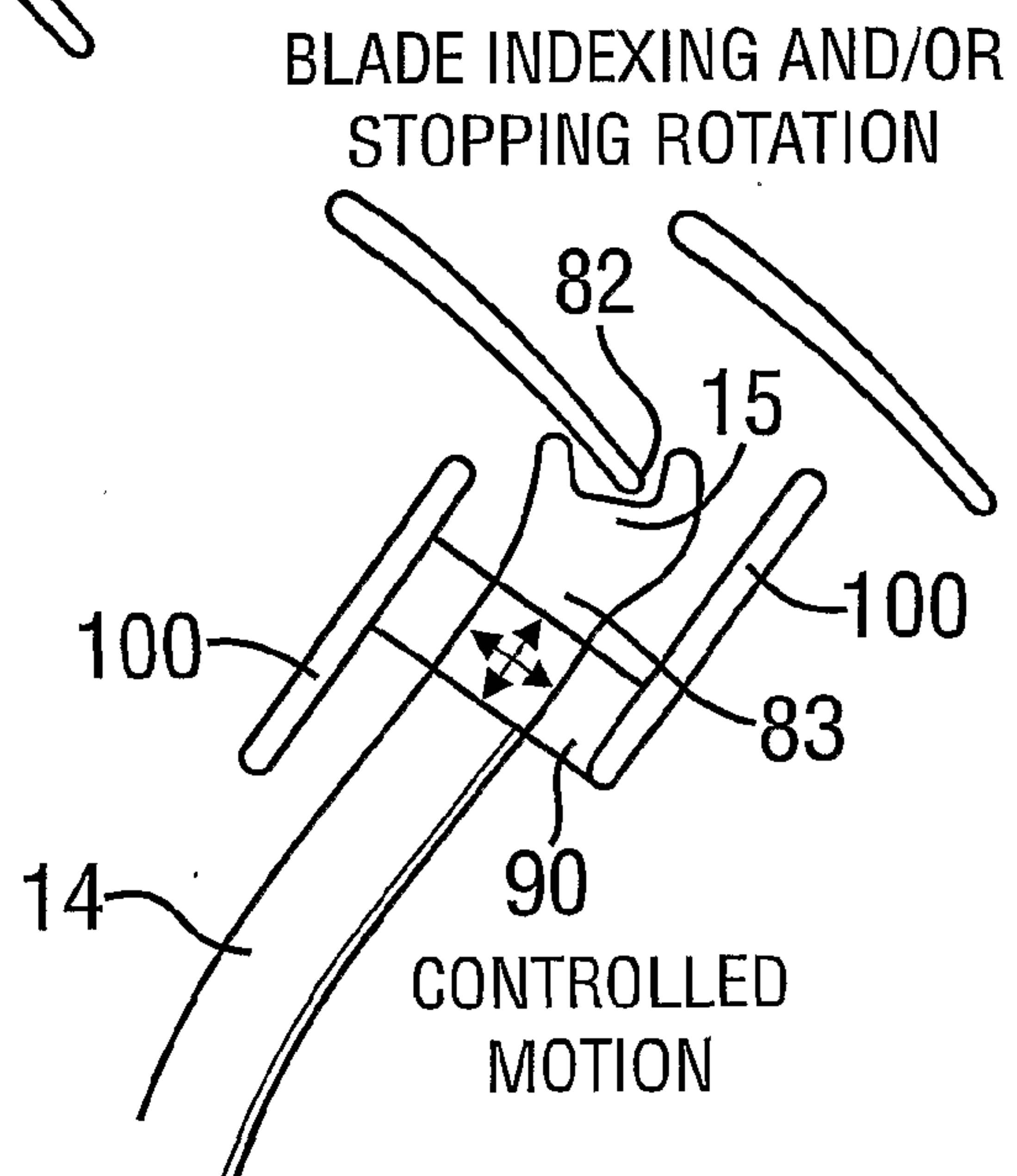
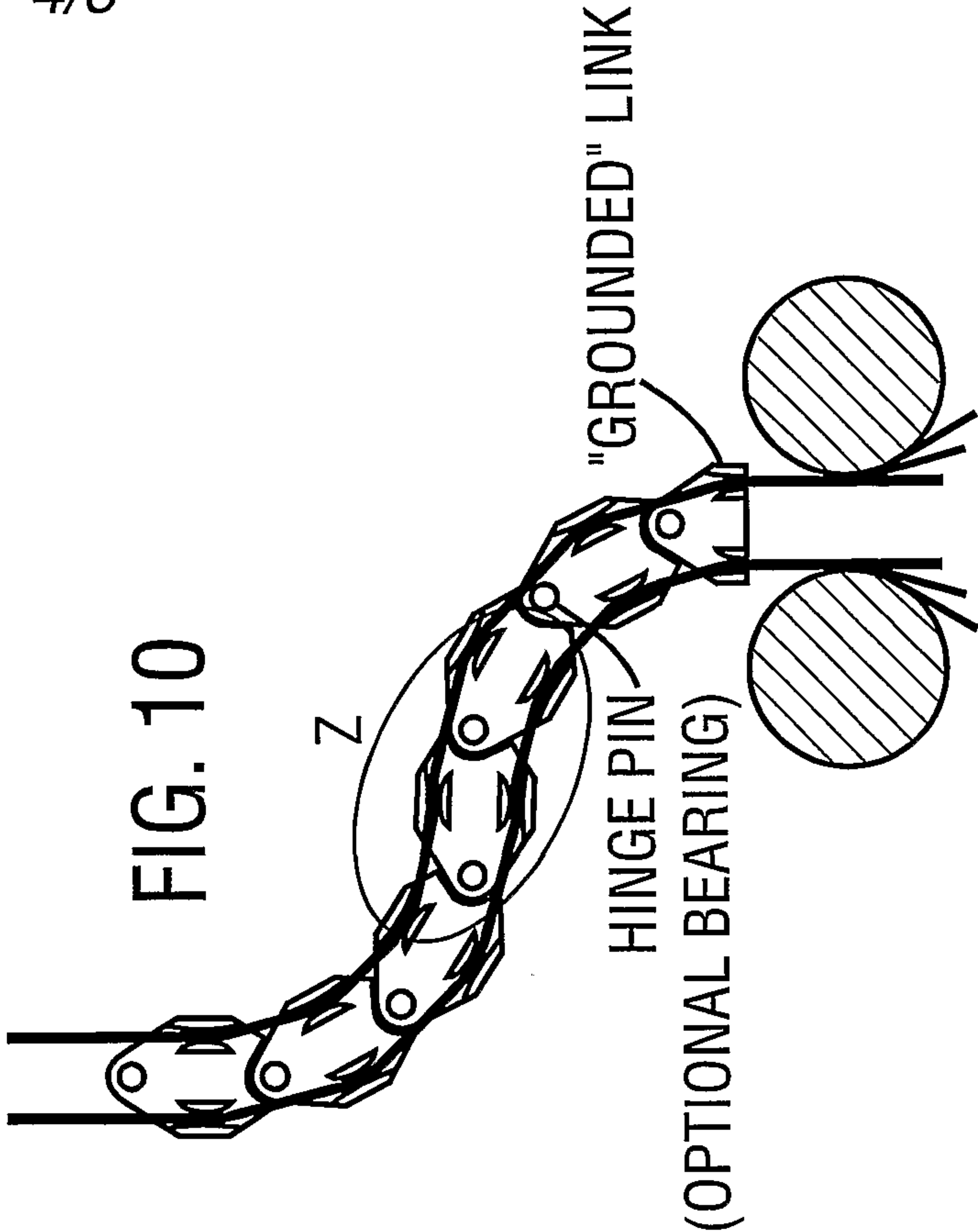
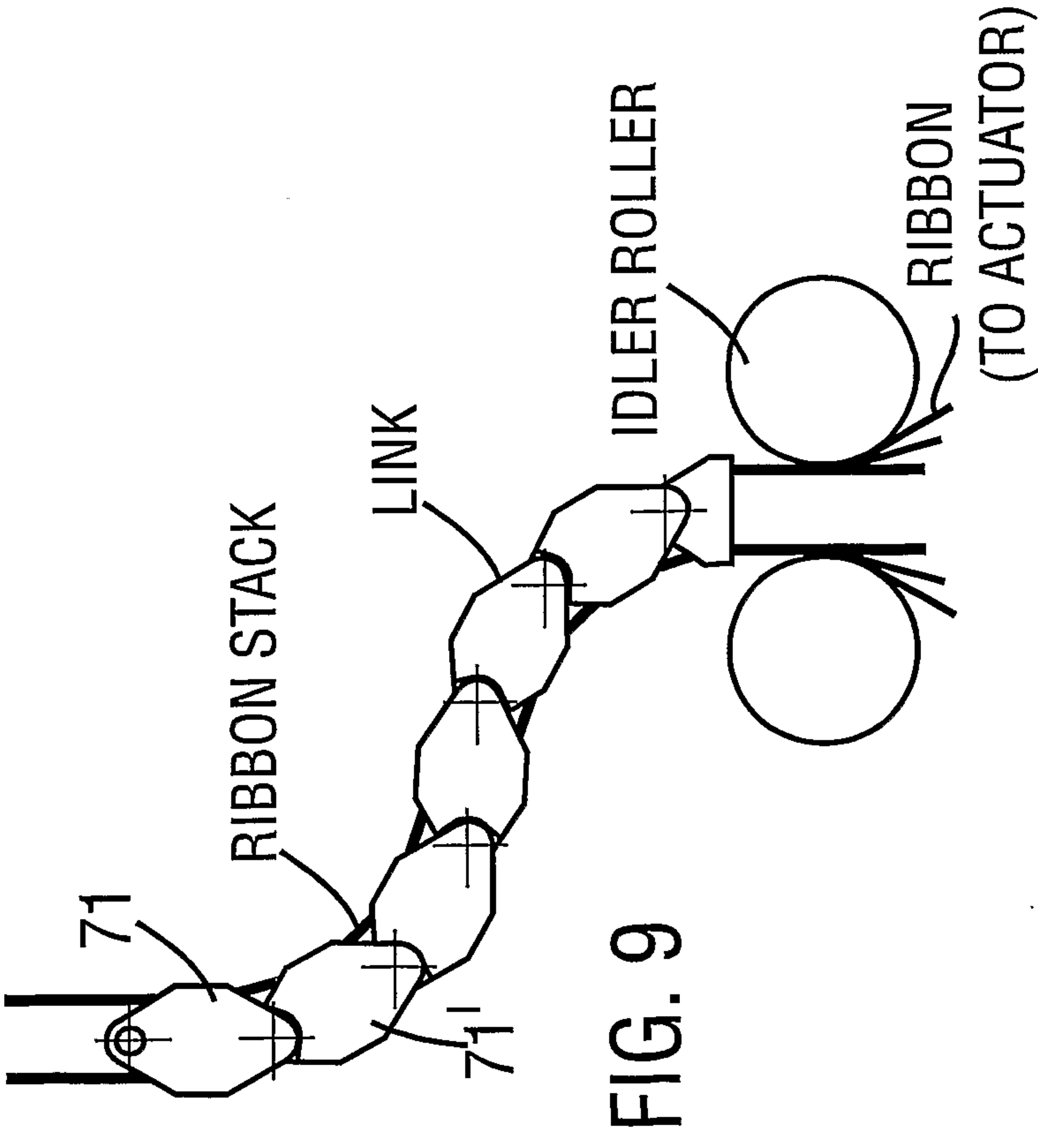
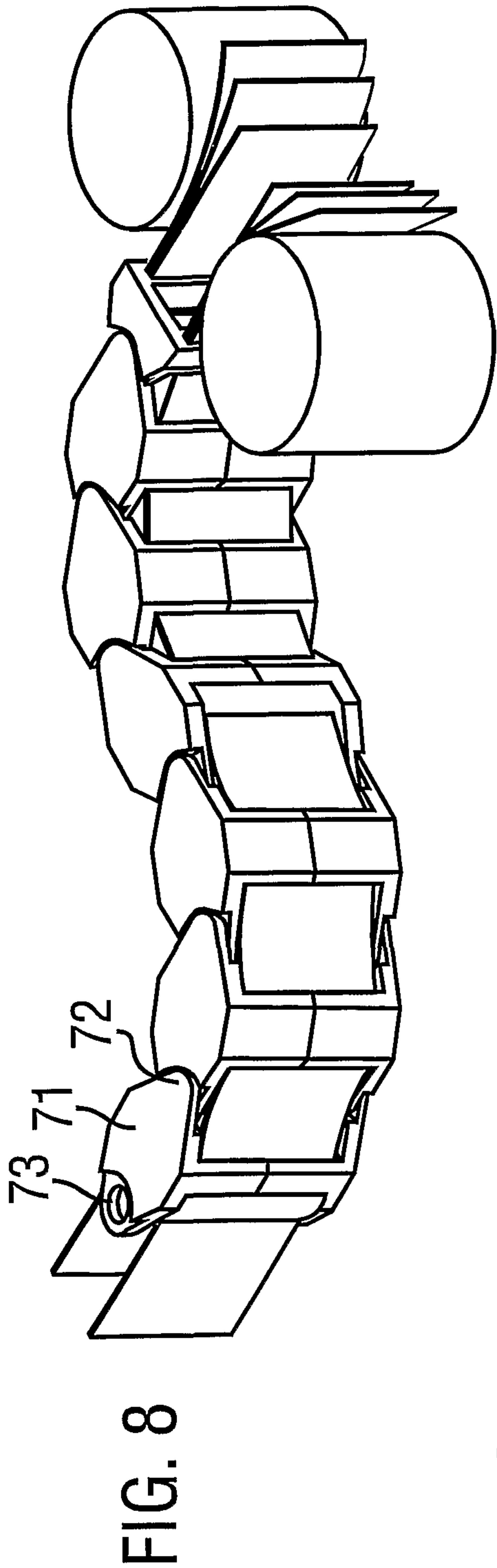


FIG. 7b





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FIG. 11

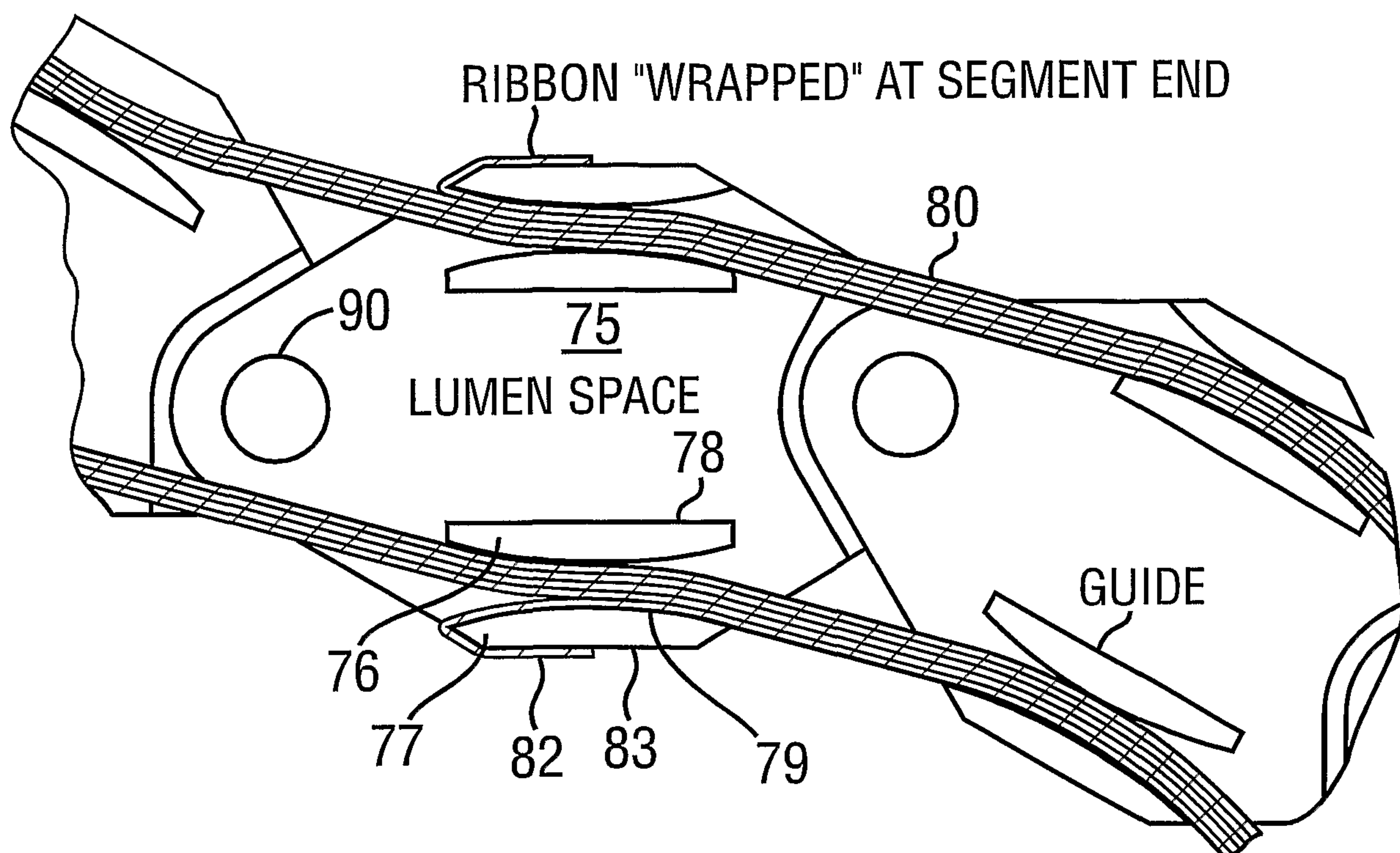
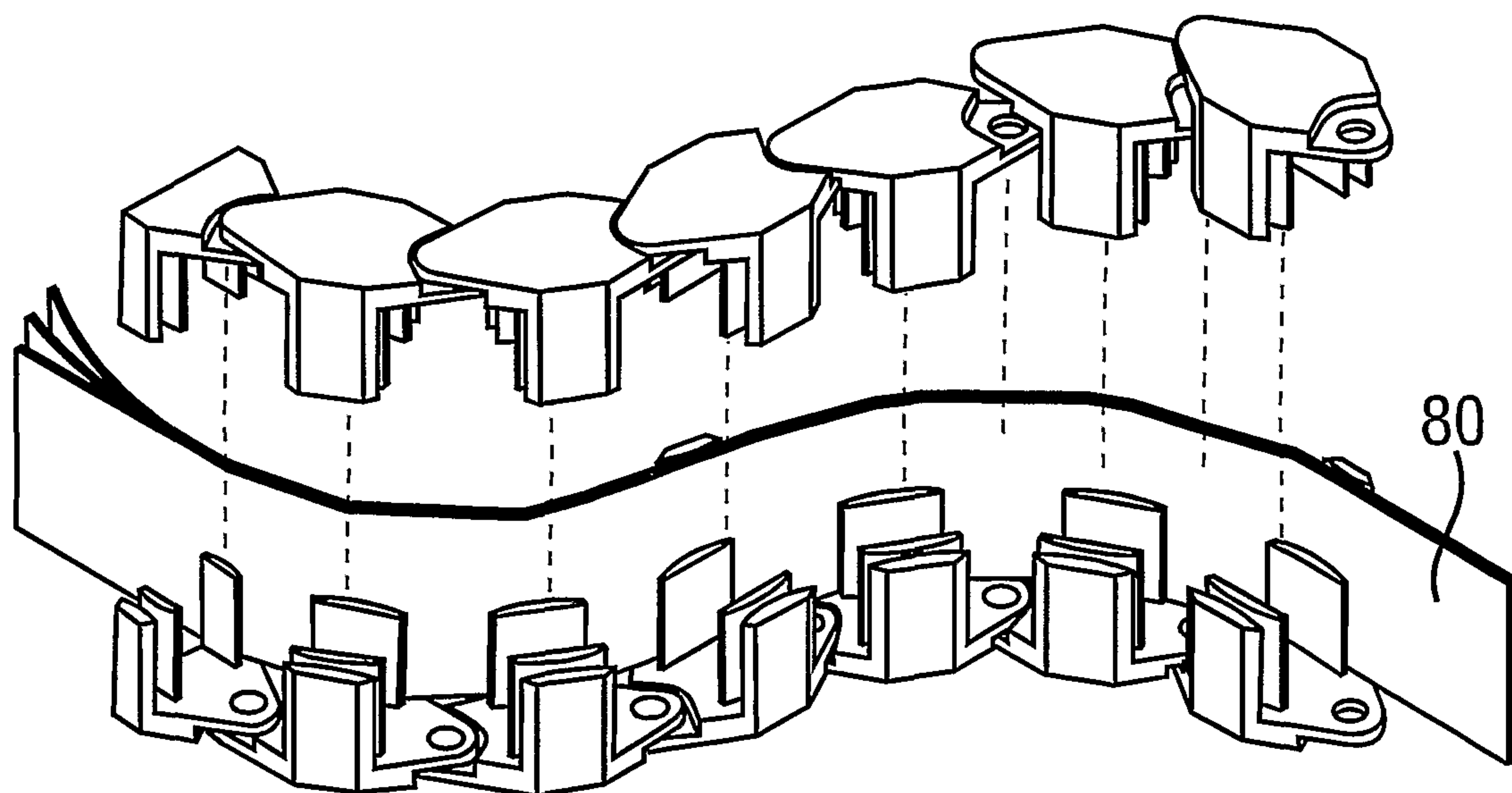


FIG. 12



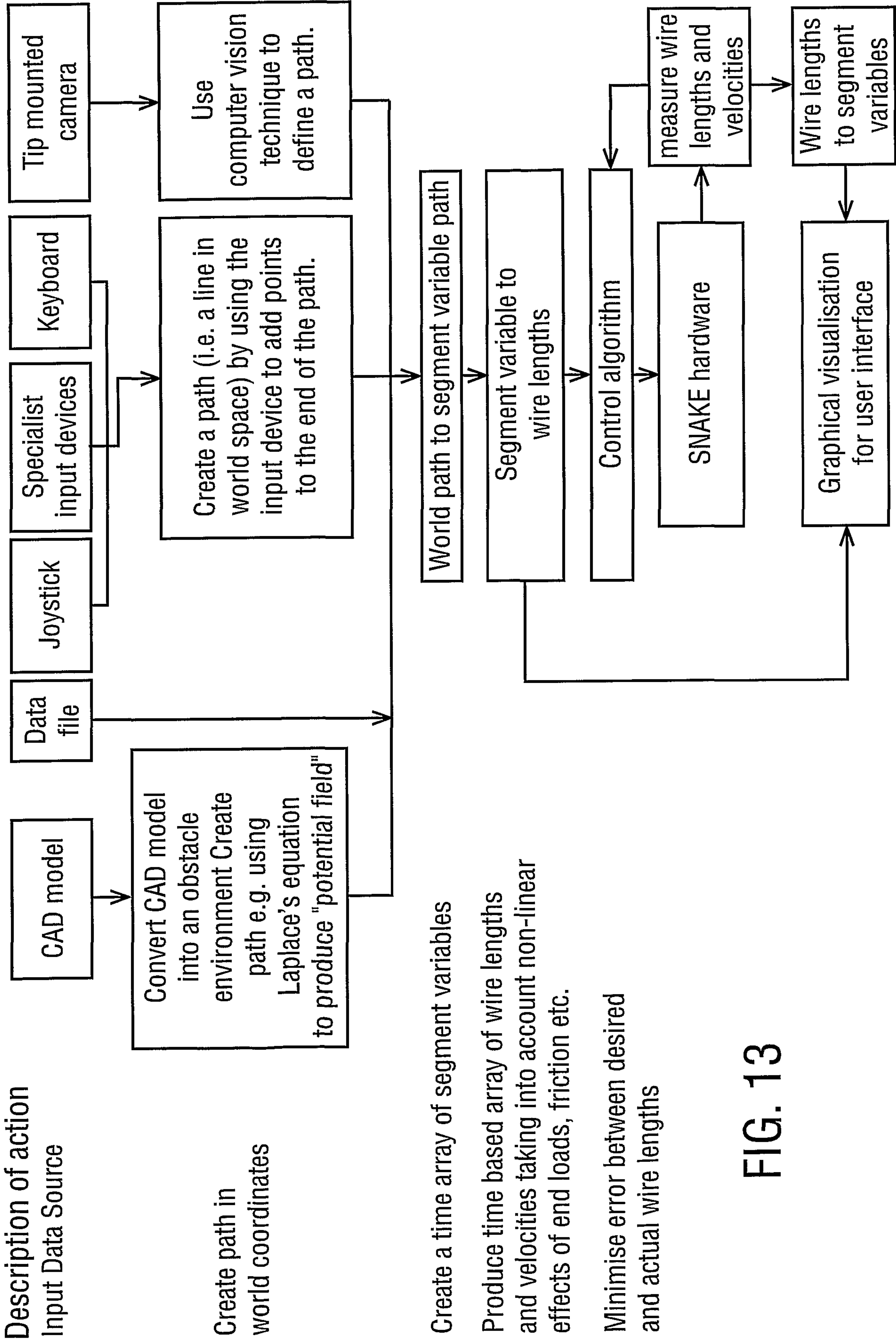


FIG. 13

