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Gregorio et al.

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(45) **Date of Patent: Jun. 6, 2006**

(54) **INTERFACE APPARATUS WITH CABLE-DRIVEN FORCE FEEDBACK AND GROUNDED ACTUATORS**

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(73) Assignee: **Immersion Corporation**, San Jose, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 206 days.

(21) Appl. No.: **10/196,563**

(22) Filed: **Jul. 15, 2002**

(65) **Prior Publication Data**

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Related U.S. Application Data

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(51) **Int. Cl.**
G09B 23/28 (2006.01)

(52) **U.S. Cl.** **434/272**; 434/262

(58) **Field of Classification Search** 434/262, 434/265, 267, 270, 271, 272, 273, 274, 275
See application file for complete search history.

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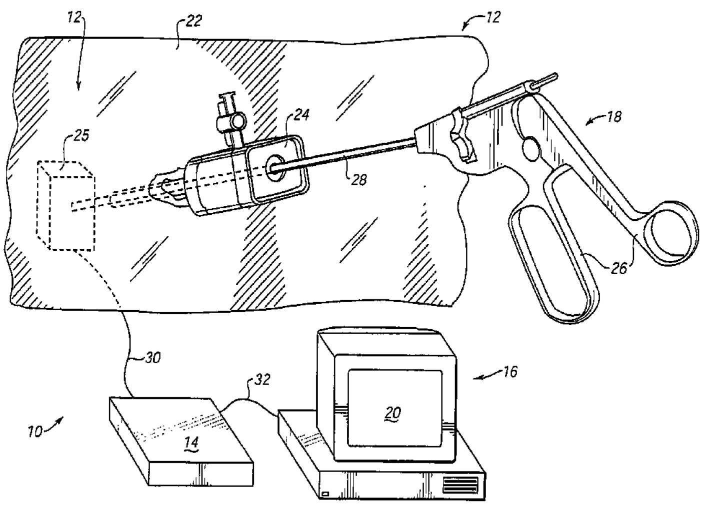
(57) **ABSTRACT**

A system for providing realistic sensation within a simulation system by providing tactile (haptic) feedback to a user. The system includes an engageable practice tool that the user engages and a mechanical simulation apparatus coupled to the practice tool. The mechanical simulation apparatus includes a ground member, a mechanical linkage rotatably coupled to the ground member, a linear axis member coupled to the practice tool and the mechanical linkage, at least four actuators coupled to the ground member, sensors for sensing movement of the actuators, and at least three cables in contact with the at least four actuators and coupled to the mechanical linkage. An interface device is coupled to the simulation apparatus and a host computer is coupled to the interface device for implementing an application program. The application program provides signals for the actuators to move the cables and thereby move the mechanical linkage.

23 Claims, 22 Drawing Sheets



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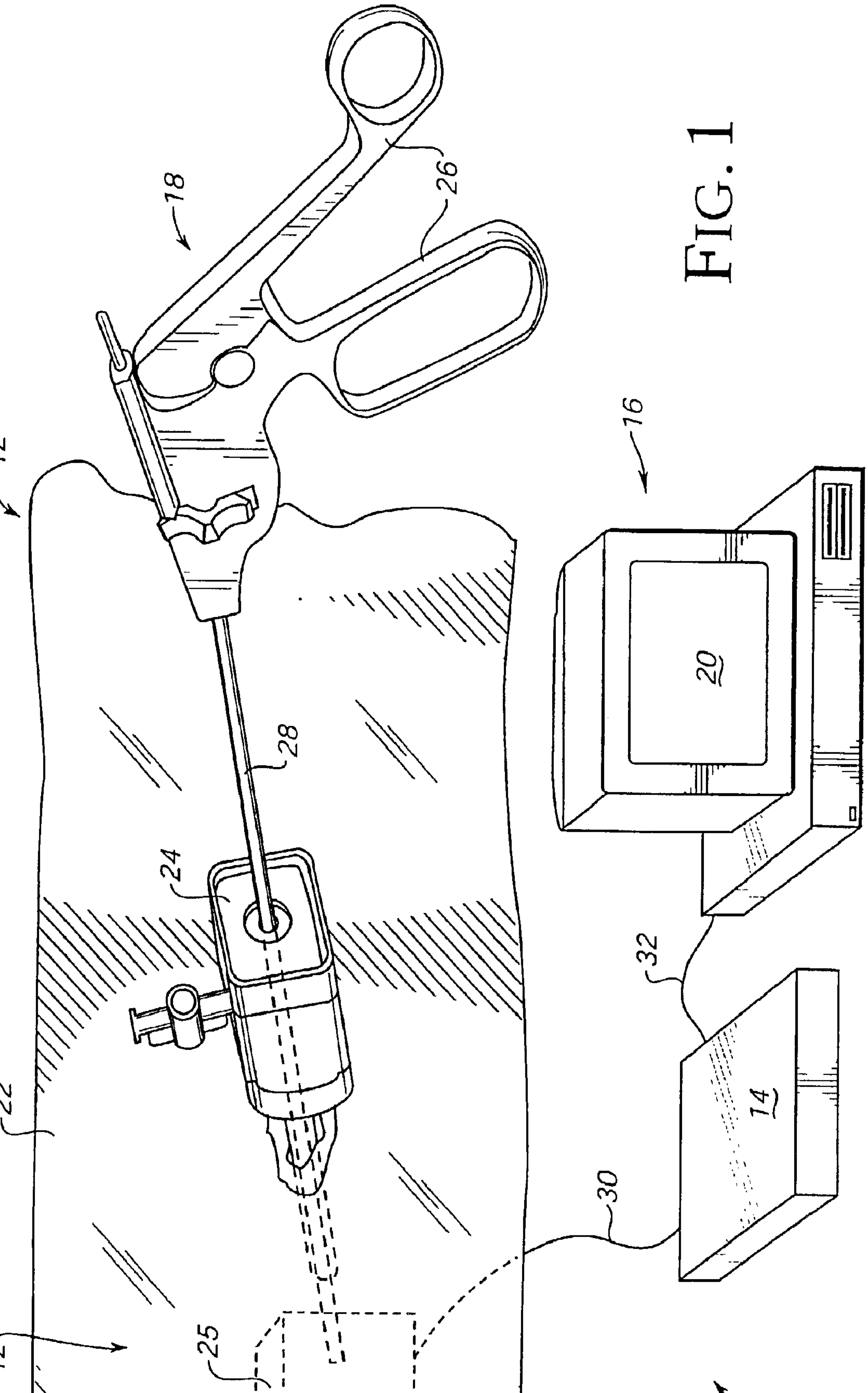


FIG. 1

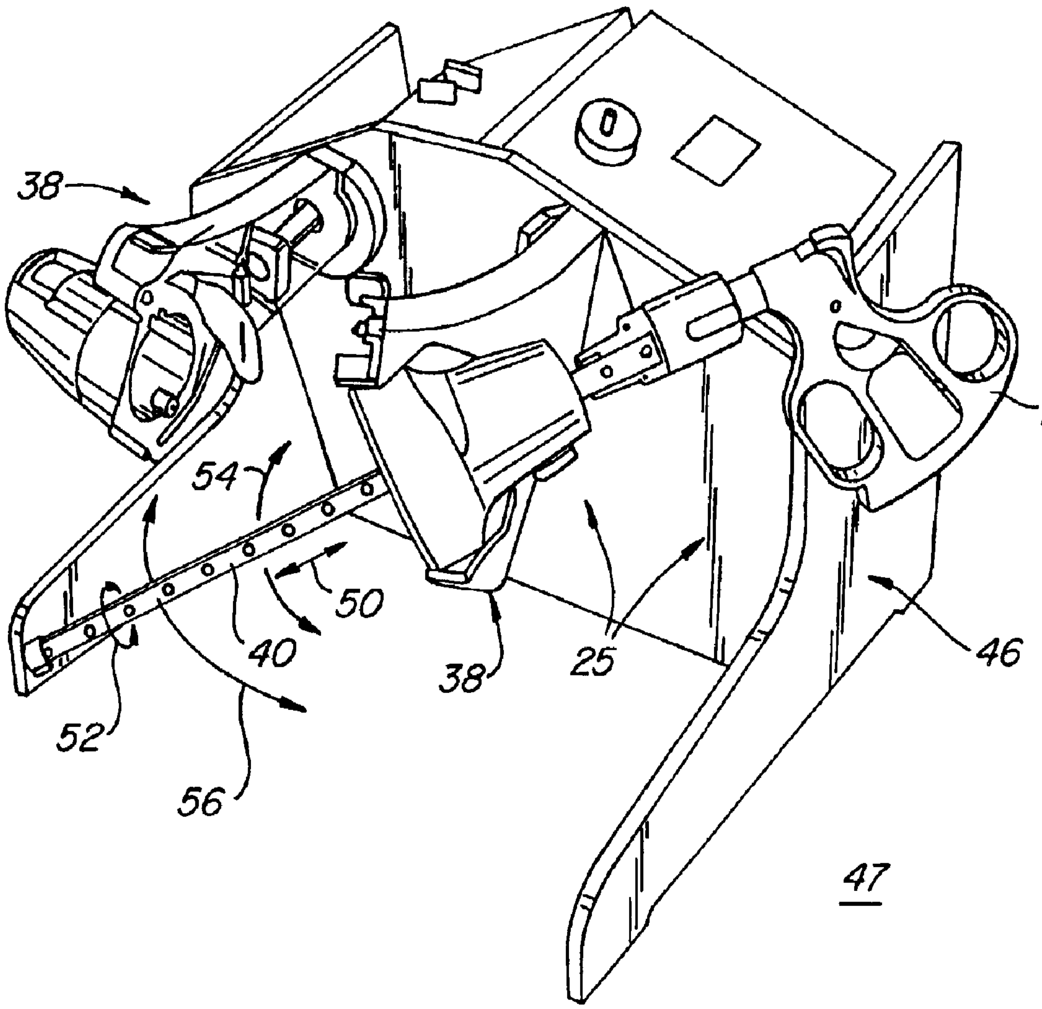


FIG. 2A.

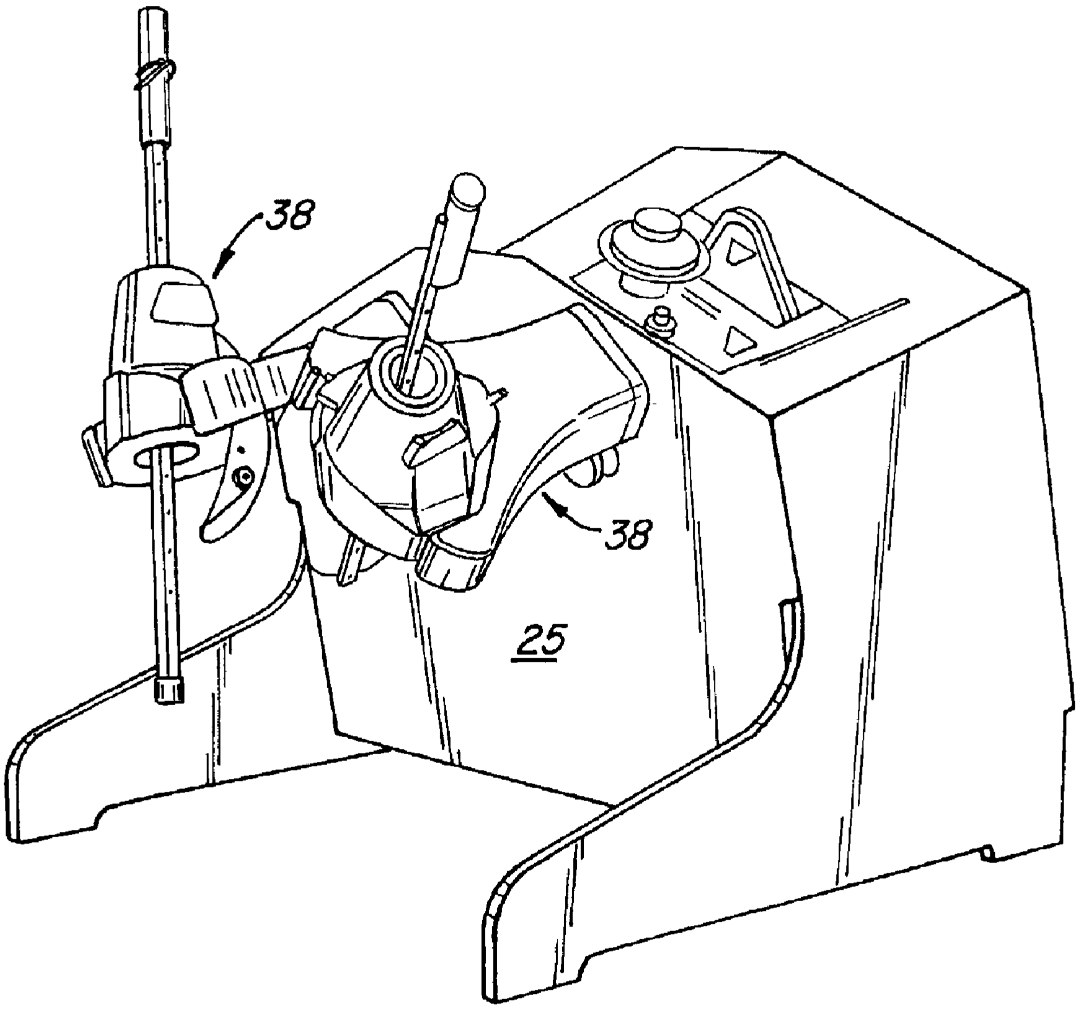
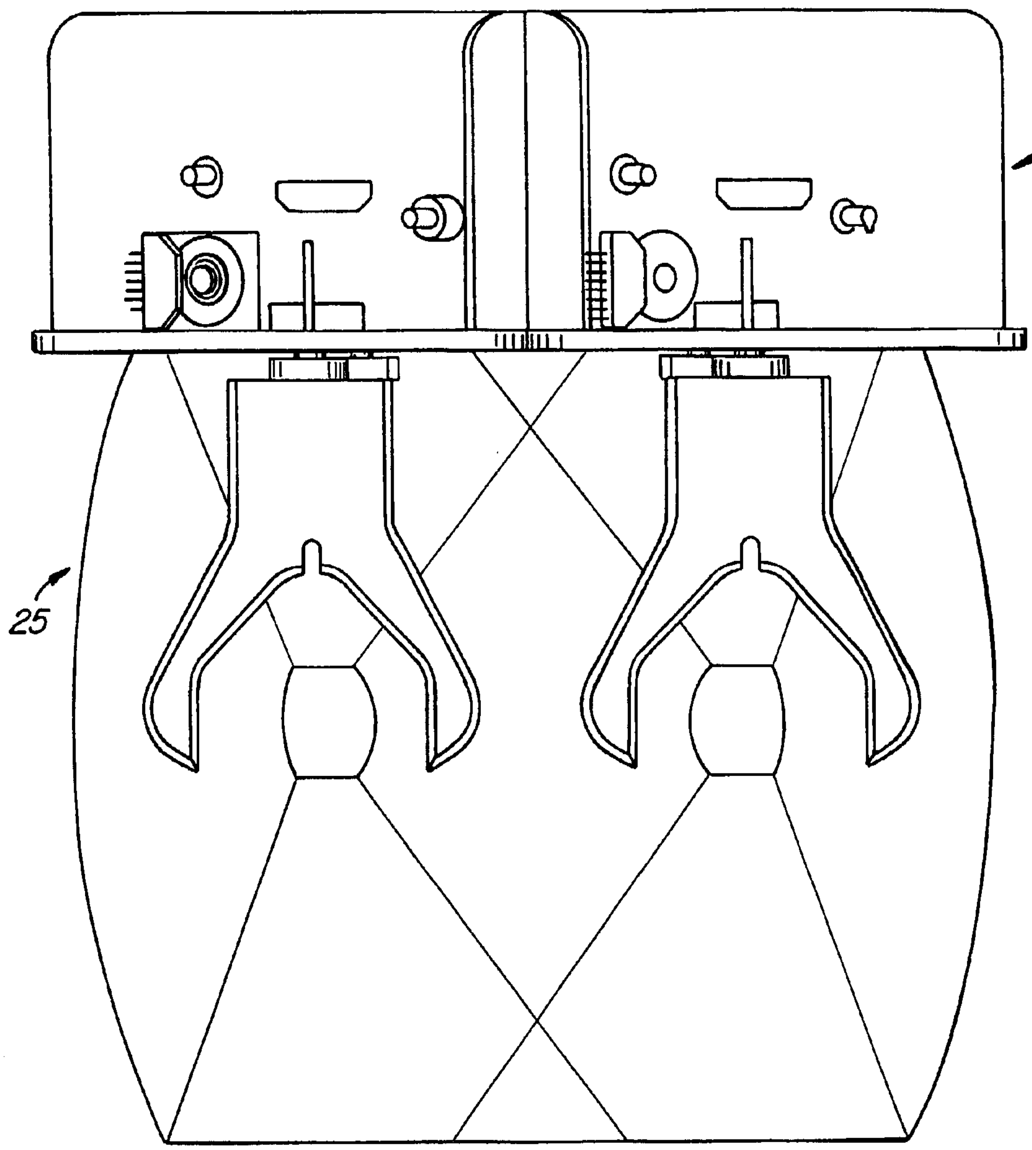


FIG. 2B.



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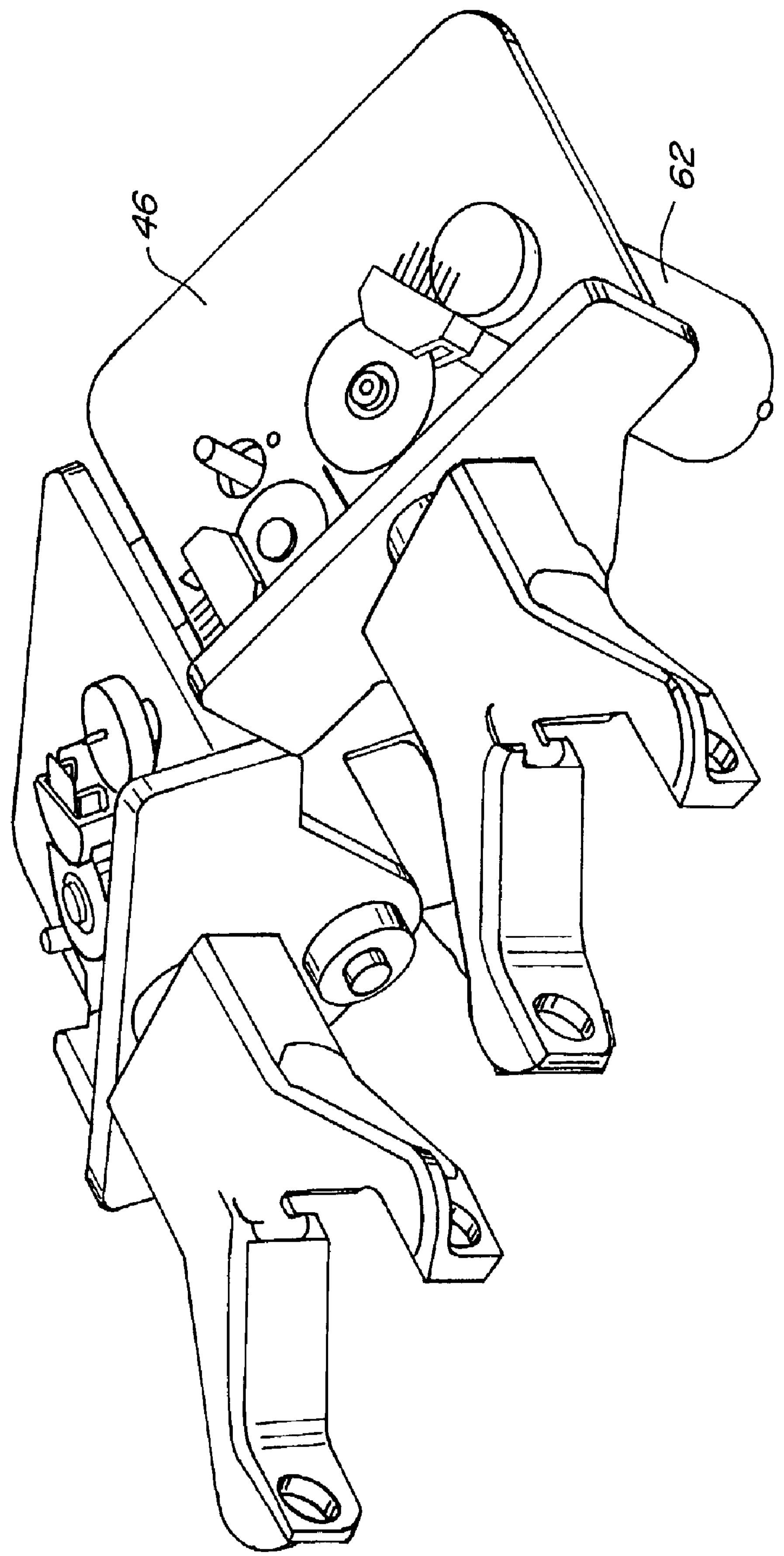


FIG. 2D.

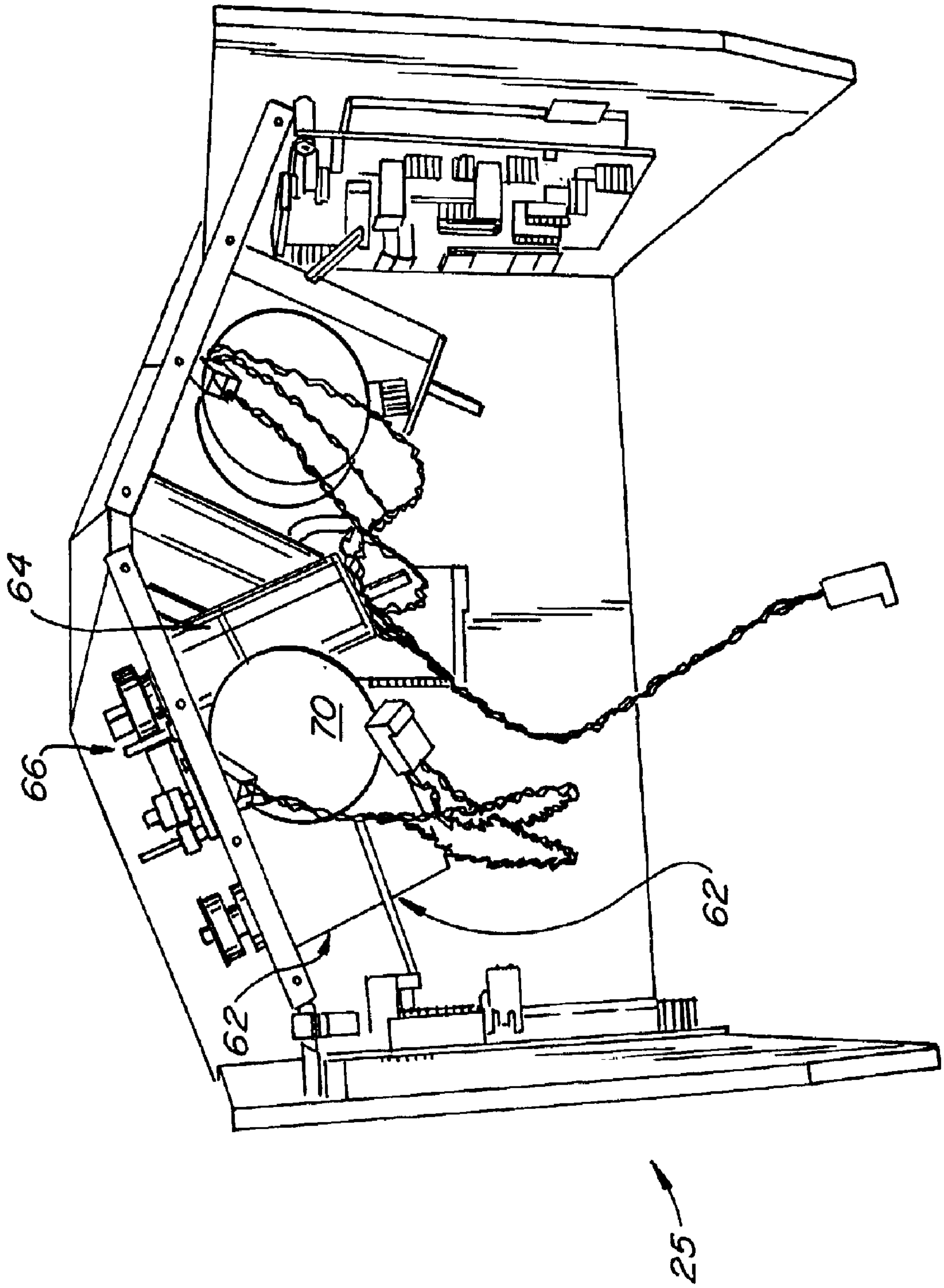
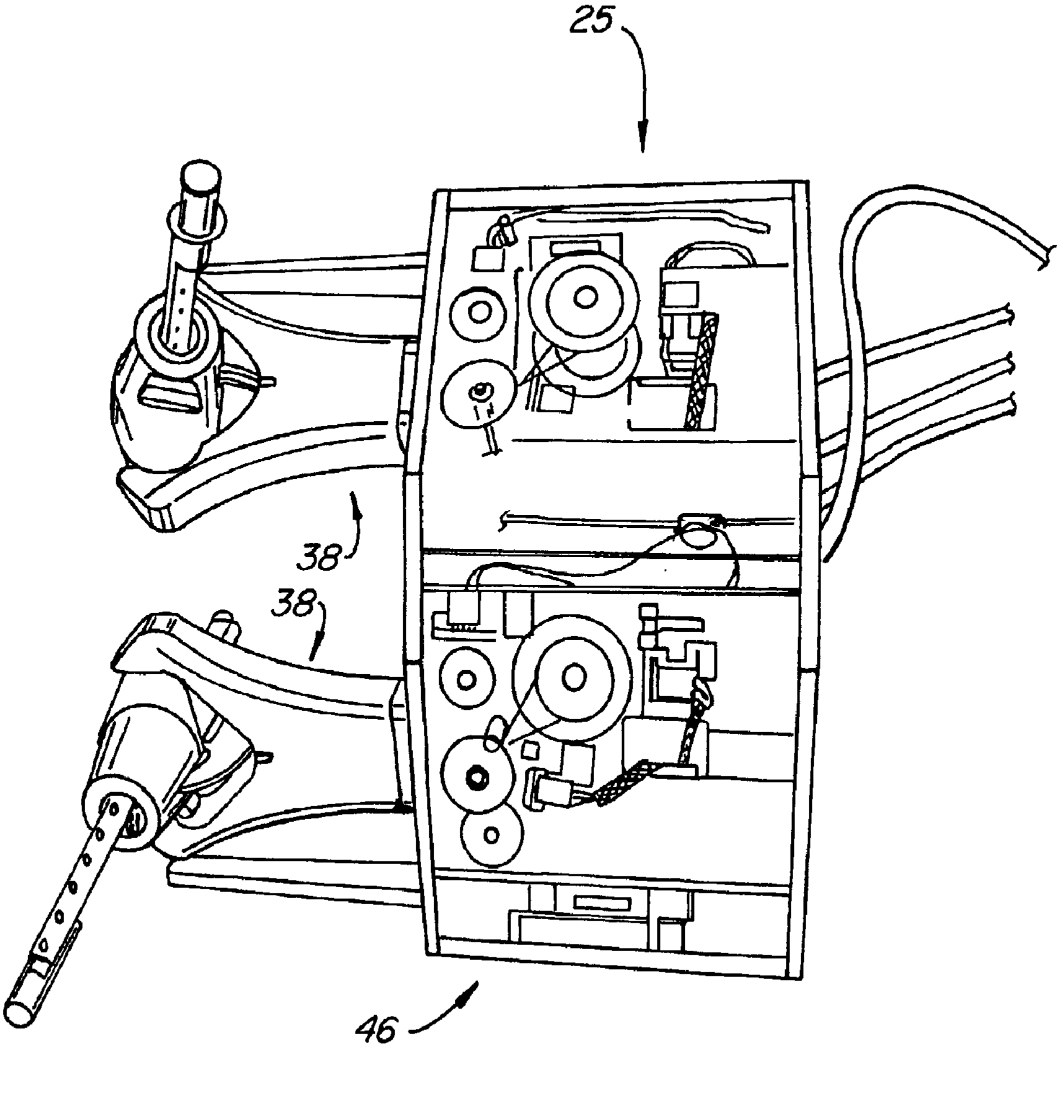


FIG. 2E.



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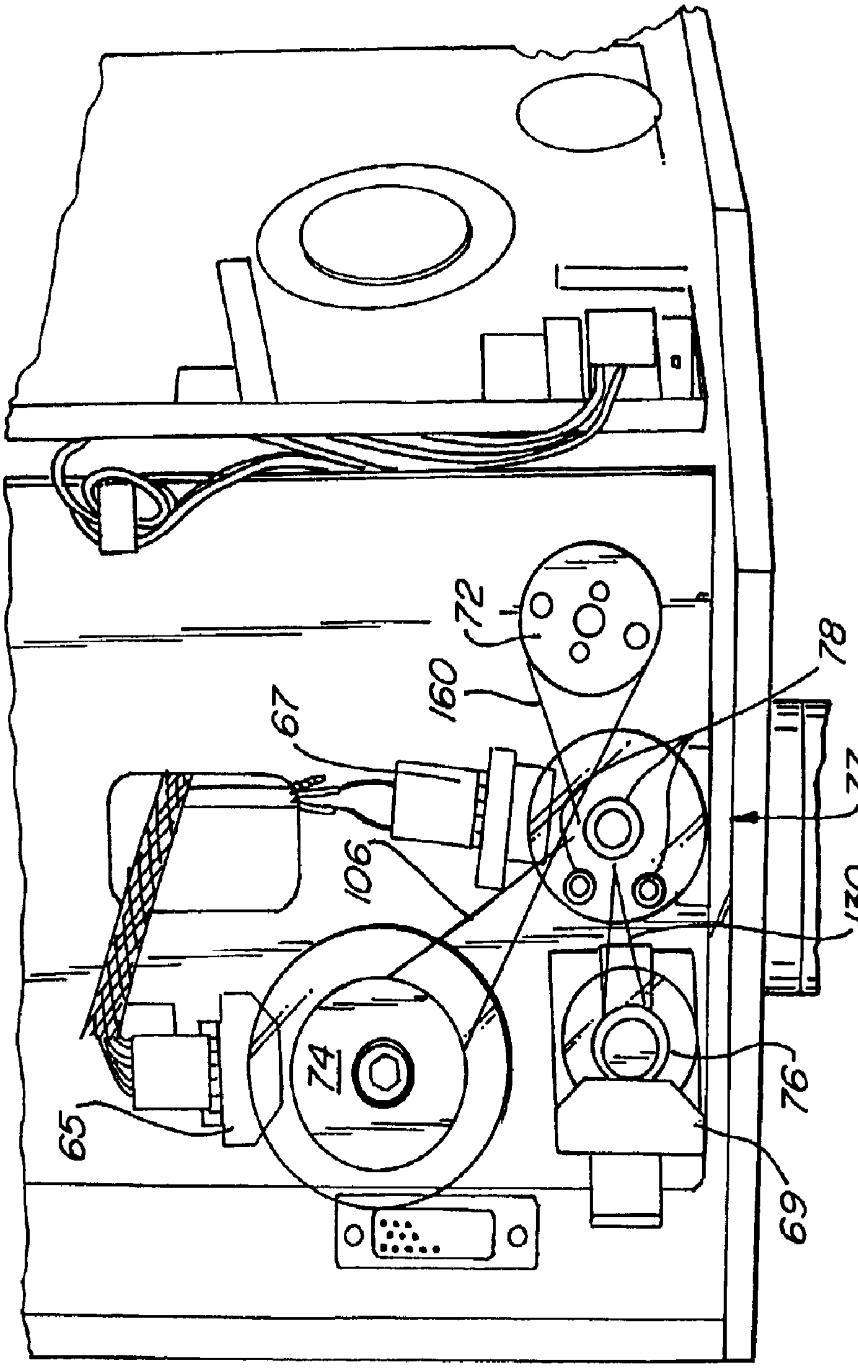

FIG. 2G

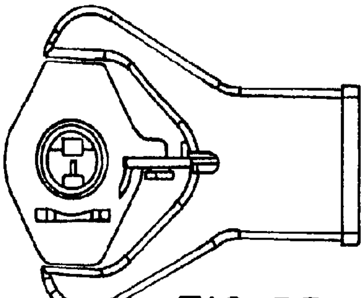

FIG. 3B.

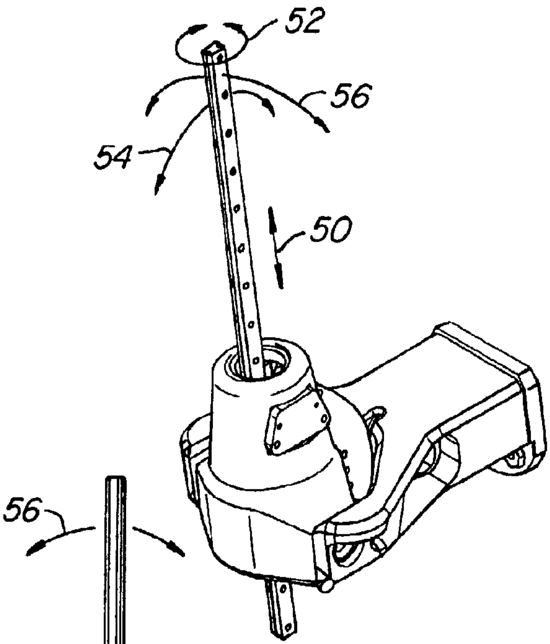

FIG. 3A.

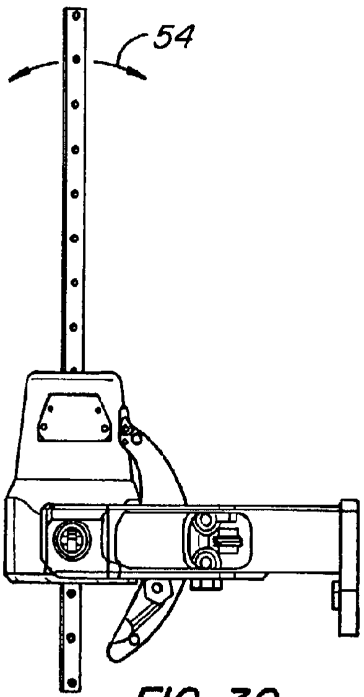

FIG. 3C.

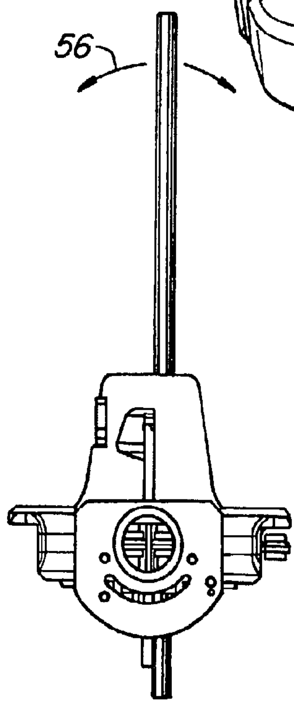

FIG. 3D.

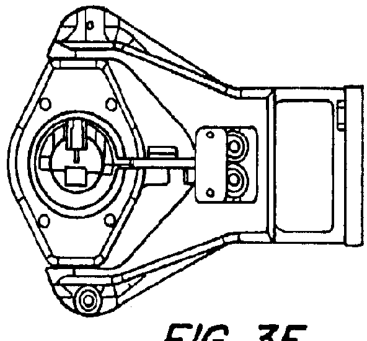

FIG. 3E.

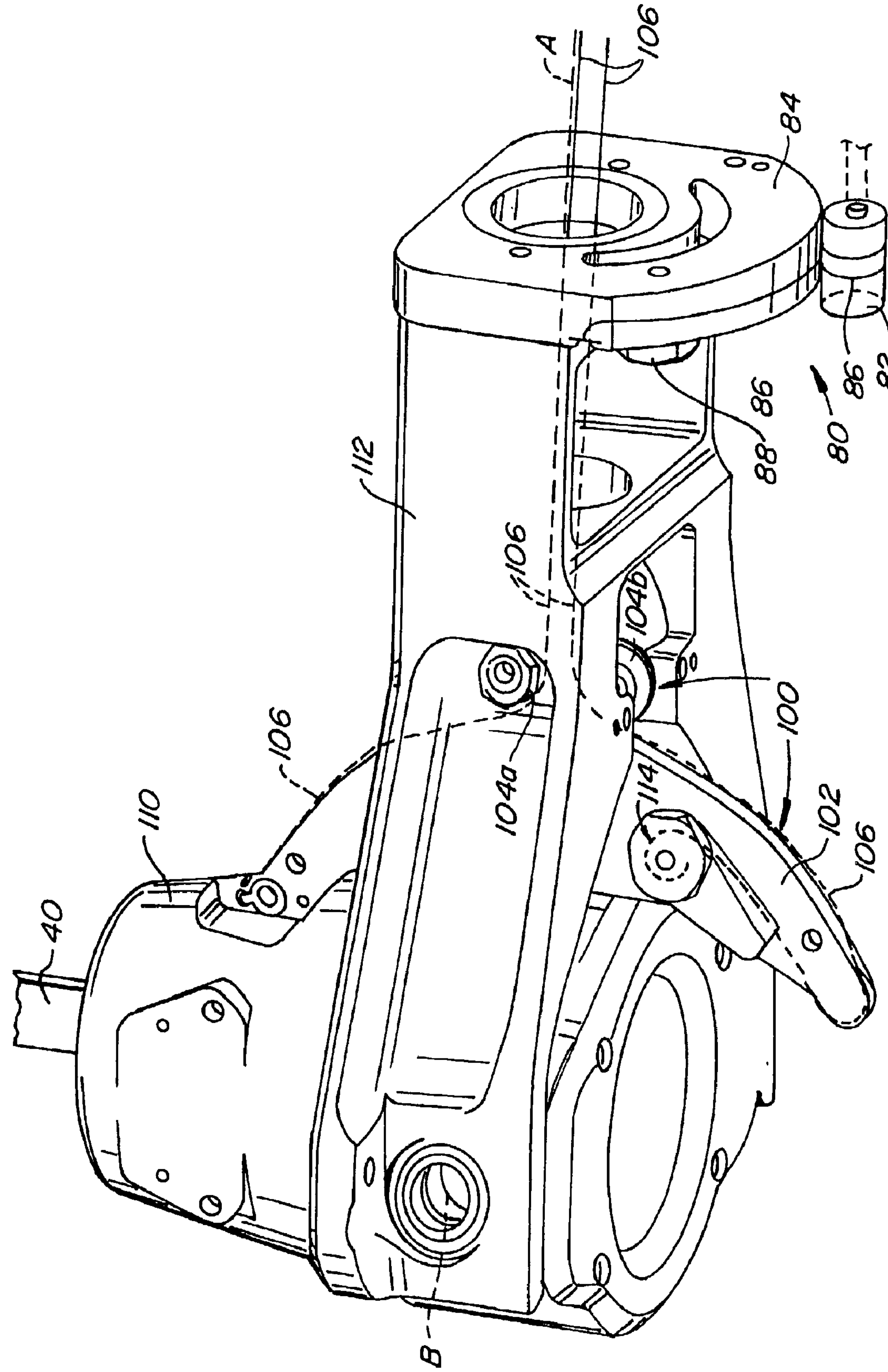

FIG. 4A.

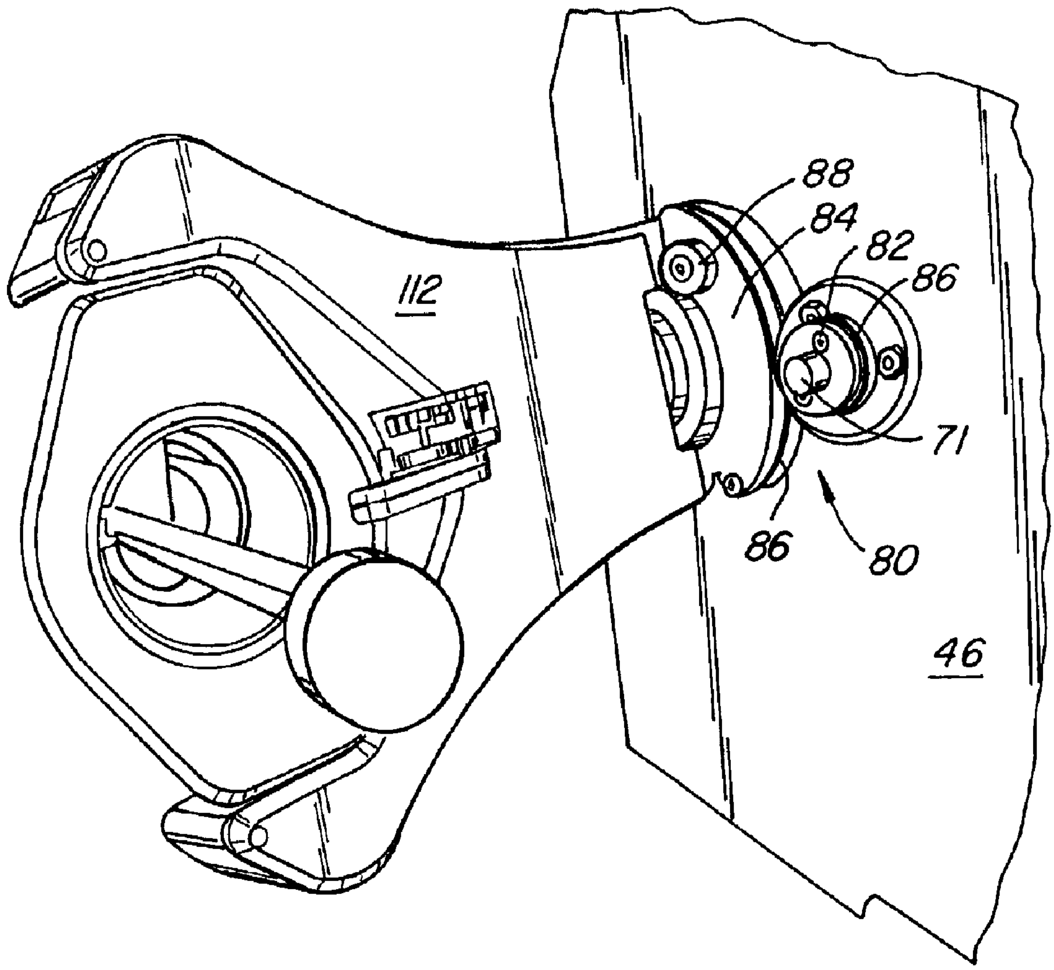

FIG. 4B.

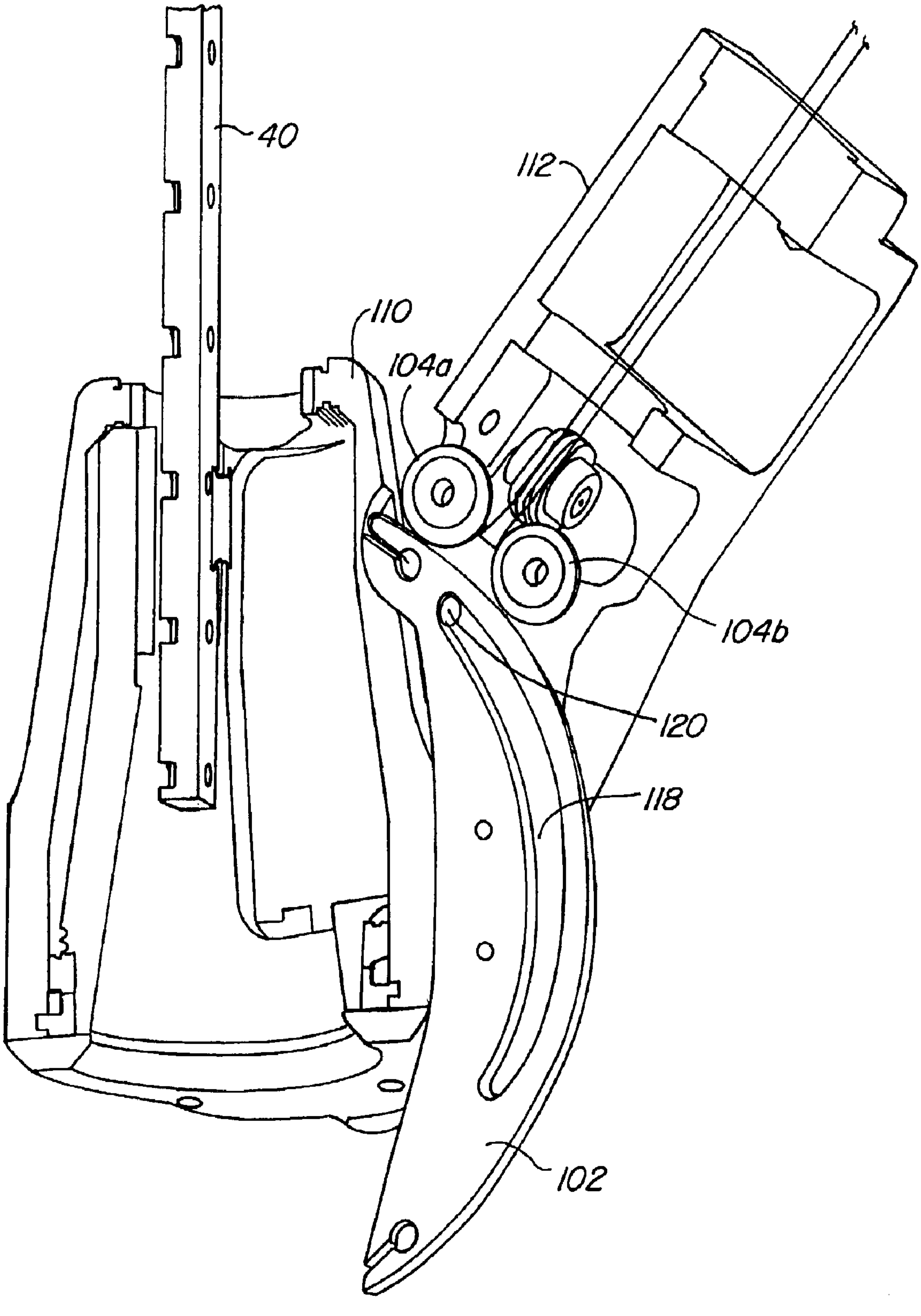

FIG. 5A.

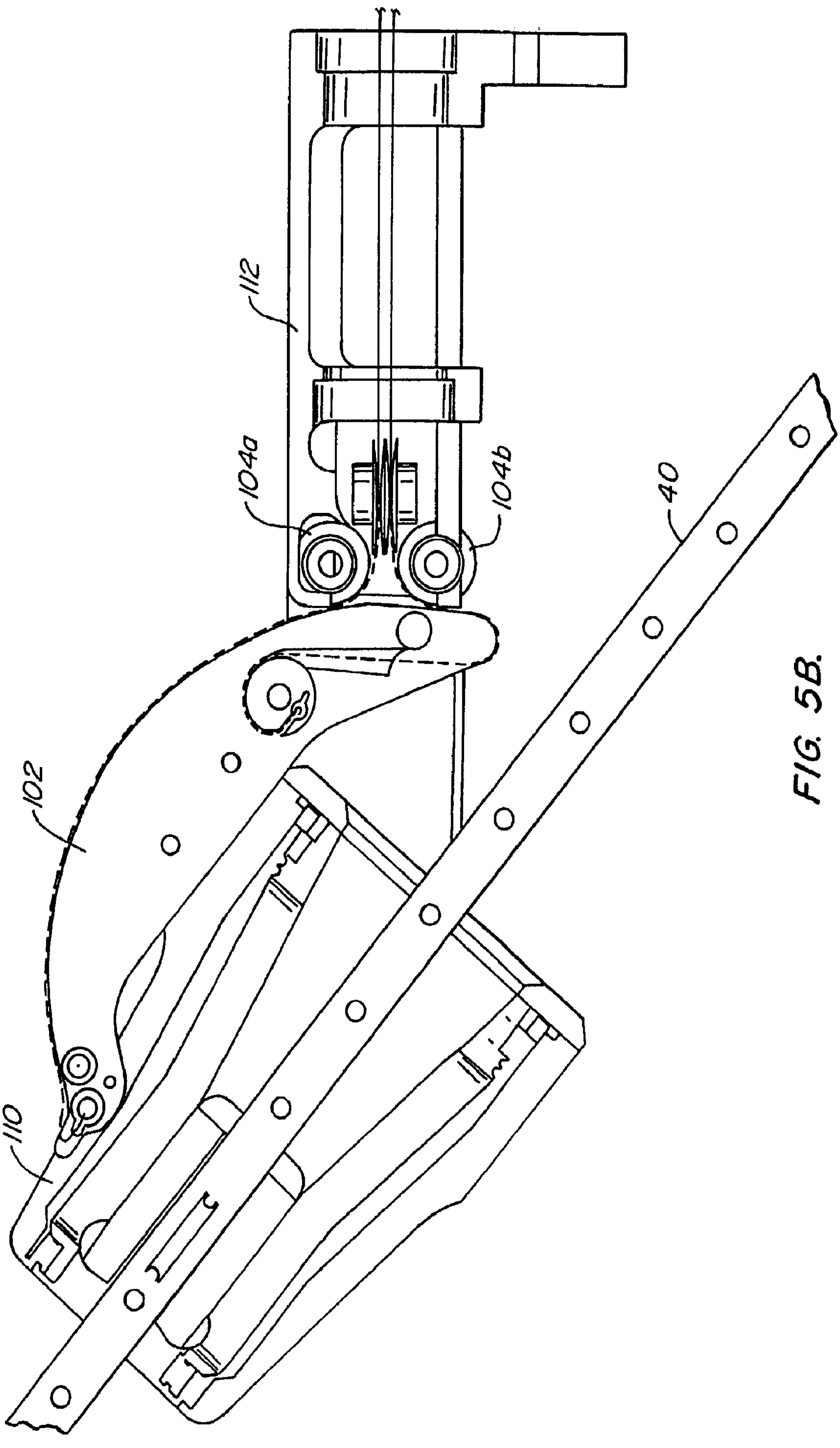

FIG. 5B.

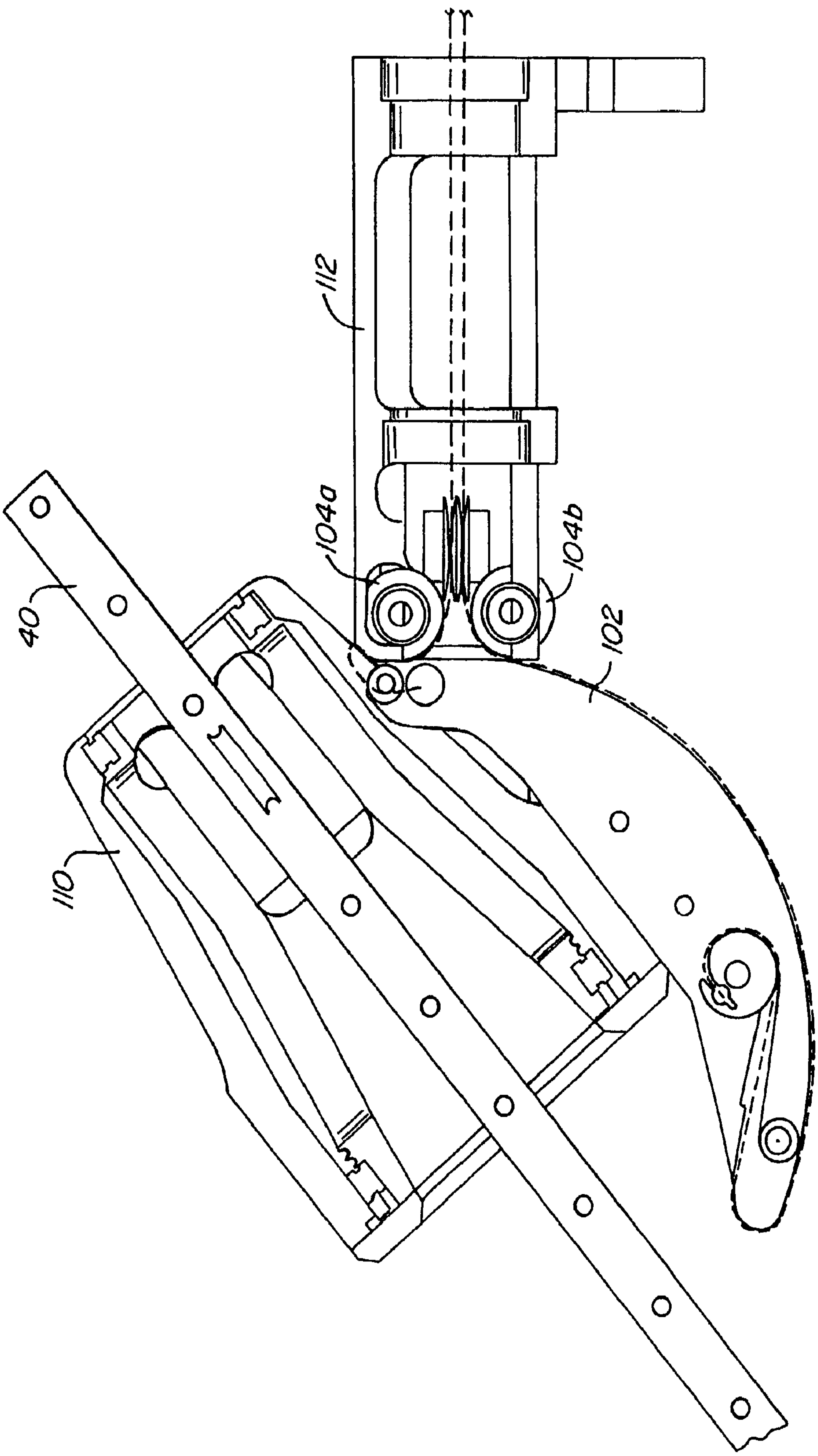

FIG. 5C

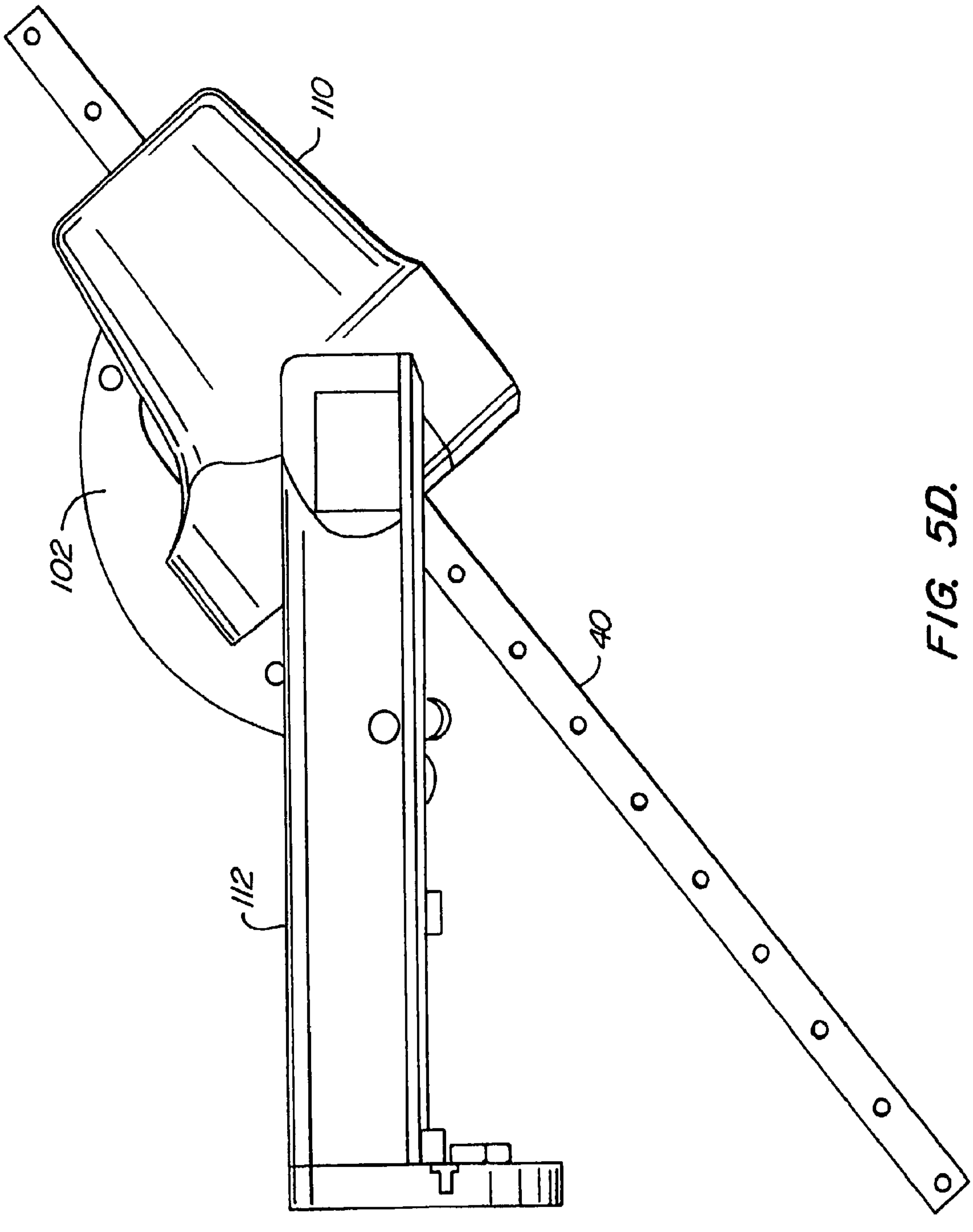

FIG. 5D.

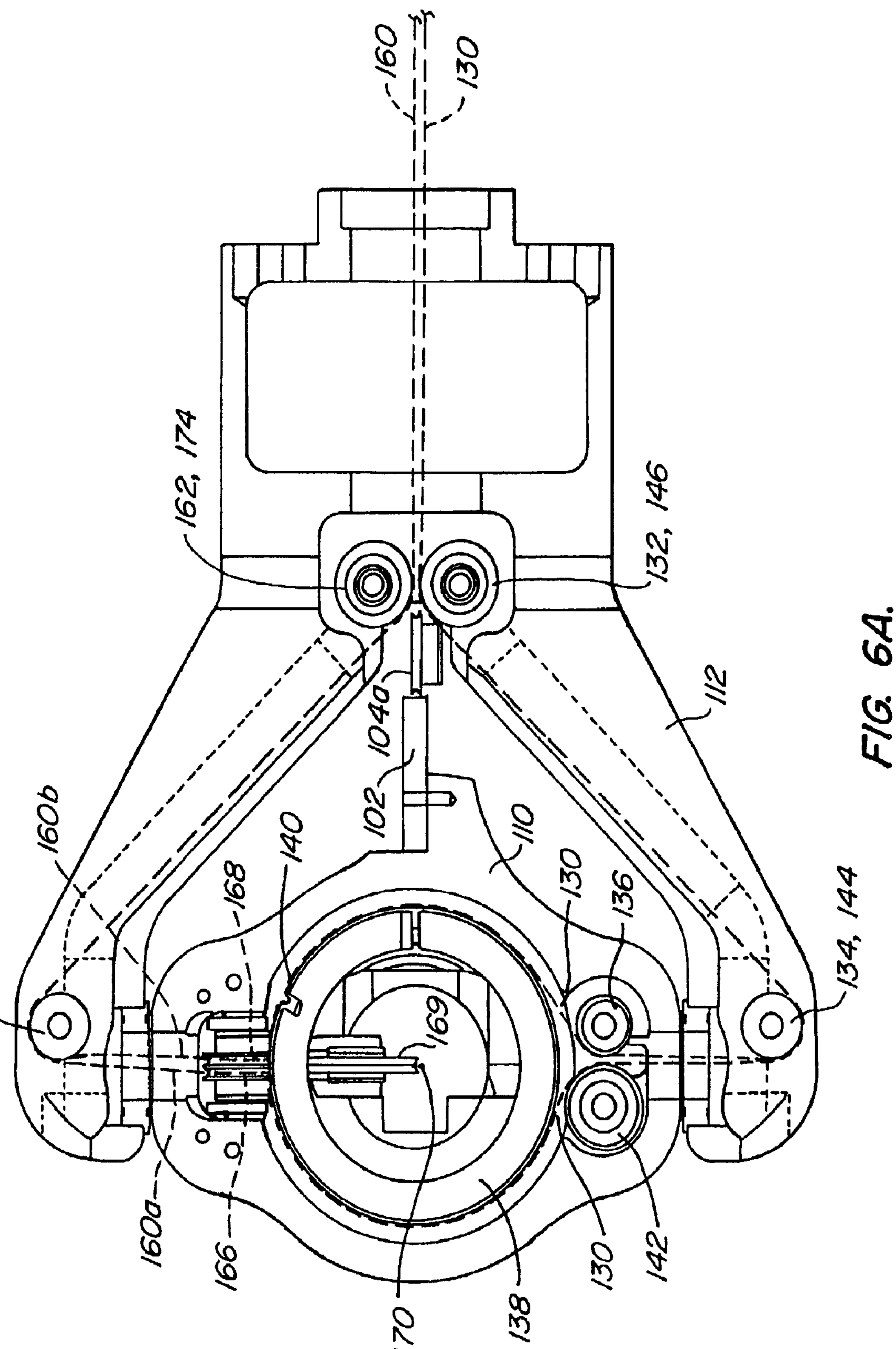
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FIG. 6A.

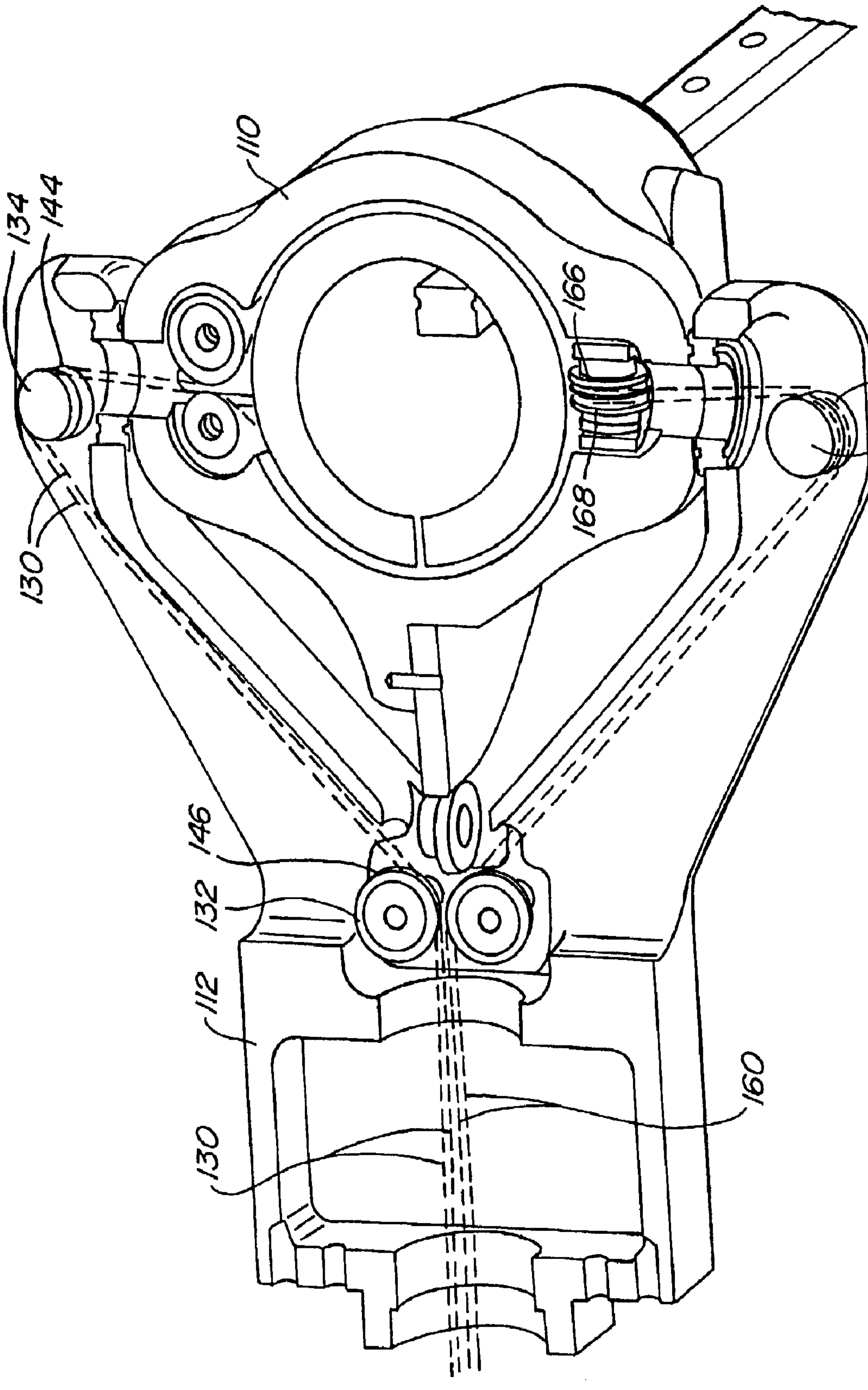

FIG. 6B.

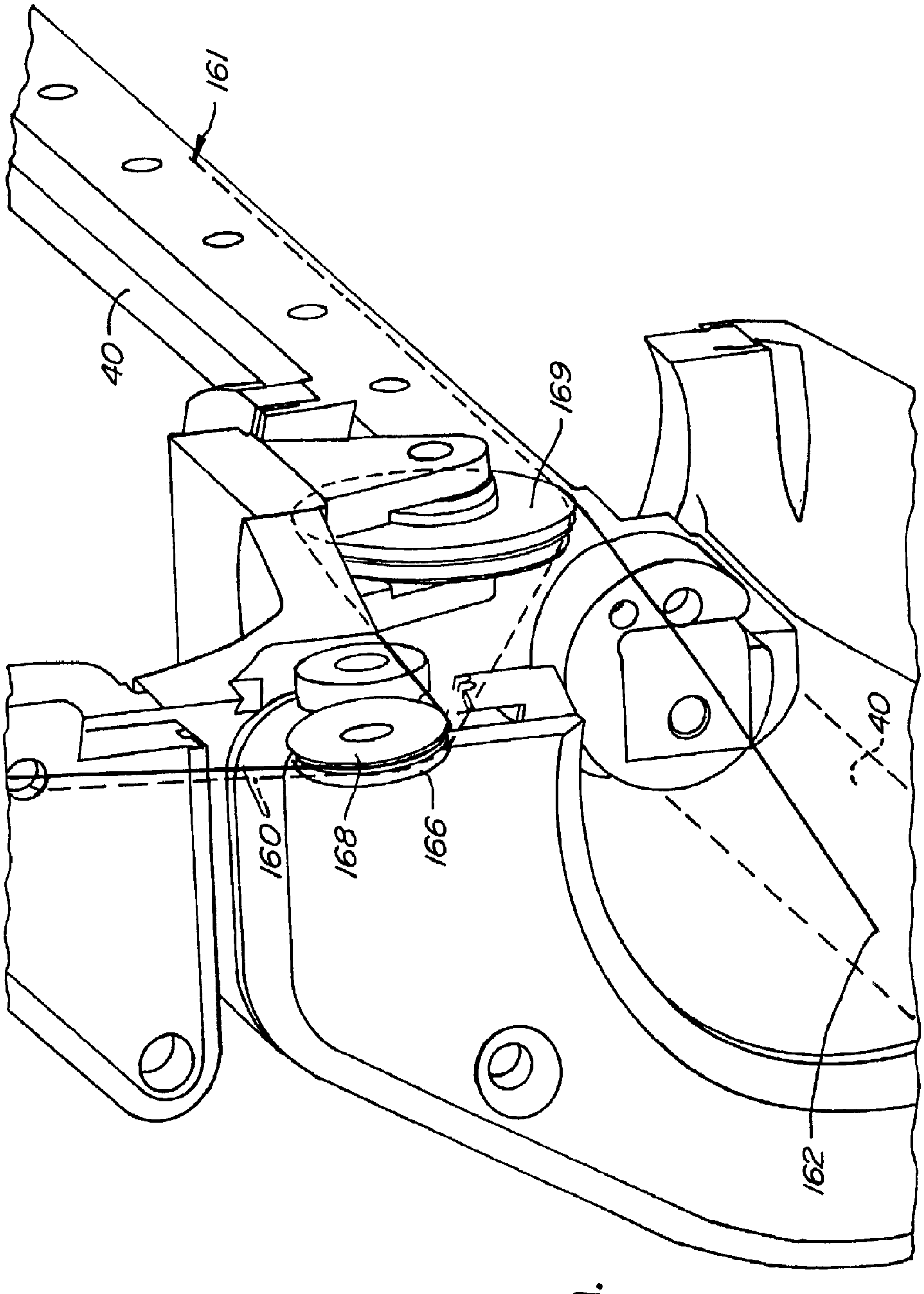

FIG. 7A.

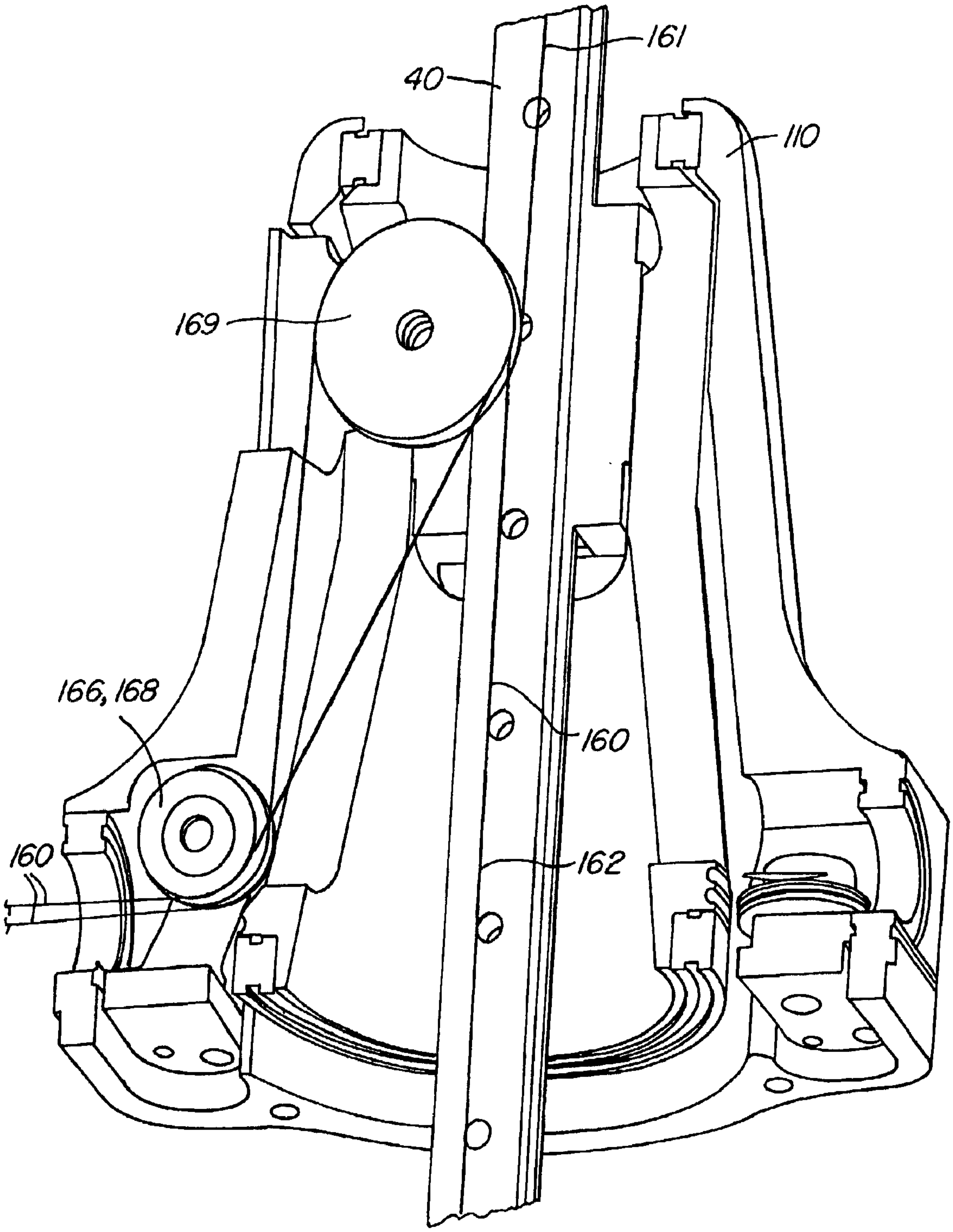

FIG. 7B.

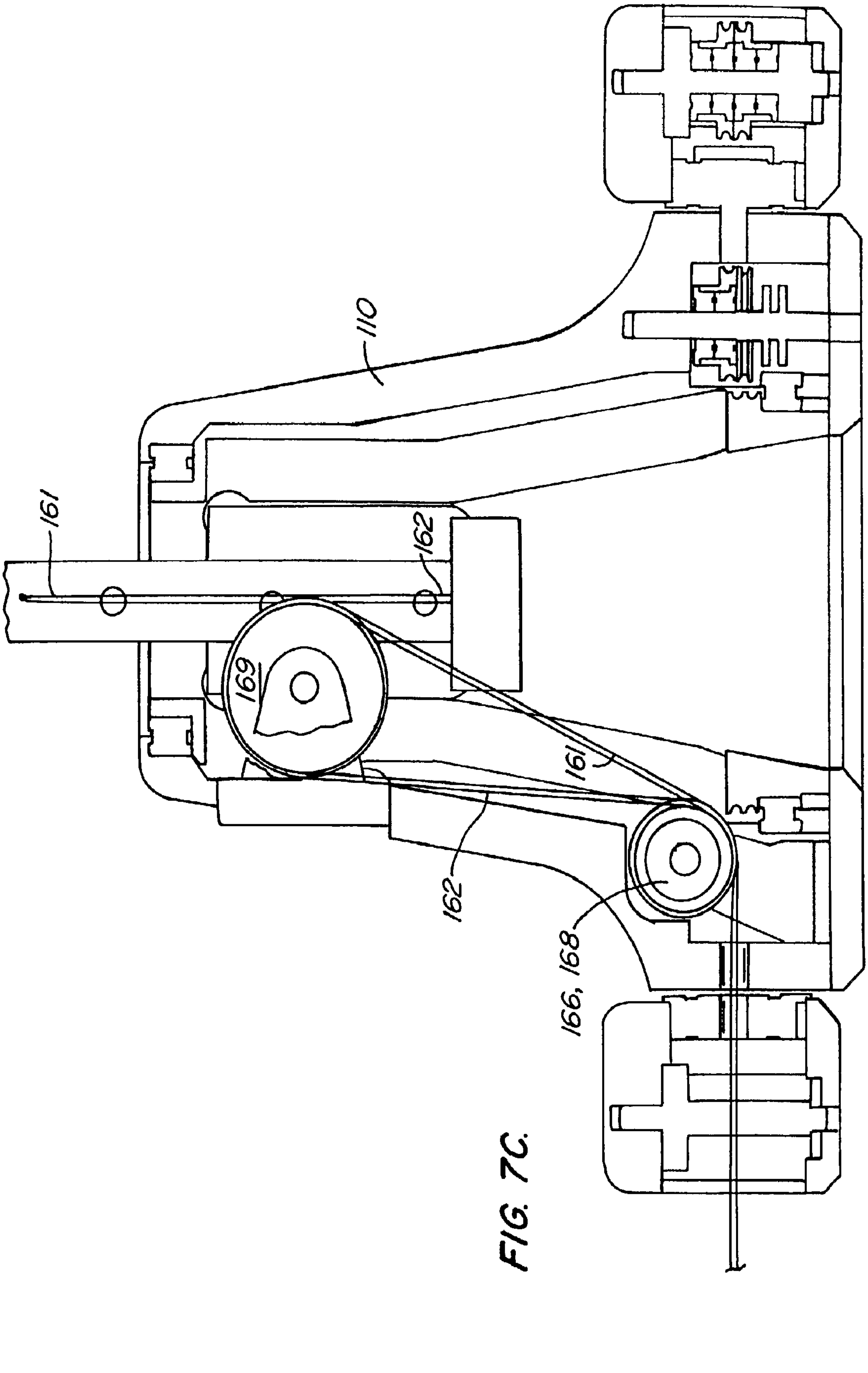

FIG. 7C.

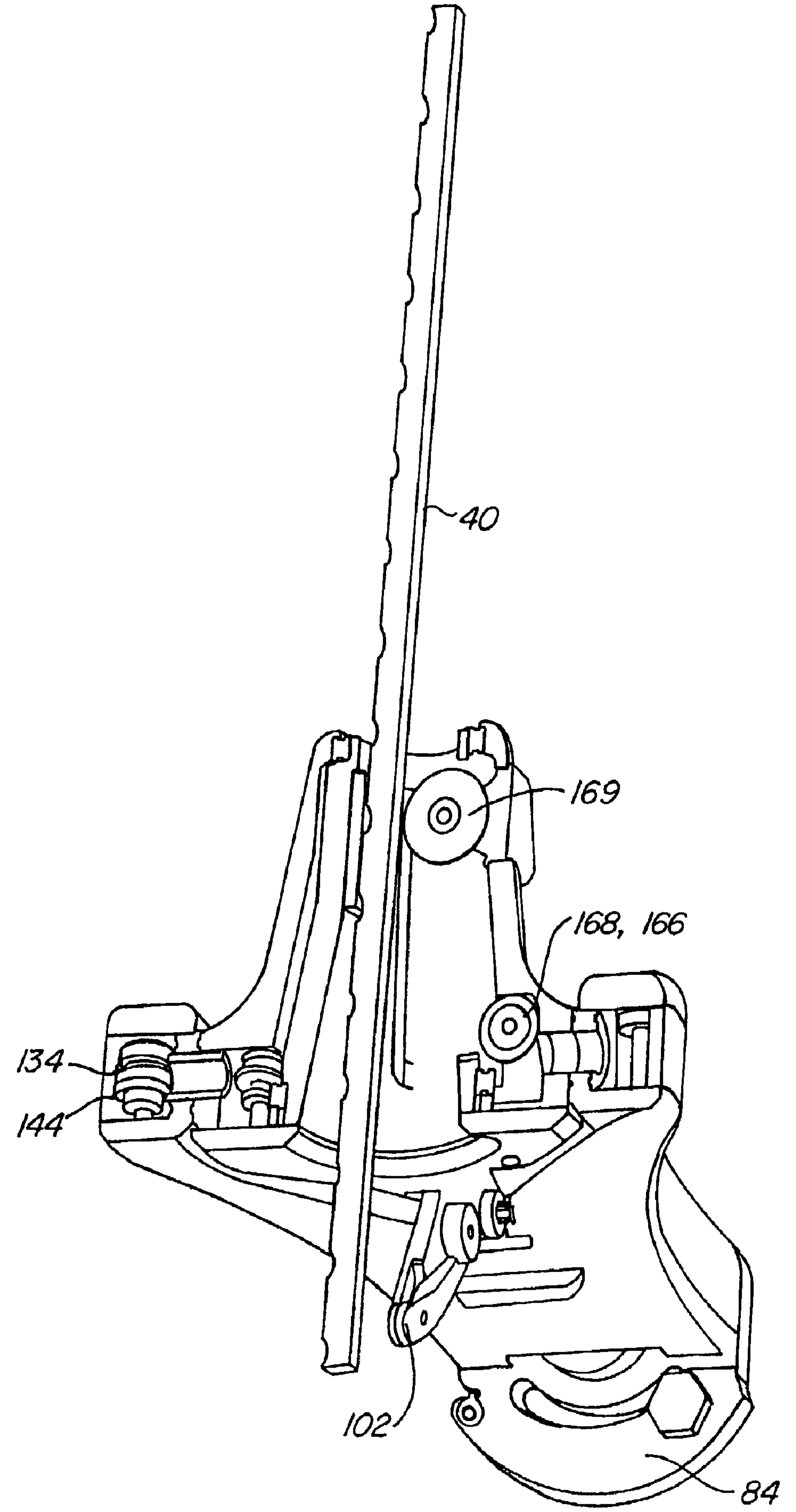

FIG. 8A.

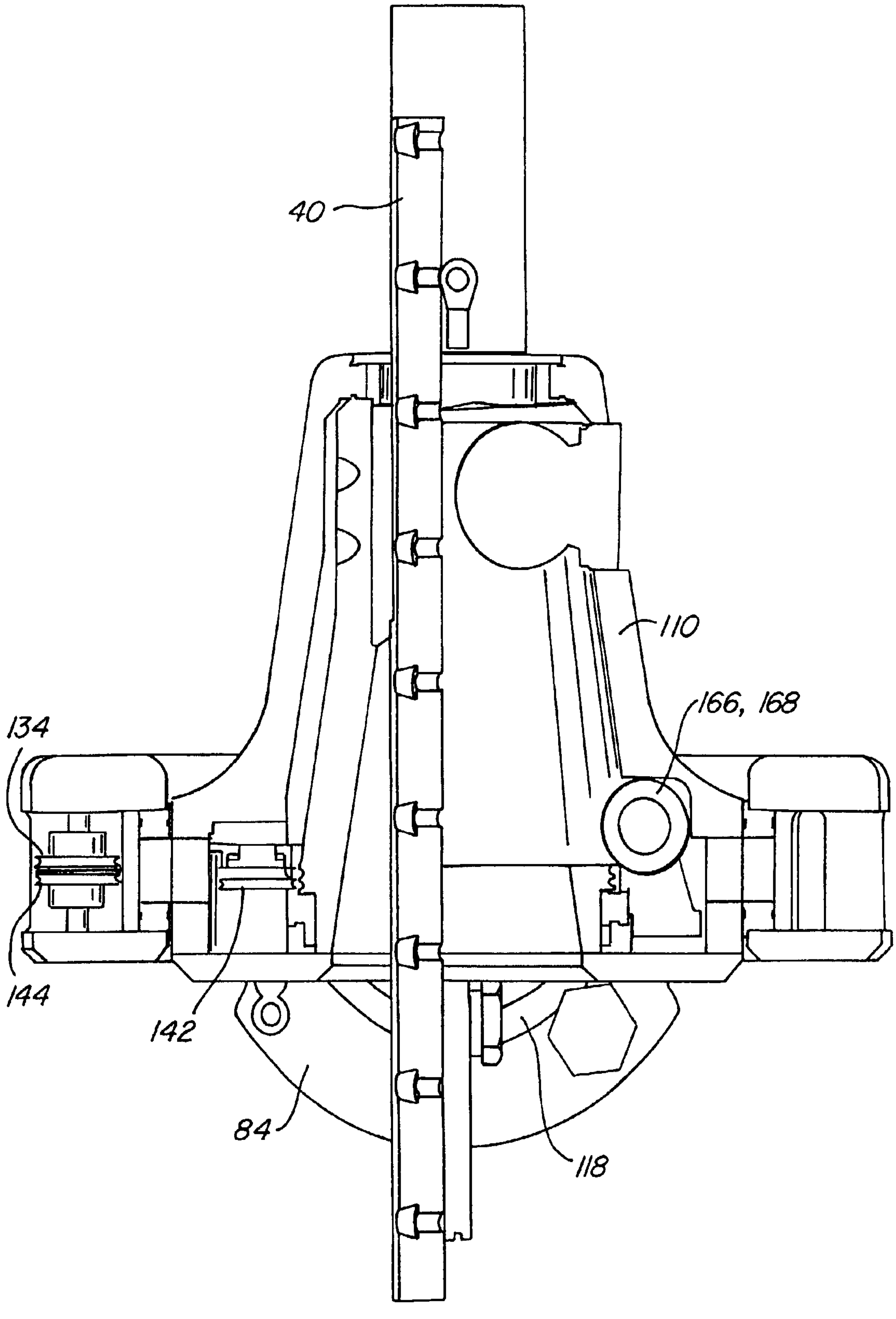

FIG. 8B.

INTERFACE APPARATUS WITH CABLE-DRIVEN FORCE FEEDBACK AND GROUNDED ACTUATORS

CROSS-REFERENCES TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Patent Application Ser. No. 60/305,957, filed Jul. 16, 2001, entitled "INTERFACE APPARATUS WITH CABLE-DRIVEN FORCE FEEDBACK AND FOUR GROUNDED ACTUATORS," the contents of which are hereby incorporated in its entirety for all purposes.

STATEMENT AS TO RIGHTS TO INVENTIONS

MADE UNDER FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

NOT APPLICABLE

REFERENCE TO A "SEQUENCE LISTING," A TABLE, OR A COMPUTER PROGRAM LISTING APPENDIX

SUBMITTED ON A COMPACT DISK

NOT APPLICABLE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to interface devices between humans and computers, and more particularly to computer interface devices that provide force feedback to the user.

2. Description of the Prior Art

Virtual reality computer systems provide users with the illusion that they are part of a "virtual" environment. A virtual reality system will typically include a computer processor, virtual reality software, and virtual reality I/O devices such as head mounted displays, sensor gloves, three dimensional ("3D") pointers, etc.

Virtual reality computer systems may be used for training. In many fields, such as aviation and vehicle and systems operation, virtual reality systems have been used successfully to allow a user to learn from and experience a realistic "virtual" environment. The appeal of using virtual reality computer systems for training relates, in part, to the ability of such systems to allow trainees the luxury of confidently operating in a highly realistic environment and making mistakes without "real world" consequences. For example, a virtual reality computer system allows a doctor-trainee or other human operator or user to "manipulate" a scalpel or probe within a computer-simulated "body," and thereby perform medical procedures on a virtual patient. In this instance, the I/O device, which is typically a 3D pointer, stylus, or the like, is used to represent a surgical instrument such as a scalpel or probe. As the "scalpel" or "probe" moves within a provided space or structure, results of such movement are updated and displayed in a body image displayed on the screen of the computer system so that the operator gains the experience of performing such a procedure without practicing on an actual human being or a cadaver. In other applications, virtual reality computer systems allow a user to handle and manipulate the controls of complicated and expensive vehicles and machinery for training and/or entertainment purposes.

For virtual reality systems to provide a realistic (and therefore effective) experience for the user, sensory feed-

back and manual interaction should be as natural as possible. In addition to sensing and tracking a user's manual activity and feeding such information to the controlling computer to provide a 3D visual representation to the user, a human interface mechanism should also provide force or tactile ("haptic") feedback to the user. The need for the user to obtain realistic haptic information is extensive in many kinds of simulation and other applications. For example, in medical/surgical simulations, the "feel" of a probe or scalpel simulator is important as the probe is moved within the simulated body. It would beinvaluable to a medical trainee to learn how an instrument moves within a body, how much force is required depending on the operation performed, the space available in a body to manipulate an instrument, etc. Other applications similarly benefit from the realism provided by haptic feedback. A "high bandwidth" interface system, which is an interface that accurately responds to signals having fast changes and a broad range of frequencies as well as providing such signals accurately to a control system, is therefore desirable in these and other applications.

Several existing devices provide multiple degrees of freedom of motion of an instrument or manipulatable object and include haptic feedback. Many of these devices, however, are limited in how many degrees of freedom that forces are provided, and may also be less accurate and realistic than desired for a particular application. Devices having greater realism yet reasonable cost are desired for medical and other virtual simulation applications.

SUMMARY OF THE INVENTION

The present invention provides a system for providing a realistic sensation to a user by providing resistance. The system includes an engageable practice tool that the user engages. A mechanical simulation apparatus is coupled to the practice tool and an interface device is coupled to the simulation device. A host computer is coupled to the interface device for implementing an application program. The application program provides signals for a mechanical simulation apparatus to provide resistance to the practice tool based upon sensed positions of the practice tool.

In accordance with one aspect of the present invention, the practice tool is configured as a practice medical tool.

In accordance with another aspect of the present invention, the interface device is included within the host computer.

In accordance with a further aspect of the present invention, the interface device is separate from the host computer.

In accordance with yet another aspect of the present invention, the interface device comprises a microprocessor local to the mechanical simulation apparatus.

In accordance with a further aspect of the present invention, the system further includes a barrier between the mechanical simulation apparatus and the user.

In accordance with another aspect of the present invention, the practice tool is configured as a laparoscopic tool and includes a trocar.

In accordance with yet another aspect of the present invention, the practice tool is configured as one of a group comprising catheters, hypodermic needles, wires, fiber optic bundles, styluses, joysticks, screw drivers, pool queues and handgrips.

In accordance with yet a further aspect of the present invention, the system includes multiple practice tools.

In accordance with one aspect of the present invention, the mechanical simulation apparatus includes a ground member, a mechanical linkage coupled to the ground member, a linear axis member coupled to the practice tool and the mechanical linkage, at least one actuator coupled to the ground member, and a cable in engagement with at least one actuator and coupled to the mechanical linkage.

In accordance with another aspect of the present invention, the system includes at least four actuators.

In accordance with a further aspect of the present invention, the actuators comprise the DC motors.

In accordance with yet another aspect of the present invention, the system includes at least three cables in various engagement with the at least four actuators.

In accordance with a further aspect of the present invention, at least one sensor is provided that senses movement of the actuators and/or the mechanical linkage.

The present invention also provides a method for providing a realistic sensation to a user by providing resistance. The method includes providing an engageable practice tool coupled to a mechanical simulation apparatus comprising a mechanical linkage, at least one actuator, at least one cable in engagement with the at least one actuator and coupled to the mechanical linkage, and a sensor. The method further includes engaging the tool by the user and applying a force to the practice tool by the user. The position of the tool is sensed with the sensor. The position sensed is provided to a host computer that includes an application program, and a signal is provided from the host computer to the at least one actuator to move the at least one cable and thereby move the mechanical linkage. The signal is based upon the position sensed and the application program.

Other features and advantages of the present invention will be understood upon reading and understanding the description of the preferred exemplary embodiments, found hereinbelow, in conjunction with reference to the drawings, in which like numerals represent like elements.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic illustration of the present invention being used for medical simulation purposes;

FIGS. **2**A and **2**B are perspective view of a mechanical simulation apparatus in accordance with the present invention;

FIGS. **2**C and **2**D are elevational views of the base structure and portions of the linkage mechanisms of the mechanical simulation apparatus;

FIG. **2**E is a rear view of the mechanical simulation of the apparatus in accordance with the present invention;

FIG. **2**F is a top view of the mechanical simulation apparatus in accordance with the present invention;

FIG. **2**G is a close up of top surfaces of the mechanical simulation apparatus in accordance with the present invention;

FIG. **3**A is a perspective view of a mechanical linkage of the mechanical simulation of the apparatus in accordance with the present invention;

FIG. **3**B is a top view of the mechanical linkage;

FIG. **3**C is a side view of the mechanical linkage;

FIG. **3**D is a front view of the mechanical linkage;

FIG. **3**E is a bottom view of the mechanical linkage;

FIGS. **4**A and **4**B are perspective views of the mechanical linkage;

FIGS. **5**A–**5**D are side sectional views of the mechanical linkage;

FIGS. **6**A and **6**B are bottom and perspective bottom views, respectively of the mechanical linkage;

FIGS. **7**A–**7**C are additional sectional perspective views of the mechanical linkage;

FIGS. **8**A and **8**B are sectional perspective and front views, respectively, of the mechanical linkage.

DESCRIPTION OF SPECIFIC EXEMPLARY EMBODIMENTS

FIG. **1** illustrates an example of the use of the present invention for medical simulation purposes. A virtual reality system **10** used to simulate a medical procedure includes a human/computer interface apparatus **12**, an electronic interface **14**, and a host computer **16**. The illustrated virtual reality system **10** is directed to a virtual reality simulation of a laparoscopic surgery procedure.

The handle **26** of a laparoscopic tool **18** used in conjunction with the present invention is manipulated by an operator and virtual reality images are displayed on a display device **20** of A digital processing system in response to such manipulations. For example, when the tool **18** is moved by the user, a graphical representation of the tool or a part of the tool may be moved correspondingly within a graphical environment displayed on device **20**. Display device **20** may be a standard display screen or CRT, 3-D goggles, or any other visual interface. The digital processing system is typically a host computer **16**. The host computer can be a personal computer or workstation or other computer device or processor, such as a home video game system commonly connected to a television set, such as systems available from Nintendo, Sega, or Sony; a "set top box" which may be used, for example, to provide interactive television functions to users; an arcade game; a portable computing device, etc. Multiple tools **18**, each manipulatable by the user, may also be provided, as in a preferred embodiment described below.

Host computer **16** implements a host application program with which a user is interacting via peripherals and interface device **14**. For example, the host application program may be a video game, medical simulation, scientific analysis program, or even an operating system or other application program that utilizes force feedback. Typically, the host application provides images to be displayed on a display output device, as described below, and/or other feedback, such as auditory signals. The medical simulation example of FIG. **1** includes a host medical simulation application program. Suitable software for such applications is available from Immersion Corporation of San Jose, Calif. Alternatively, display screen **20** may display images from a game application program or other program.

One example of a human/interface apparatus **12** as illustrated herein is used to simulate a laparoscopic medical procedure. In addition to the handle of a standard laparoscopic tool **18**, the human/interface apparatus **12** may include a barrier **22** and a standard laparoscopic trocar **24** (or a facsimile of a trocar). The barrier **22** is used to represent a portion of the skin covering the body of a patient. Trocar **24** is inserted into the body of the virtual patient to provide an entry and removal point from the body of the patient for the laparoscopic tool **18**, and to allow the manipulation of the laparoscopic tool. Barrier **22** and trocar **24** may be omitted from apparatus **12** in other embodiments if desired. Preferably, the laparoscopic tool **18** is modified; in one embodiment, the shaft is replaced by a linear axis member, as described below. In other embodiments, the end of the shaft of the tool (such as any cutting edges) may be removed. The distal end of the laparoscopic tool **18** may not be required for the virtual reality simulation.

The laparoscopic tool **18** includes a handle or "grip" portion **26** and a shaft portion **28**. The shaft portion is an elongated mechanical object, described in greater detail below. In one embodiment, the present invention is concerned with tracking the movement of the shaft portion **28** in three-dimensional space, e.g. four degrees of freedom. The shaft **28** is constrained at some point along its length such that it may move with four degrees of freedom within the simulated patient's body.

A mechanical apparatus **25** for interfacing mechanical input and output is shown within the "body" of the patient in phantom lines. When an interaction is simulated on the computer, the computer will send feedback signals to the tool **18** and mechanical apparatus **25**, which has actuators for generating forces in response to the position of the virtual laparoscopic tool relative to surfaces or features displayed on the computer display device. Mechanical apparatus **25** is described in greater detail below. Signals may be sent to and from apparatus **25** via interface **30**, which may be similar to interface **72** described below.

While one embodiment of the present invention will be discussed with reference to the laparoscopic tool **18**, it will be appreciated that a great number of other types of objects may be used with the method and apparatus of the present invention. In fact, the present invention may be used with any mechanical object where it is desirable to provide a human/computer interface with one to six degrees of freedom. Such objects may include endoscopic or other similar surgical tools used in medical procedures, catheters, hypodermic needles, wires, fiber optic bundles, styluses, joysticks, screw drivers, pool cues, hand grips, etc.

The electronic interface **14** is a component of the human/computer interface apparatus **12** and may couple the apparatus **12** to the host computer **16**. Electronic interface **14** may be included within a housing of mechanical apparatus **25**, within host computer **16**, or may be provided as a separate unit. More particularly, interface **14** is used in preferred embodiments to couple the various actuators and sensors of apparatus **25** (described in detail below) to computer **16**. In some embodiments, the interface may include a microprocessor local to the apparatus **25** to handle sensor data and actuator control. Suitable electronic configurations are described, for example, in U.S. Pat. Nos. 5,623,582; 5,821,920; 5,731,804; 5,734,373; 5,828,197; and 6,024,576, all of which are incorporated herein by reference.

Signals may be sent to and from interface **14** and computer **16** by a standard interface **32** (RS-232, USB, Firewire, serial, parallel, etc.) or by wireless transmission and reception. In various embodiments of the present invention, interface **14** may serve solely as an input device for the computer **16**, solely as an output device for the computer **16**, or as an input/output (I/O) device for the computer **16**. The interface **14** may also receive inputs from other input devices or controls that are associated with apparatus **12** and may relay those inputs to computer **16**. For example, commands sent by the user activating a button on apparatus **12** may be relayed to computer **16** to implement a command or cause the computer **16** to output a command to the apparatus **12**.

In FIGS. **2**A and **2**B, perspective views of mechanical apparatus **25** for providing mechanical input and output in accordance with the present invention are shown. Apparatus **25** may include two or more tools **18** (only one is shown) to allow a user to realistically simulate an actual surgical procedure using laparoscopic instruments. A user may manipulate each of the tools **18** independently, where each tool is independently sensed and actuated in the present invention.

Each tool **18** is coupled to a linear axis member **40**, which is coupled to a mechanical linkage **38**, which will be described in more detail below. The user object **44**, such as a handle, is preferably coupled to linear axis member **40**. The mechanical linkage is grounded via a base structure **46**. The actuators, such as DC motors, which output the forces on each linear axis member **40** and tool **18**, are in the described embodiment located within the base structure **46**, and are therefore all grounded. This configuration allows high fidelity and efficient haptic feedback to be produced with the apparatus **25**. The actuators may also include sensors which sense the rotation of the actuators and thus, detect the motion of the tool in the four degrees of freedom. In other embodiments, sensors may be coupled to parts of the linkage **38** to sense the motion of the tool more directly.

In the described embodiment, each linear axis member **40**/tool **18** may be moved in four degrees of freedom, shown as the insert degree of freedom **50**, the twist degree of freedom **52**, the first rotation (yaw) **54**, and the second rotation (pitch) **56**. Other embodiments may limit the degrees of freedom to a lesser number, or provide additional degrees of freedom.

FIGS. **2**C and **2**D further illustrate the base structure **46** and portions of the linkage mechanisms **38** that are rotatably coupled to the base structure.

FIG. **2**E illustrates a rear view of the apparatus **25** showing many of the actuators and some of the sensors of the described embodiment. A rotary actuator **62**, such as a DC motor, drives the insert degree of freedom **50**, a rotary actuator **64** drives the yaw degree of freedom **54**, and a rotary actuator **66**, positioned behind actuator **64** in FIG. **2**E, drives the twist degree of freedom **52**. An actuator-sensor pair **70** drives the pitch degree of freedom **56**.

FIG. **2**F illustrates a top view of the apparatus **25** and FIG. **2***g* is a close up of the top surfaces of the apparatus. A pulley **72** is coupled to actuator **62** and has a cable **160** wrapped around it. A pulley **74** is coupled to the actuator **64** and has a cable **106** wrapped around it. A pulley **76** is coupled to the actuator **66** and has a cable **130** wrapped around it. These cables are described in greater detail below. The cables are all routed to the mechanical linkage **38** through an aperture **77** in the side of the base structure; in the described embodiment, the cables may each be wrapped around its own central spindle **78** before being routed to their respective pulleys **72**, **74**, or **76**. In the described embodiment, a sensor **65** senses the motion of the shaft of actuator **64**, a sensor **67** senses the motion of the spindle **78** connected to the shaft of actuator **62**, and a sensor **69** senses the motion of the shaft of actuator **66**. The sensors are optical encoders having emitters and detectors sensing marks on an encoder wheel coupled to the pulley or spindle, as shown. In the described embodiment, the sensor for the pitch degree of freedom **56** is provided on the housing of actuator/sensor **70** to measure the actuator shaft rotation directly.

Other types of sensors and actuators, which essentially serve as transducers for the system, may be used in other embodiments, such as analog potentiometers, Polhemus (magnetic) sensors, lateral effect photo diodes, etc. Alternatively, sensors may be positioned at other locations of relative motion or joints of mechanical apparatus **25**. It should be noted that the present invention may utilize both absolute and relative sensors. The actuators may also be of various types, such as active actuators and/or passive actuators. Active actuators may include linear current control motors, stepper motors, pneumatic/hydraulic active actuators, stepper motor, brushless DC motors, pneumatic/

hydraulic actuators, a torquer (motor with limited angular range), a voice coil, and other types of actuators that transmit a force to move an object. Passive actuators may also be used. Magnetic particle brakes, friction brakes, or pneumatic/hydraulic passive actuators may be used in addition to or instead of a motor to generate a damping resistance or friction in a degree of motion. In addition, in some embodiments, passive (or "viscous") damper elements may be provided on the bearings of apparatus **25** to remove energy from the system and intentionally increase the dynamic stability of the mechanical system. In other embodiments, this passive damping may be introduced by using the back electromotive force (EMF) of the actuators to remove energy from the system. In addition, in the voice coil embodiments, multiple wire coils may be provided, where some of the coils may be used to provide back EMF and damping forces.

The actuators and sensors are decoupled, meaning that these transducers are directly coupled to ground member **46** which is coupled to a ground surface **47**, i.e. the ground surface carries the weight of the transducers, not the user handling tool **18**. The weights and inertia of the transducers are thus substantially negligible to a user handling and moving the tool. This provides a more realistic interface to a virtual reality system, since the computer may control the transducers to provide substantially all of the forces felt by the user in these degrees of motion. In contrast, in typical prior art arrangements of multi-degree of freedom interfaces, one actuator "rides" upon another actuator in a serial chain of links and actuators. This low bandwidth arrangement causes the user to feel the inertia of coupled actuators when manipulating an object.

Optionally, additional transducers may be added to apparatus **25** to provide additional degrees of freedom for the tool **18**. For example, a transducer may be added to the grip of laparoscopic tool **18** to sense and/or output forces to the degree of freedom provided by the user moving two portions of a tool **18** relative to each other to simulate extending the cutting blade of the tool, for example.

FIGS. **3**A (perspective view), **3**B (top view), **3**C (side view), **3**D (front view), and **3**E (bottom view) illustrate the mechanical linkage **38** of the apparatus **25**. The linkage **38** is rotatably coupled to the base structure **46** to allow the second rotation **56**, where cables from various moving parts of the linkage **38** extend to the actuators of the base structure, as detailed below. Linear axis member **40** may be moved relative to the linkage **38** to provide two degrees of freedom **50** and **52**, and moves with portions of the linkage to provide two other degrees of freedom **54** and **56**.

FIGS. **4**A and **4**B shows a perspective view of mechanical linkage **38**. The second rotation (pitch) **56** is provided by a mechanical bearing positioned between the linkage **38** and the base structure **46**. To provide forces in the second rotation **56** from grounded actuator **70**, a capstan drive **80** may be a mechanical transmission transmitting forces from the actuator to the linkage **38**. A capstan pulley **82** may be rigidly coupled to the rotating shaft **71** of the actuator **70**, where the pulley has an axis of rotation parallel to the axis of rotation A of the linkage **38** for the degree of freedom **56** and the pulley is positioned adjacent to a drum **84** that is rigidly coupled to the linkage **38** as shown. A cable **86** is connected at one end of the drum **84**, routed along the edge of the drum, around the pulley **82** one or more times, and is routed along the remaining edge of the drum to its other side. The cable may be tensioned using tensioning nut **88**, for example. Other types of transmissions may be used in other embodiments, e.g. gears, friction wheels, belt drives, etc.

The first rotation (yaw) **54** of linkage **38** is provided by a different cable drive **100**. Cable drive **100** includes a drum **102** which is rigidly coupled to linkage member **110**, which rotates about degree of freedom **54** about axis B with respect to linkage member **112**. Two idler pulleys **104***a* and **104***b* are rotatably coupled to linkage member **112** and rotating about axes parallel to axis B. A cable **106**, shown as a dashed line, is routed from one end of drum **102**, around idler pulley **104***a*, through the linkage member **38** and out to the base structure and driven pulley **74** of actuator **64**, where it is wrapped multiple times. The cable then is routed back into and through the linkage **38**, around the idler pulley **104***b*, and along the edge of drum **102** to the tensioner **114**. This configuration allows the actuator to rotate the linkage member **110** by pulling the desired side of the drum **102** with the cable **106**.

FIGS. **5**A, **5**B, **5**C, and **5**D are other side sectional views of the linkage **38**, where examples of extremes of rotation of the linkage member **110** with respect to the linkage member **112** are shown. The motion may be limited by stops provided in the path of movement of the drum **102**. For example, as shown in FIG. **5**A, an opening **118** may be placed in the drum **102**. A stop member **120**, such as a cylinder, may be coupled to the linkage member **112** and positioned within the opening **118**, so that the stop member **120** will engage the ends of the opening **118** to provide the limits of motion of the drum.

FIGS. **6**A and **6**B are bottom and perspective bottom views, respectively, of the linkage mechanism **38**. To allow forces to be output in the twist degree of freedom **52**, a first end of cable **130** (represented by a dashed line) is routed from directly-driven pulley **76** of the actuator **66** in the base structure **46** and through the linkage mechanism **38**. The cable **130** is routed around an idler pulley **132**, around another idler pulley **134**, and around another idler pulley **136**. The cable **130** is then wrapped counterclockwise (as viewed in FIG. **6***a*) around a rotatable drum **138** and connected to the drum at a point **140** (point **140** may be located elsewhere in other embodiments). The other, second end of the cable **130** is also connected to the drum **138** at point **140** and may be wrapped counterclockwise (as viewed in FIG. **6***a*) on the remaining side around the drum **138** to the pulley **142**. Cable **130** is routed from the second end around idler pulley **142** and then idler pulley **144**, where idler pulley **144** and idler pulley **134** are positioned adjacent to each other and have the same axis of rotation. Cable **130** is then routed around idler pulley **146**, which is positioned adjacent to and has the same axis of rotation as pulley **132**. The cable **130** is then routed through the linkage member **38**, both ends represented by line **130**, to the actuator **66** in the base structure, where it is wrapped multiple times around the pulley **76** directly driven by the actuator **66**.

In operation, the actuator **66** may rotate the drum **138** in either direction, thereby rotating the linear axis member **40** and tool **18**. When the actuator shaft is rotated in one direction, the first end of cable **130** around pulley **136** is pulled, causing the drum to rotate about center point **170** in the corresponding direction. When the actuator shaft is rotated in the opposite direction, the second end of cable **130** is pulled around pulley **142**, causing the drum to rotate about central point **170** in its other direction.

To allow forces to be output in the linear insert degree of freedom **50**, a first end of cable **160** (represented by dashed line in FIG. **6***a*) is routed from directly-driven pulley **72** of actuator **62** in the base structure **46** through the linkage mechanism **38**. The cable **160** is routed around idler pulley **162**, around idler pulley **164**, and then around idler pulley

166. This first end 161 of cable 160 is then routed around pulley 169 (shown in FIG. 7*a*) and is coupled to the linear axis member 40. The second end 162 of the cable 160 is coupled to the linear axis member 40 on the other side of the central pivot point 170. The cable 160 is routed from the second end, around pulley 168, around pulley 172 which is adjacent to and rotates about the same axis as pulley 164, and around pulley 174 which is adjacent to and rotates about the same axis as pulley 162. The cable is then routed through the linkage mechanism 38 to the pulley 72 driven by the actuator 62, where it is wrapped multiple times.

In operation, the actuator 62 may rotate its driven pulley in either direction to correspondingly pull on the first end or the second end of the cable 160. If the first end is pulled, a downward force on the linear axis member 40 (as oriented in FIG. 3) is output, while if the second end is pulled, an upward force on the linear axis member is output.

FIGS. 7A–7C are additional sectional perspective views of the linkage mechanism 38 and the cables and pulleys described above, illustrating the mechanism of the insert degree of freedom 50.

FIGS. 8A and 8B are sectional perspective and front views of the linkage mechanism 38 showing features described above.

Thus, the mechanism of the present invention preferably provides four grounded actuators to provide forces in four degrees of freedom of the tool 18. To make the actuators grounded, cables are used to allow the actuators to output forces to a remote mechanical motion, i.e. the rotated drums or moved linear axis member is located far from the driven pulley, unlike standard capstan drives. The three cables (six ends) routed through the interior of the mechanical linkage and out to the base structure are bent in various ways around idler pulleys and about their lengthwise axes; however, this does not cause significant stretching in the cables. The six ends of the cables are preferably arranged close together close to the pitch axis A so as to minimize bending of the cables. For example, the six cable lengths may be arranged so that their cross sections approximately form a circle around the rotation axis A.

While this invention has been described in terms of several preferred embodiments, it is contemplated that alterations, modifications and permutations thereof will become apparent to those skilled in the art upon a reading of the specification and study of the drawings. For example, the linked members of apparatus 25 may take a number of actual physical sizes and forms while maintaining the disclosed linkage structure. Likewise, other types of gimbal mechanisms or different mechanisms providing multiple degrees of freedom may be used with the drive mechanisms disclosed herein to reduce inertia, friction, and backlash in a system. A variety of devices may also be used to sense the position of an object in the provided degrees of freedom and to drive the object along those degrees of freedom. In addition, the sensor and actuator used in the transducer system having desired play may take a variety of forms. Similarly, other types of couplings may be used to provide the desired play between the object and actuator. Furthermore, certain terminology has been used for the purposes of descriptive clarity, and not to limit the present invention.

What is claimed is:

1. A system, comprising:

a manipulandum;

a simulation apparatus including a linkage coupled to the manipulandum, the simulation apparatus being one of a simulated body part and configured to be coupled to a simulated body part; and

an interface device coupled to the simulation apparatus and configured to be coupled to a host computer, the linkage configured to move based on a control signal associated with the host computer, the interface device being included within one of the host computer and the simulation apparatus.

2. The system of claim 1, wherein the manipulandum is one of a simulated medical instrument and a medical instrument.

3. The system of claim 1, wherein the interface device includes a microprocessor, the interface device being disposed in the simulation apparatus.

4. The system of claim 1, further comprising a barrier between the simulation apparatus and the manipulandum.

5. The system of claim 1, wherein the manipulandum is configured as a laparoscopic tool including a trocar.

6. The system of claim 1, wherein the manipulandum is configured as one of a catheter, a hypodermic needle, a wire, a fiber optic bundle, a stylus, a joystick, a screw driver, a pool cue and a hand grip.

7. The system of claim 1, wherein the manipulandum is one manipulandum from a plurality of manipulandums.

8. The system of claim 1, wherein the simulation apparatus includes

a ground member;

a linear axis member coupled to the manipulandum and the linkage;

an actuator coupled to the ground member; and

a cable coupled to the at least one actuator and the linkage.

9. The system of claim 1, wherein the simulation apparatus includes

a ground member;

a linear axis member coupled to the manipulandum and the linkage;

at least four actuators coupled to the ground member; and

at least three cables coupled to the at least four actuators and the linkage.

10. The system of claim 9, wherein the at least four actuators include DC motors.

11. The system of claim 8 comprising at least one sensor configured to sense a movement of at least one of the actuator and the linkage.

12. The system of claim 9, further comprising at least four sensors configured to sense a movement of at least one of the at least four actuators and the linkage.

13. A system, comprising:

manipulandum;

a simulation apparatus coupled to the manipulandum, the simulation apparatus comprising:

a ground member;

a linkage rotatably coupled to the ground member;

a linear axis member coupled to the manipulandum and the linkage;

at least four actuators coupled to the ground member;

at least one sensor configured to sense a movement of at least one of the at least four actuators and the linkage; and

at least three cables coupled to the at least four actuators and coupled to the linkage;

an interface device coupled to the simulation apparatus and a host computer, the

host computer configured to output a control signal, the linkage configured to move based on the control signal.

14. The system of claim 13, wherein the manipulandum is one of a simulated medical tool and a medical tool.

15. The system of claim **13**, wherein the interface device is included within one of the host computer and the simulation apparatus.

16. The system of claim **13**, wherein the interface device is separate from the host computer and the simulation apparatus.

17. The system of claim **13**, wherein the at least four actuators include DC motors.

18. The system of claim **13**, wherein the interface device includes a microprocessor local to simulation apparatus, the interface device being disposed in the simulation apparatus.

19. The system of claim **13**, further comprising a barrier between the simulation apparatus and the manipulandum.

20. The system of claim **13**, wherein the manipulandum is configured as a laparoscopic tool including a trocar.

21. The system of claim **13**, wherein the practice tool is one of a catheter, hypodermic needle, a wire, a fiber optic bundle, a stylus, a joystick, a screw driver, a pool cue and a hand grip.

22. The system of claim **13**, wherein the manipulandum is one manipulandum from a plurality of manipulandums.

23. A method, comprising:

receiving an input signal from a sensor, the signal being associated with at least one of a position of a linkage and an input force applied to the linkage, the linkage being coupled between a ground member of a simulation apparatus and a manipulandum, the simulation apparatus being one of a simulated body part and configured to be coupled to a simulated body part; and

outputting haptic feedback via an actuator, the actuator being one actuator from a plurality of actuators, the haptic feedback being operative to move the linkage via a plurality of cables coupled between the plurality of actuators and the linkage, the haptic feedback based on the input signal and a control signal received from a host computer.

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patsnap

专利名称(译)	具有电缆驱动力反馈和接地致动器的接口设备		
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摘要(译)

一种通过向用户提供触觉(触觉)反馈来在仿真系统内提供逼真感觉的系统。该系统包括用户接合的可接合练习工具和连接到练习工具的机械模拟装置。机械模拟装置包括接地构件，可旋转地连接到接地构件的机械连杆，连接到练习工具和机械连杆的线性轴构件，连接到接地构件的至少四个致动器，用于感测致动器的运动的传感器至少三根电缆与至少四个致动器接触并连接到机械连杆。接口设备耦合到模拟设备，主计算机耦合到接口设备以实现应用程序。应用程序为致动器提供信号以移动电缆，从而移动机械连杆。