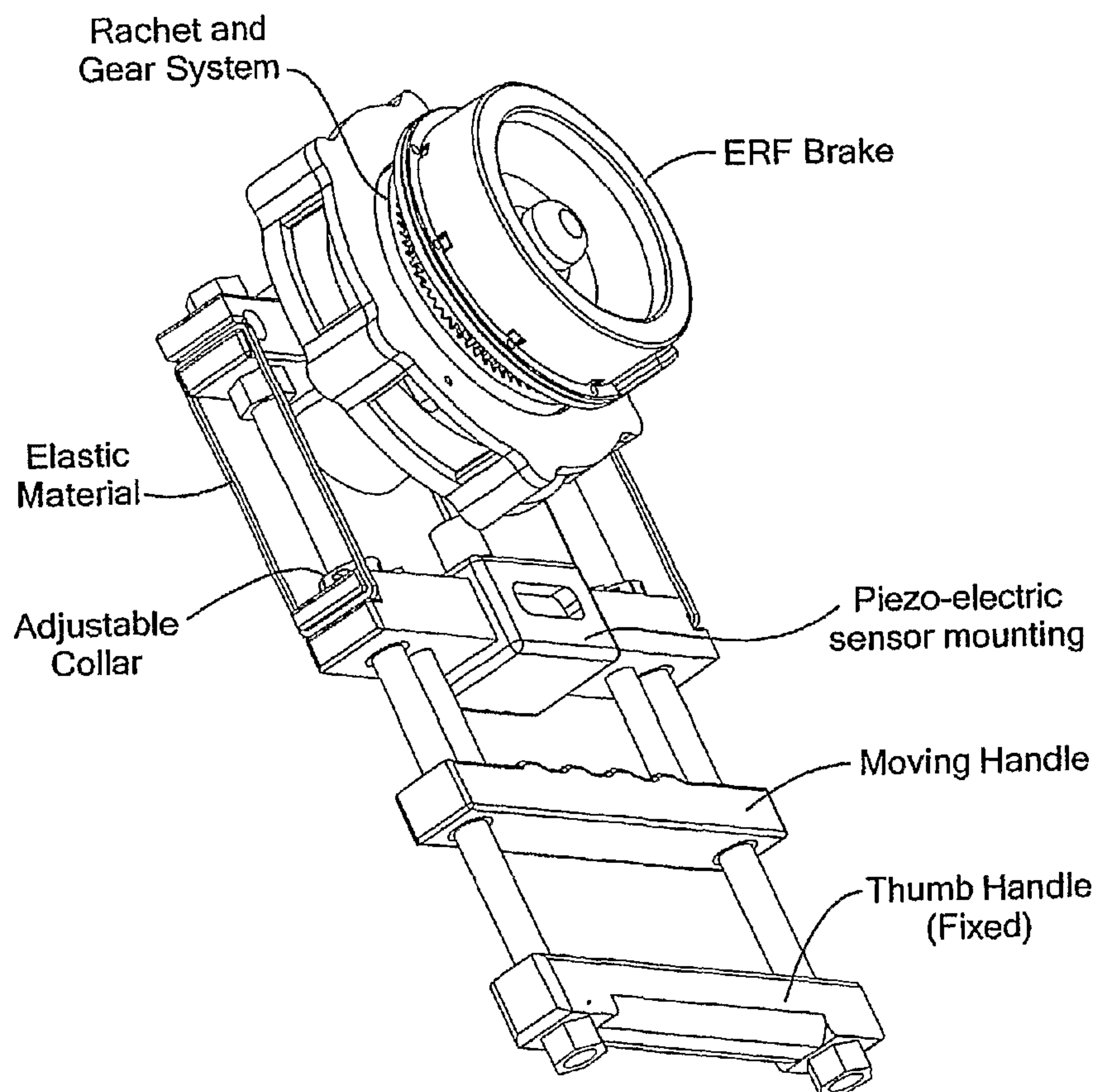




(86) Date de dépôt PCT/PCT Filing Date: 2006/03/14  
(87) Date publication PCT/PCT Publication Date: 2006/09/21  
(85) Entrée phase nationale/National Entry: 2007/09/14  
(86) N° demande PCT/PCT Application No.: US 2006/009314  
(87) N° publication PCT/PCT Publication No.: 2006/099484  
(30) Priorité/Priority: 2005/03/14 (US60/661,625)

(51) Cl.Int./Int.Cl. *A63B 21/00* (2006.01),  
*A63B 22/00* (2006.01)  
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(54) Titre : DISPOSITIF MANUEL DE REEDUCATION ET D'EXERCICE A RESISTANCE VARIABLE  
(54) Title: VARIABLE RESISTANCE EXERCISE AND REHABILITATION HAND DEVICE



(57) Abrégé/Abstract:

An exercising and rehabilitation hand device is disclosed. The hand device according to the invention is portable and controllable by smart fluid-based brakes/dampers to provide a compact, lightweight mechanism whose resistance to motion can be changed



(57) **Abrégé(suite)/Abstract(continued):**

on- the- fly, through computerize control, to vary the exercises that can be performed and tune the workout or rehabilitation session to the responses of the user.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization  
International Bureau(43) International Publication Date  
21 September 2006 (21.09.2006)

PCT

(10) International Publication Number  
**WO 2006/099484 A1**

(51) International Patent Classification:

A63B 21/00 (2006.01) A63B 22/00 (2006.01)

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(21) International Application Number:

PCT/US2006/009314

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(22) International Filing Date: 14 March 2006 (14.03.2006)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

60/661,625 14 March 2005 (14.03.2005) US

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

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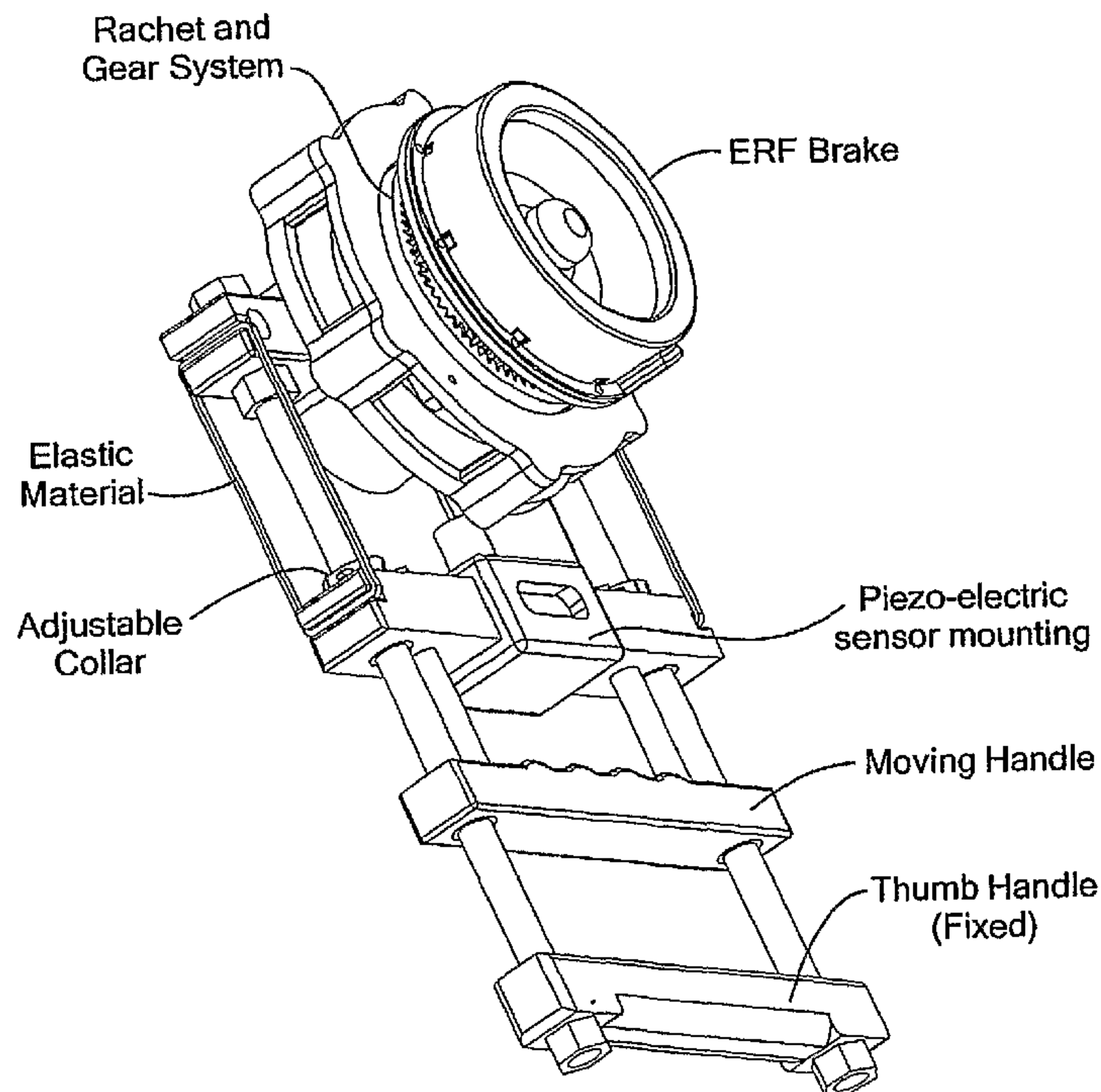
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(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ,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

[Continued on next page]

(54) Title: VARIABLE RESISTANCE EXERCISE AND REHABILITATION HAND DEVICE



(57) Abstract: An exercising and rehabilitation hand device is disclosed. The hand device according to the invention is portable and controllable by smart fluid-based brakes/dampers to provide a compact, lightweight mechanism whose resistance to motion can be changed on-the-fly, through computerized control, to vary the exercises that can be performed and tune the workout or rehabilitation session to the responses of the user.

WO 2006/099484 A1

**WO 2006/099484 A1**



**Declarations under Rule 4.17:**

- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
- *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*
- *of inventorship (Rule 4.17(iv))*

**Published:**

- *with international search report*

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

TITLE OF THE INVENTION  
VARIABLE RESISTANCE EXERCISE AND  
REHABILITATION HAND DEVICE

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the priority of U.S. Provisional Application No. 60/661,625 filed March 14, 2005 entitled, SMART VARIABLE RESISTANCE EXERCISE HAND DEVICE, the whole of which is hereby incorporated by reference herein.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

N/A

BACKGROUND OF THE INVENTION

Various devices exist to provide training and rehabilitation exercises for the human hand. These devices are usually based on simple mechanical systems such as springs and designed to provide resistive forces. Heavy Grips® hand grippers and Digi-Flex® rehabilitation systems are among the hand/finger exercise devices that are currently available and use springs to strengthen the hand grip. Other commercially available exercise devices for the hand and finger are even simpler, such as a flexible putty that provides resistance when a user squeezes it. Other similar exercise devices utilize rubber balls, egg-shapes or flexible sacks filled with various materials. While these are capable devices, the amount of resistive force that is available is fixed based on the material used and is not changeable in real time. Consequently, the range of exercises that are available with these devices is limited. Such devices must be changed in order to experience differing levels of resistance. However, these exercise and rehabilitative devices are in widespread use, and their low

cost, availability and simplicity have contributed to their usefulness.

Another category of rehabilitative devices is the rehabilitation machines, such as isokinetic and CPM machines. These devices move all the joints of the hand passively through a range of motion. They supply resistive and assistive forces, while providing a unique tailoring of the rehabilitation regime to nearly any individual.

#### BRIEF SUMMARY OF THE INVENTION

The present invention is directed to an exercising and rehabilitation hand device that addresses the shortcomings of existing devices. The hand device according to the invention is portable and controllable by smart fluid-based brakes/dampers to provide a compact, lightweight mechanism whose resistance to motion can be changed on-the-fly, through computerize control, to vary the exercises that can be performed and tune the workout or rehabilitation session to the responses of the user.

Smart fluids are a category smart materials, those whose properties can be altered through the application of various stimuli such as electric fields, magnetic fields and heat. As exemplified herein, smart fluids can be incorporated into small but powerful dampers to create lightweight devices whose properties can be changed to adapt to changing requirements. In one embodiment, a brake/damper based on the class of smart fluids known as Electro-Rheological Fluids (ERFs) is presented as an example of a smart fluid-based brake/damper system. An exercise and rehabilitation hand device utilizing an ERF brake/damper according to the invention is compact and lightweight with strong, highly tunable torque and force capabilities; is fully portable with onboard sensors, power and control circuitry; and has real time capabilities for closed loop computer control for optimizing rehabilitation exercises while in use. In comparable embodiments

of the invention, a magneto-rheological fluid could alternatively be used.

Thus, in one aspect, the invention directed to a rotary electro-rheological fluid brake/damper device for providing resistance to a torque or force input, the brake device including a housing comprising an insulative case, a shaft rotatably mounted in the case; one or more rotatable cylindrical electrodes mounted to the shaft for rotation therewith; one or more ground cylindrical electrodes fixed to the case and disposed in opposition to and concentrically with the rotatable electrodes, a gap disposed between the ground electrode and the rotatable electrodes; and an electro-rheological fluid disposed within the gap. Preferably, the rotatable cylindrical electrodes comprise a single integral part and the ground cylindrical electrodes comprise a single integral part. The rotatable cylindrical electrodes can comprise notches and holes sufficient to introduce discontinuities in the surface of the rotatable electrode to reduce eddy currents for utilizing the brake/damper in high magnetic field devices such as magnetic resonance imaging (MRI) .

In another aspect, the invention is directed to a linear electro-rheological fluid brake/damper for providing resistance to a torque or force input, the "concentric channel" damper ERF device including a housing comprising an insulative case, an interior ground cylindrical electrode fixed to the case, the interior cylindrical electrode being a concentric cylinder with the exterior electrode fixed on the case, two flow channels at both sides of the ground electrode mounted on the case, a gap disposed between the ground interior electrode and the exterior electrode, a piston that moves linearly inside the interior electrode, a two-way relief valve or a one-way valve mounted on the piston to adjust baseline damping; and an electro-rheological fluid disposed within the gap and the interior electrode.

In a further aspect, the invention is directed to a strength training and rehabilitative device for the hand including a handle assembly having one or more gripping elements for gripping and squeezing by a hand of a user and a damper assembly including a smart fluid as described herein. Preferably, the damper assembly includes the electro-rheological brake/damper described herein, a gear assembly attached to the shaft of the electro-rheological fluid damper to couple an input or output force or torque to the handle assembly; and a ratchet assembly to minimize the return force of the movable handle. Alternatively, the hand device according to the invention can include either of the electro-rheological fluid brake devices described herein. More preferably, the hand device includes a sensor system comprising a sensor assembly operative to measure angle, velocity, and acceleration of the handles, wherein the sensor assembly is operative to provide closed-loop control of the device. The sensor assembly can also be operative to measure torque on the shaft or/and force on the handles to provide closed-loop control of the device. A preferred hand device further includes a controller assembly operative to control the electro-rheological fluid device, wherein the control assembly is operative to provide remote communication. More preferably, the hand device is operable under battery power comprising one or more batteries, which can be disposed within the device or externally to the device.

In a most general aspect, the invention is directed broadly to a human interface stand-alone device for exercise or rehabilitation, the device including a frame assembly manipulatable by a user; and a damper assembly coupled to the frame assembly and operative to provide a controllable variable resistive force reactive to motion provided by a user's input, the damper assembly including a smart fluid damper. Preferably, the stand-alone device is configured as a desktop device. The device

is manipulatable via a hand, leg, foot, arm or any other appendage, or movable part of the body.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Other features and advantages of the invention will be apparent from the following description of the preferred embodiments thereof and from the claims, taken in conjunction with the accompanying drawings, in which:

Fig. 1 shows one embodiment of a hand device according to the invention, having pincer handle motion and a rotary brake;

Fig. 2 is a cross-sectional, 3-dimensional view of the ERF brake element of the embodiment of Fig. 1 showing fixed and rotating electrodes;

Fig. 3 is a cross-sectional, 3-dimensional exploded view of the fixed electrode surrounded by the resistive element prior to insertion of the rotating electrode;

Fig. 4 is a 3-dimensional exploded view of a portion of the embodiment of Fig. 1 showing the gears including the planet carrier and shafts;

Figs. 5A and 5B are 3-dimensional views from different perspectives of a portion of the view of Fig. 1 showing the transmission bracket connecting the handles and the gear system;

Fig. 6 is a cross-sectional, 3-dimensional exploded view of a portion of the embodiment of Fig. 1 showing the position of sensors with the handles fully extended at 45°;

Fig. 7 shows a further embodiment of a hand device according to the invention, having linear handle motion and a rotary brake;

Fig. 8 shows the rotating electrode of the rotary brake of the embodiment of Fig. 7;

Fig. 9 shows the planetary gear and ratchet/pawl mechanism of the embodiment of Fig. 7;

Figs. 10A-10C show the connection between the linear handle and the transmission (output) shaft of the embodiment of Fig. 7;

Fig. 11A shows the embodiment of Fig. 7 with the handles in the start position (open);

Fig. 11B shows the embodiment of Fig. 7 with the handles in the finish position (closed);

Figs. 12A and 12B are two views of a further embodiment of a hand device according to the invention, having linear handle motion and a linear damper;

Figs. 13A and 13B are cross-sectional, 3-dimensional views of the linear damper of the embodiment of Figs. 12A and 12B;

Fig. 14 is a cross-sectional, 3-dimensional view of the linear damper of the embodiment of Figs. 12A and 12B having a solid piston;

Fig. 15A is a cross-sectional, 3-dimensional view of the embodiment of Figs. 12A and 12B having an integrated one-way valve, the valve being in the closed position;

Fig. 15B is a cross-sectional, 3-dimensional view of the linear damper of the embodiment of Fig. 15A showing the direction of fluid flow;

Figs. 15C is a cross-sectional, 3-dimensional views of the embodiment of Figs. 12A and 12B having an integrated one-way valve, the valve being in the open position;

Fig. 15D is a cross-sectional, 3-dimensional view of the linear damper of the embodiment of Fig. 15C showing the direction of fluid flow; and

Figs. 16A and 16B are 3-dimensional views of an embodiment of the invention for individual fingers.

#### DETAILED DESCRIPTION OF THE INVENTION

Described herein is a portable, controllable, computerized, and variable resistance exercise and rehabilitation hand device that uses smart fluids to provide real-time controllable resistive forces. Smart fluids are an example of smart materials whose properties can be altered through the application of various

stimuli such as electric fields, magnetic fields and heat. Smart fluids can be incorporated into compact but powerful dampers/brakes to create lightweight devices whose properties can be changed to adapt to changing requirements. Smart fluids have been incorporated into exercising and rehabilitative devices according to the invention, as described herein, for hand therapy and hand-grip muscle strengthening.

Electro-rheological fluids, one class of smart fluids, experience changes in rheological properties, such as viscosity, in the presence of an electric field. The fluids are made from suspensions of particles on the order of 0.01 to 0.1  $\mu\text{m}$  in size in an insulating base fluid, such as an oil. The volume fraction of the particles is generally between 20% and 60%. The electro-rheological effect, sometimes called the Winslow effect, is thought to arise from the difference in the dielectric constants of the fluid and particles in the electro-rheological fluid (ERF). In the presence of an electric field, the particles, due to an induced dipole moment, form chains along the field lines. The induced structure changes the ERF's viscosity, yield stress, and other properties, allowing the ERF to change consistency from that of a liquid to something that is viscoelastic, such as a gel, at response times on the order of milliseconds. ERFs can apply very high electrically controlled resistive forces while their size (weight and geometric parameters) can be very small. ERFs are not abrasive, toxic, or polluting, thus meeting health and safety requirements. Using the electrically controlled rheological properties of ERFs, compact dampers/brakes capable of applying high resistive and controllable forces and torques are developed. They do not store energy like a spring or a weight machine, they are perfectly suited for haptics and rehabilitation because the human body is the actuator and the ERF is the damper/brake. The human body must always exert a force of its own in order to feel something. Therefore, only a resistive force from an ERF brake is

necessary for applications in muscle strengthening and rehabilitation.

The hand device according to the invention functions in real time and can precisely control the resistive force, as well as record the precise force and position, capabilities that separate it from its less efficient counterpart devices. The smart gripper hand device is operated by closing it by compressing (squeezing) its handles, and it is remotely adjusted to different levels of different resistive force. The controlled resistance option enables the person to control the resistance or amount of force required to open and close the hand grip, or move each individual finger in a smart finger/hand exercise device. Alternatives include: (1) isotonic, which will provide a constant amount of force for the individual to overcome in order to open and close the hand grip or move the finger in a finger exercise device; (2) variable resistance, in which the force at the beginning of the motion and the force at the end of the movement are different, with the computer regulating a smooth transition between the two values; (3) programmed resistance, which will permit the individual to specify a unique force pattern throughout the range of movement; and (4) velocity controlled mode wherein a precise velocity is programmed and the resistive force is varied to maintain this velocity dependent on the force input by the user. An interactive menu enables the user to indicate the precise initial and final values and the number of repetitions to be used. The hand grip motion will be independently programmed for the different alternatives.

The compact and lightweight characteristics of the device allow it to be used in any restricted-space area, such as homes, offices, and many medical and rehabilitative facilities. Another important feature is the portability of the device, which could enhance on-site therapeutic procedures. A patient can bring the device home with him/her to train and exercise. The doctor can

remotely monitor the patients training and performance. The doctor will not only know if the patient is actually doing the exercises but will also be able to monitor and optimize the dynamic resistance exercise remotely, via computer. This could be particularly important for those individuals whose immobility would prohibit receipt of such services.

Computerization provides for several important innovations. The activities performed are programmable for "individualized" diagnostic routines and/or exercise protocols with results stored for subsequent evaluations. The feedback control afforded by rapid computerized assessment and adjustment ensure that the equipment adjusts to the performance levels of the individuals. Individualized adjustment assures that size and/or gender are irrelevant for successful operation. Furthermore, graphic displays and audio cues can provide information to the individual with such items as current strength level, repetition number, and handle location. The sound cues are modulated in proportion to the exerted force in order to inform the individual about his or her performance response without the need to see the computer monitor. This simplifies operation as well as providing biofeedback.

The described devices use ERF dampers as the preferred method of applying resistive forces. However, this is not the only possible method for applying the necessary resistive forces. Other smart materials perform very similarly and can be used in the same fashion. For example, magneto-rheological fluids perform nearly identically to ERFs, using a magnetic field as opposed to an electric field. The important factor would be to maintain a compact, portable, computerized design with all the versatility that an ERF element provides.

The following examples are presented to illustrate the advantages of the present invention and to assist one of ordinary skill in making and using the same. These examples are not intended in any way otherwise to limit the scope of the disclosure.

#### EXAMPLE I

##### Hand Rehabilitation Device with Pincer Handle Motion and Rotary Brake

This design for the novel hand rehabilitation device consists of four major subsystems: a) an ERF resistive element; b) a gearbox; c) handles and d) two sensors, one optical encoder and one force sensor, to measure the patient induced motion and force. Each subsystem includes several components of varying complexity. In general, all of the components were designed, with strength and safety in mind, to be non-magnetic, and optimized for regular and high-stress testing. The device is made of polymers (plastic) and non magnetic materials, so it can be used in a wide variety of environments including high magnetic fields.

The maximum gripping force that can be generated by the hand in males is 400 N and in females 228 N. All components were designed so that the device is capable of applying 150N of force at the human operator's hand holding the device's handles (approximately 50% of a healthy hand's gripping force). The complete CAD model is shown in Fig. 1.

The unique controllable variable resistance of non-magnetic smart hand device is achieved through an ERF element that connects to the output of the gear system. The smart hand rehabilitation device uses a rotary ERF resistive element to control the resistive torque. The resistive element consists of two electrodes, each one being a set of multiple concentric cylinders. They were configured in a concentric circular pattern (Fig. 2).

One of the electrodes served as the fixed one and was located on the external side of the resistive element, while the second electrode served as the rotating one that could "mate" with the fixed one so that several consecutive pairs of concentric cylinders are formed. Fig. 3 shows each one of the electrodes, fixed and rotating, with each one's concentric cylinders ready to be "mated". The multiple concentric cylinder design for the two electrodes allows for maximum shearing surface area while maintaining a compact overall volume for the resistive element. The actuation of the viscous fluid occurs within the very small gap between consecutive cylinders of the fixed and rotating electrodes and is consequently creating a resistive torque on the rotating shaft. By manipulating the strength of the electric field applied on the fluid, at each pair of consecutive concentric cylinders, the torque can be easily controlled.

A gearbox was used to increase the resistive torque capabilities of the system as felt by the user. The resistive torque coming from the ERF resistive element is relatively small compared to what can be generated from a human hand. A resistive torque element without a gearbox would need to be excessively large. To keep the volume and weight of the entire device small, a large ratio gear box, 1 to 31.6 (Fig. 4) was designed. The gear system multiplies the ERF resistive torque and also serves as the foundation for the sensor sub-systems.

In this embodiment, the hand motion is applied to pincer handle mechanism. The handles are the haptic interface for the operator. They are designed to rotate 45 degrees about the center axis and were balanced at the center of mass. The thumb grip is the stationary grip and the center of mass of smart hand rehabilitation device is well centered just above the column of the grip. The hand grip assembly allows one degree of freedom and the transmission bracket transmits the force from the handles to the gear box input. The transmission bracket rotates about the

axis and transfers the force from the output gear system to the ERF brake (Fig. 5).

All of the necessary clinical data can be obtained by employing two primary sensors into the device design. The first is an optical encoder (Fig. 5) to measure angles, velocities, and accelerations of the hand. The optical encoder is attached to the input side of the gearbox and gives a direct reading of the handles position. The ideal sensor, which has been included into the present design, is a Renco Low-Profile Encoder with a 1024 resolution.

The second sensor is a miniature force sensor for measuring the gripping strength of the patients' hand and for closed-loop control of the ERF resistive element. The FUTEK force sensor (aluminum strain gage) links the stationary thumb grip/gearbox to the ERF resistive element via two parallel surfaces either loading the sensor in tension or compression (Fig. 6). The force sensor is supported at two ends with 3 degree of freedom (rotation) ball and socket pin connections so that the gage is loaded as a two force member. The pin connections are attached to the hand device by plastic sockets so that the force sensor is electrically insulated from the rest of the device. The ERF case and gear box case stay aligned along the central axis by a large plastic bearing. The ERF housing is free to rotate about its axis and the force sensor measures a direct reaction force from the ERF housing.

#### EXAMPLE II

##### Hand Rehabilitation Device with Linear Handle Motion and Rotary Brake

This proposed design for the novel hand rehabilitation device consists of five major subsystems: a) an ERF resistive element; b) a gearbox; c) ratchet system; d) handles and e) two sensors, one optical encoder and one force sensor, to measure the patient induced motion and force. Each subsystem includes several

components of varying complexity. In general, all of the components were designed, with strength and safety in mind, to be non-magnetic, and optimized for regular and high-stress testing. The smart hand rehabilitation device is configured to rest next to the person so no weight would be felt by the individual. The device is made of polymers (plastic) and non magnetic materials, so it can be used in a wide variety of environments including high magnetic fields.

The maximum gripping force that can be generated by the hand in males is 400 N and in females 228 N. All components were designed so that the device is capable of applying 300N of force at the human operator's hand holding the device's handles. The complete CAD model is shown in Fig. 7.

The unique controllable variable resistance of non-magnetic smart hand device is achieved through an ERF element that connects to the output of the gear system. The smart hand rehabilitation device uses a rotary ERF resistive element to control the resistive torque.

The resistive element consists of stationary and fixed aluminum electrodes, which were configured in a concentric circular pattern. The fixed electrode is a set of two concentric cylinders and is located on the external side of the resistive element. The rotating electrode is a simple concentric cylinder that mates with the fixed one so that several consecutive pairs of concentric cylinders are formed. These alternating plates serve as the positive and negative electrodes that generate the electric field to actuate the ERF. The actuation of the viscous fluid occurs within the very small gap between consecutive cylinders of the fixed and rotating electrodes and is consequently creating a resistive torque on the rotating shaft. By manipulating the strength of the electric field applied on the fluid, at each pair of consecutive concentric cylinders, the torque can be easily controlled. As shown in Fig. 8, some notches and holes are

implemented in the rotating electrode to introduce discontinuities in the rotating surface and avoid the effect of eddy currents if the smart hand device is used in the strong magnetic fields.

A gearbox is used to increase the resistive torque capabilities of the system as felt by the user. The resistive torque coming from the ERF resistive element is relatively small compared to what can be generated from a human hand. A resistive torque element without a gearbox would need to be excessively large. To keep the volume and weight of the entire device small, a planetary gear system (gear ratio of 1 to 5.5) is used to multiply the ERF resistive torque. Gear box is made of Delrin which is non-magnetic.

A ratchet gear system is employed to minimize the return force of the system (opening of the handles) so that the device can be reset into the start position with a minimally sized spring force. The ratchet and pawl mechanism allows motion in one direction but locks it in the other direction (a pawl which is a beam pivoted at one end, designed to engage with the ratchet teeth to prevent the wheel from moving in one direction). Ratchet-wheel teeth are designed on the perimeter of the ring gear. When the user is closing (squeezing) the handles, the ratchet system allows the motion of gears and the ERF brake; and transfers the resistive torque to the housing that the pawl is attached to, and therefore to the output shaft. When the handles are closed, the ratchet system locks the motion of the gear system and the ERF resistive brake. The ratchet system prevents the reverse rotation when the handles are released and the input force by the person is removed. Then the pawl housing and output shaft disengages from the ERF resistive element and the device is reset into the start position by an elastic material or small size springs. Ratchet and gear mechanism is shown in Fig. 9.

The torque coming from the ERF resistive element is multiplied by the planetary gear system and is transferred to the

pawl housing. This torque is transferred to the linear handles. In this design, the rotary motion of the brake/gears/ratchet is converted to the linear motion of handles through a flexible wire that is wrapped around the output shaft. This wire at the other end is connected to the piezo-electric sensor mounting that has a linear motion since the mounting is connected to the moving handle. For a known torque, higher force is generated when the moment arm (shaft diameter) is smaller ( $\text{torque} = \text{force} \times \text{moment arm}$ ). Therefore, for generating the highest resistive force from the resistive torque, the wire is wrapping around a shaft that has a very small diameter. This output shaft connects to the pawl housing and transfers the resistive torque from the ER brake to the flexible wire. Figs. 10A-10C show how the linear handle is connected to the transmission (output) shaft. The ratchet system, pawl housing, and output shaft are made of non magnetic materials.

In this embodiment, the hand motion is applied to a linear sliding mechanism and the handles are the haptic interface for the operator. The sliding motion is converted to a rotary motion through a flexible wire that connects the sensor mounting (linear motion) to the transmission shaft (rotary motion) like a pulley. The hand grip assembly allows one degree of freedom and transmits the force of the system to the ratchet and gear box system.

Two adjustable collars are implemented in the arms of the handles to adjust the stroke of the handles for different persons with different grip hand sizes. Also, the length of the arms in this handle assembly can be adjusted to allow the brake/gear/ratchet system portion to be positioned further than the grip handles. The handles are made of plastic and non magnetic materials. Fig. 11A shows the handles when they are in the start position, and Fig. 11B shows the handles when they are completely closed.

All of the necessary clinical data can be obtained by employing two primary sensors into the device design. The first is

an optical encoder (Fig. 10A) to measure angles, velocities, and accelerations of the hand. The optical encoder is attached to transmission shaft and gives a direct reading of the handles' position. The ideal sensor, which has been included into the present design, is a Renco Low-Profile Encoder with a 1024 resolution.

The second sensor is a piezo-electric sensor for measuring the gripping strength of the person's hand and for closed-loop control of the ERF resistive element (see Fig. 10B). The piezo-electric sensor is installed in the sensor housing and gives the direct reading of the hand grip force from the linear motion of the handles. The sensor housing is designed to connect the moving (sliding) handle to the flexible wire rope. The piezo-electric force sensor is positioned between the housing and moving handle.

A second option for the force sensor is a miniature force sensor (aluminum strain gage type) to measure the torque from the ERF resistive element as in the previously described embodiments. The force sensor links the stationary thumb grip/gearbox to the ERF resistive element. With this option, the ERF housing is free to rotate about its axis and the force sensor measures a direct reaction force from the ERF housing. Then this force can be easily multiplied by the gear ratio and the grip strength is measured.

### EXAMPLE III

#### Hand Rehabilitation Device with Linear Handle Motion and Linear Damper

A second configuration of the hand device places a linear damper in line with the direction of motion. A novel ERF "concentric channel" damper (ERF-CCD) (Figs. 12A and 12B) has been designed. There are several advantages to a linear configuration including decreased device complexity, reduced part count, and elimination of the need for gears, and a ratchet subsystem. The outer case of the damper is attached to the frame. The shaft

attaches directly to the force sensor. Motion is captured using a linear encoder or a rotary encoder modified for linear use. The return force is provided by two springs or "bungee" cords that can be adjusted in length and stiffness. The overall stroke of the device can be quickly adjusted using shaft collars.

In commercially available linear ERF dampers, fluid flows through channels in or around outside of the piston. For these designs, to obtain maximum damping the piston must be very large (to maximum surface area of the electrodes) or the fluid flow channels must be very small. Both configurations have distinct disadvantages. The configuration with a large piston (in length and/or diameter) forces the design to be large so a compact high performance device is impossible. The small fluid channel option also introduces negative performance characteristics, as the channels reduce the flow of fluid even when the device is not energized reducing the dynamic range of damping that the device will be capable of.

The ERF-CCD generates damping by modulating (dependent on field strength) the flow of fluid between its two chambers using concentric gap surrounding the cylinder body. The fluid flows through channels at either of the damper. These channels lead to a gap that is formed by the exterior surface of the cylinder body and another concentric cylinder with a slightly larger diameter (see Figs. 13A-13B and 15A-15D). The piston can be solid as shown in Fig. 14, include a two-way relief valves (not shown) to adjust baseline damping, or include a one-way valve (ball type, butterfly type, etc.) as shown in Figs. 13A-13B and 15A-15D. The choice depends on the end application of the damper. For the hand rehabilitation device, a one-way valve is integrated into the piston to allow reduced damping in one direction (see Figs. 15A-15D). This novel design leverages the largest possible electrode surface area per damper volume and offers significant gains in

power density over alternative designs. The low part count and simplified design also lead to low cost and high reliability.

Figs. 15A and 15B show the fluid flow pathway details of ERF-CCD with a one-way valve. Fig. 15B shows that in the presence of an electric field, the one-way valve is closed, and the fluid flow rate through the concentric channel is being modulated by adjusting the field strength. The higher the field, the thicker the ERF and the higher the damping. Fig. 15D shows how the one-way valve opens when the handles are close together, allowing flow of fluid through the piston. Fluid can also move through the concentric gap, further reducing the force needed to return the handles to the starting position.

#### EXAMPLE IV

##### Finger/Hand Rehabilitation Device

This device is designed to operate as a portable and computerized rehabilitation or exercising device for the finger and palm. This device incorporates compact and linear type of electro-rheological fluid type resistive elements to provide resistance to individual fingers that can be changed in real-time for each individual finger. Figs. 16A and 16B show two conceptual drawings in which linear smart fluid resistive elements are attached to the fingers and grounded to a core which is fixed to the inside of the palm. The image shows configurations for two or four fingers, but can easily be extending to cover all five fingers by attaching on additional resistive elements to the central core. Forces are generated by smart-fluid resistive elements whose resistance can be changed through computer control software. This allows for individualized exercise regimens that can be changed, on-the-fly, to adapt to the needs of a patient, or to the different exercise needs of each finger.

While the present invention has been described in conjunction with one or more preferred embodiments, one of ordinary skill, after reading the foregoing specification, will be able to effect various changes, substitutions of equivalents, and other alterations to the compositions and methods set forth herein. It is therefore intended that the protection granted by Letters Patent hereon be limited only by the definitions contained in the appended claims and equivalents thereof.

## CLAIMS

What is claimed is:

1. A variable resistance hand device comprising:  
a handle assembly having one or more gripping elements for gripping and squeezing by the hand of a user; and  
a damper assembly coupled to the handle assembly and operative to provide a controllable variable resistive force reactive to squeezing of the gripping elements of the handle assembly by a user's hand, said damper assembly comprising a smart fluid damper.
2. The hand device of claim 1, further comprising a force sensor assembly operative to provide a force signal representing the magnitude of the squeezing force.
3. The hand device of claim 2, wherein the force sensor assembly is operative to provide closed-loop control of the device.
4. The hand device of claim 1, further comprising a position sensor assembly operative to provide a position signal representing the relative position of the gripping elements.
5. The hand device of claim 3, wherein the position sensor assembly is operative to provide closed-loop control of the device.
6. The hand device of claim 1, wherein said smart fluid is an electro-rheological fluid (ERF).
7. The hand device of claim 1, further comprising a controller assembly operative to control the operation of the device.

8. The hand device of claim 7, wherein the controller assembly is operative to provide remote communication.
9. The hand device of claim 1 or claim 6, wherein the handle assembly comprises pincer handles and wherein the damper assembly comprises a rotary brake.
10. The hand device of claim 1 or claim 6, wherein the handle assembly comprises linear handles and wherein the damper assembly comprises a rotary brake.
11. The hand device of claim 1 or claim 6, wherein the handle assembly comprises linear handles and wherein the damper assembly comprises a linear brake.
12. The hand device of claim 1, wherein said smart fluid is a magneto-rheological fluid (ERF).
13. The hand device of claim 1, wherein the damper assembly comprises a gear box coupling the handle assembly to the damper assembly.
14. The hand device of claim 1, wherein the damper assembly comprises a ratchet mechanism to minimize the return force of the handle assembly to rest position following squeezing by the user.
15. The hand device of claim 1, wherein the device is constructed substantially of materials that are MRI compatible.
16. The hand device of claim 4, wherein the damper assembly comprises:

a housing comprising an insulative case and a shaft rotatably mounted in the case;

one or more rotatable cylindrical electrodes mounted to the shaft for rotation therewith;

one or more ground cylindrical electrodes fixed to the case and disposed in opposition to and concentrically with the rotatable electrodes, a gap disposed between the ground electrode and the rotatable electrodes; and

an electro-rheological fluid disposed within the gap.

17. The hand device of claim 1, wherein the damper assembly comprises a rotatable electrode, the rotatable electrode comprising notches and/or holes sufficient to introduce discontinuities in the surface of the electrode, to reduce eddy currents in said electrode upon operation of said device in a high magnetic field.

18. A variable resistance brake comprising:

a housing comprising an insulative case and a shaft rotatably mounted in the case;

one or more rotatable cylindrical electrodes mounted to the shaft for rotation therewith;

one or more ground cylindrical electrodes fixed to the case and disposed in opposition to and concentrically with the rotatable electrode, a gap disposed between the ground electrode and the rotatable electrode;

a smart fluid disposed within the gap; and

a ratchet mechanism operative to control direction of rotation of the rotatable electrode.

19. The variable resistance brake of claim 18, wherein the smart fluid is an electro-rheological fluid.

20. A variable resistance brake comprising:

a housing comprising an insulative case and a shaft rotatably mounted in the case;

one or more rotatable cylindrical electrodes mounted to the shaft for rotation therewith;

one or more ground cylindrical electrodes fixed to the case and disposed in opposition to and concentrically with the rotatable electrode, a gap disposed between the ground electrode and the rotatable electrode; and

a smart fluid disposed within the gap, wherein the rotatable electrode comprises notches and/or holes sufficient to introduce discontinuities in the surface of the electrode, to reduce eddy currents in said electrode upon operation of said brake in a high magnetic field.

21. The variable resistance brake of claim 20, wherein the smart fluid is an electro-rheological fluid.

22. A human interface stand-alone device for exercise or rehabilitation, said device comprising:

a frame assembly manipulatable by a user; and

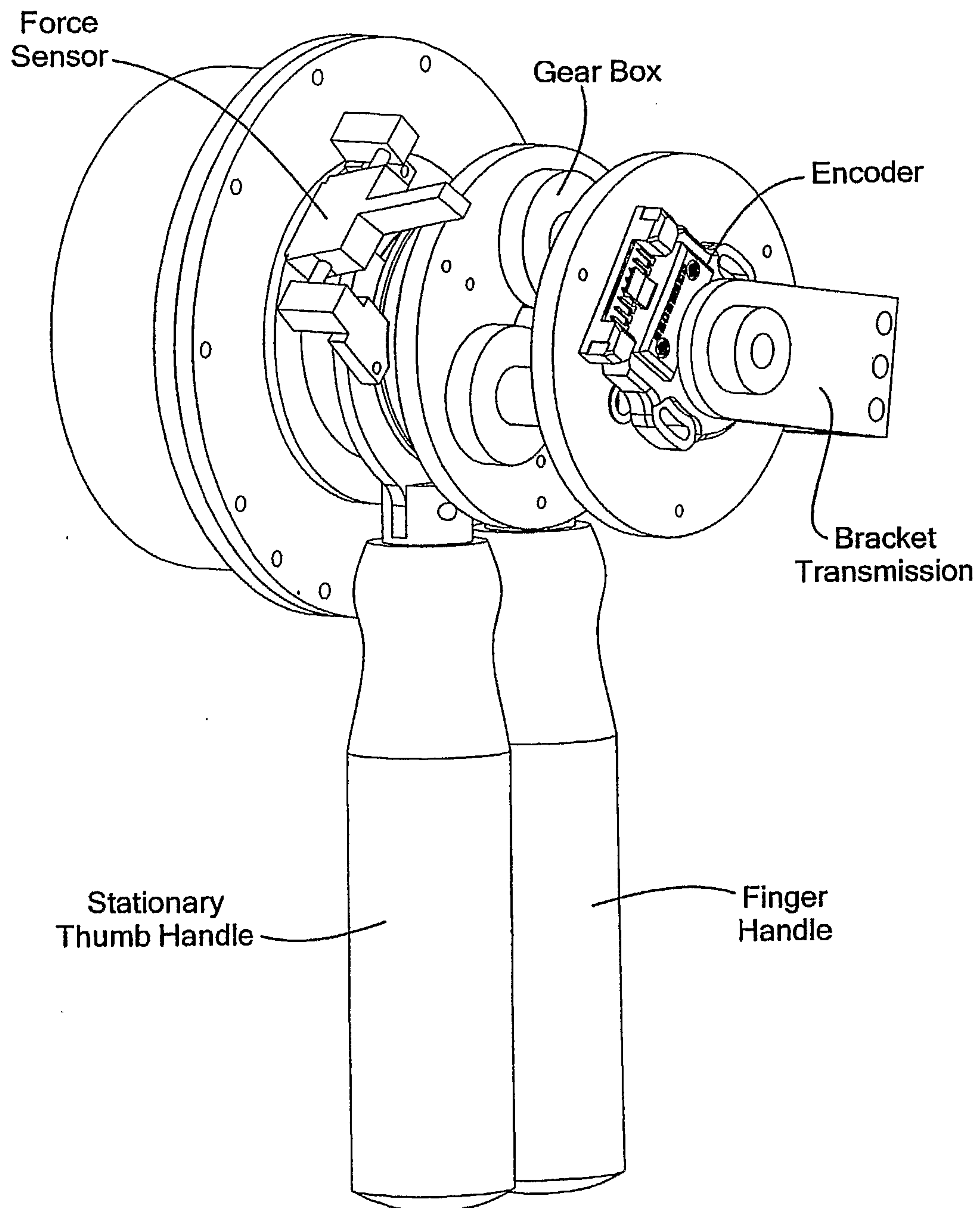
a damper assembly coupled to the frame assembly and operative to provide a controllable variable resistive force reactive to motion provided by a user's input, said damper assembly comprising a smart fluid damper.

23. The stand-alone device of claim 20, wherein said device is configured as a desktop device.

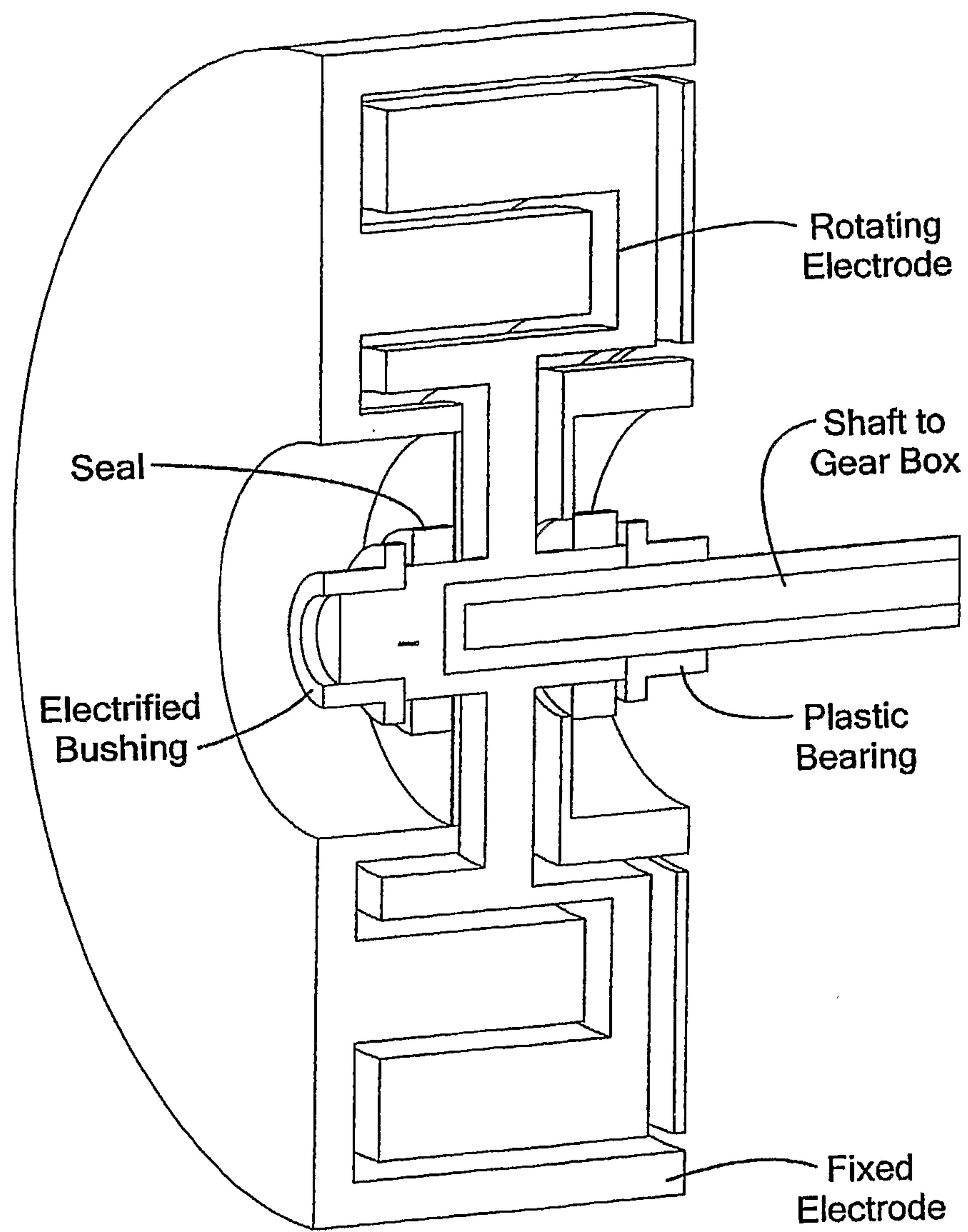
24. The stand-alone device of claim 20, wherein said device is manipulatable via a hand, leg, foot, arm or any other appendage or movable part of the body.

25. The stand-alone device of claim 20, wherein said smart fluid is an electro-rheological fluid.

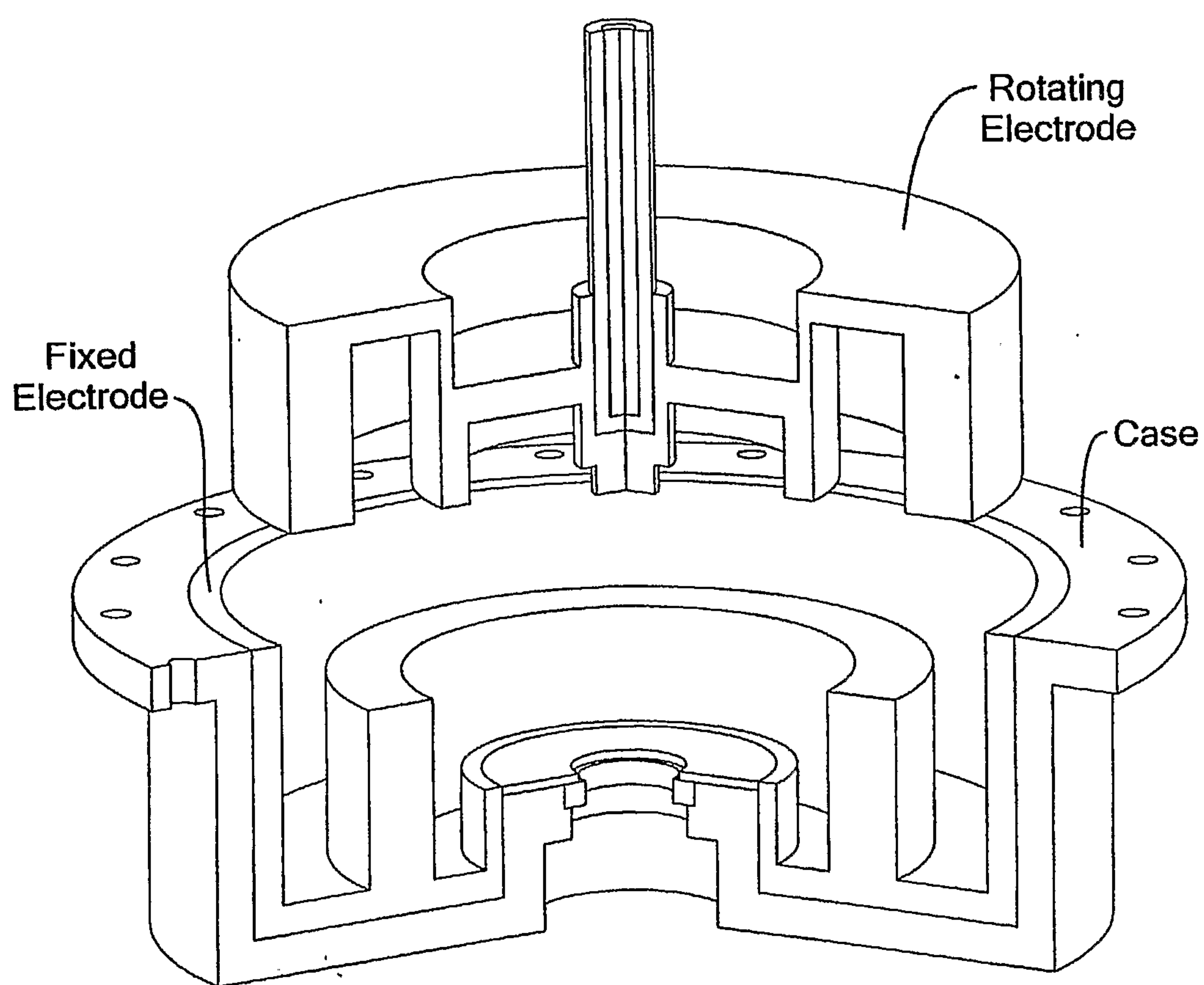
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**FIG. 1**

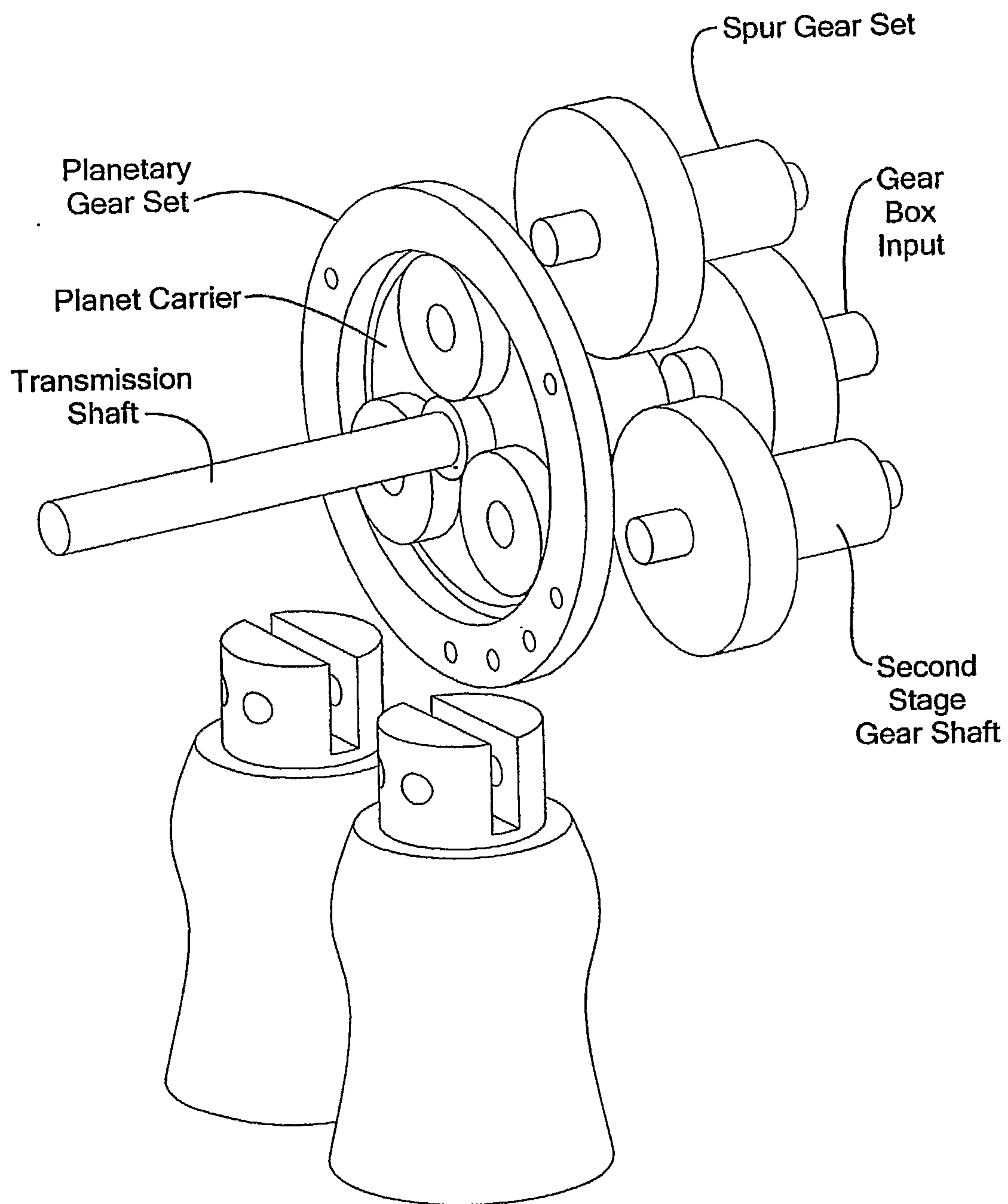
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**FIG. 2**

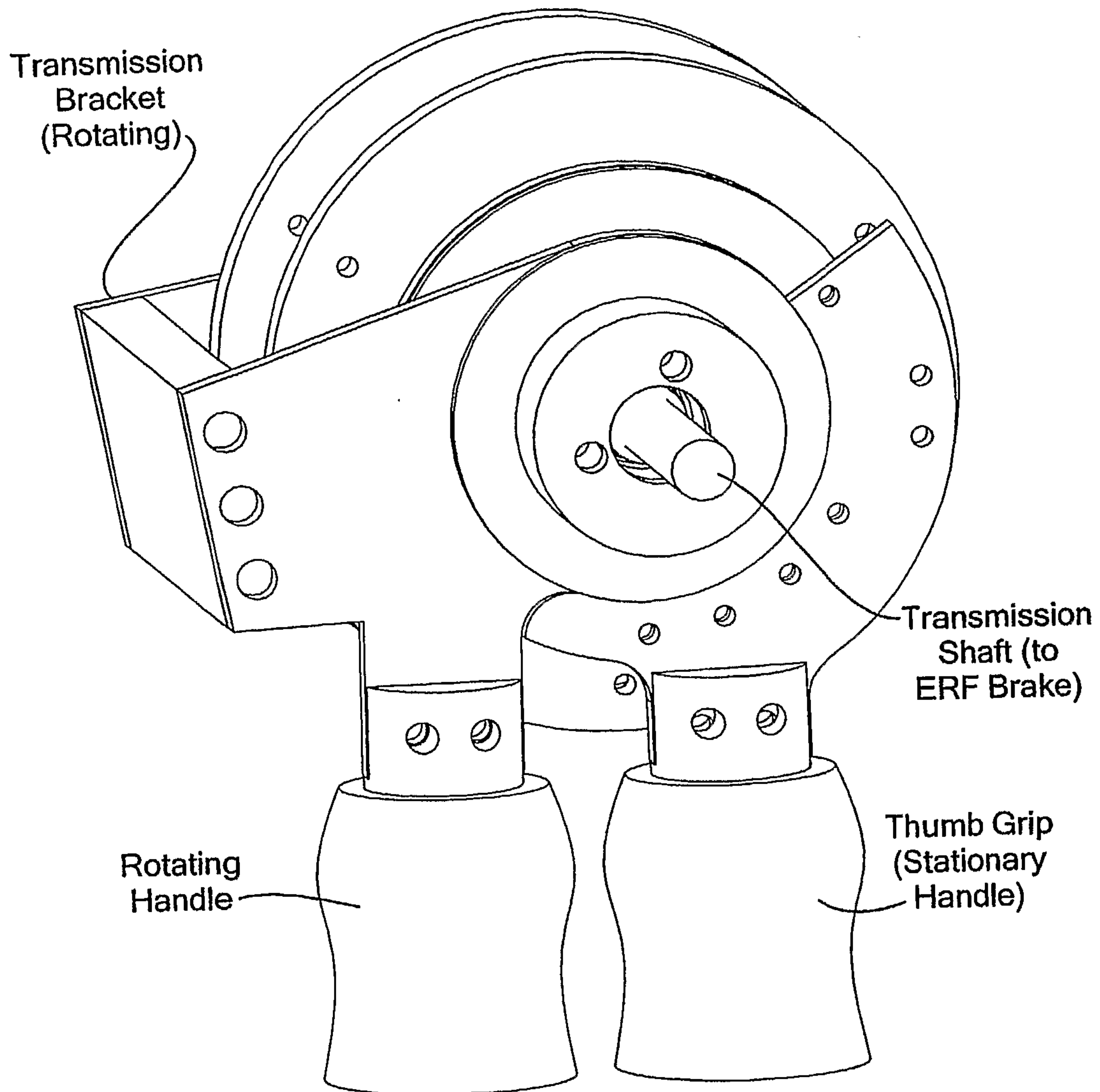
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***FIG. 3***

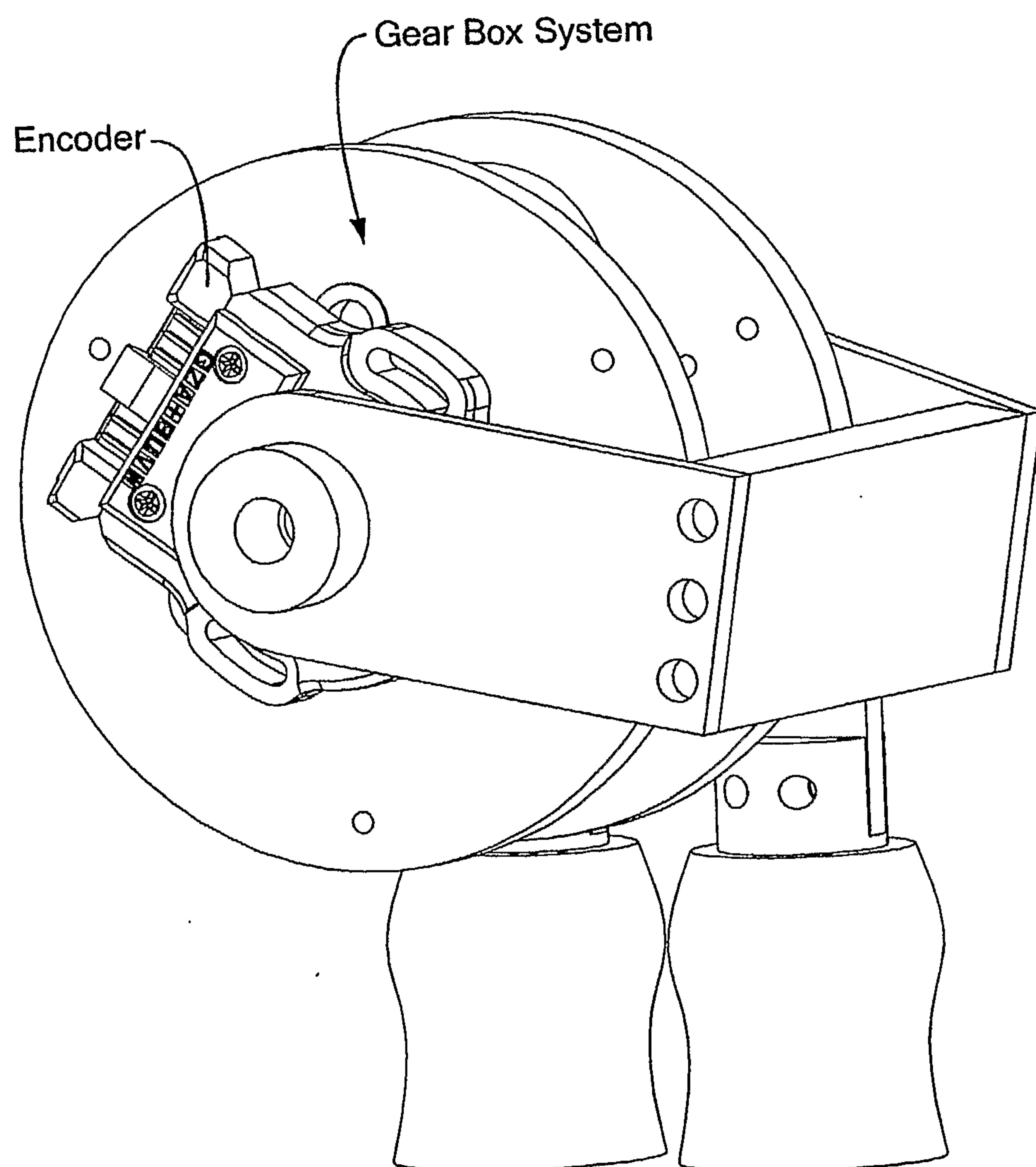
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**FIG. 4**

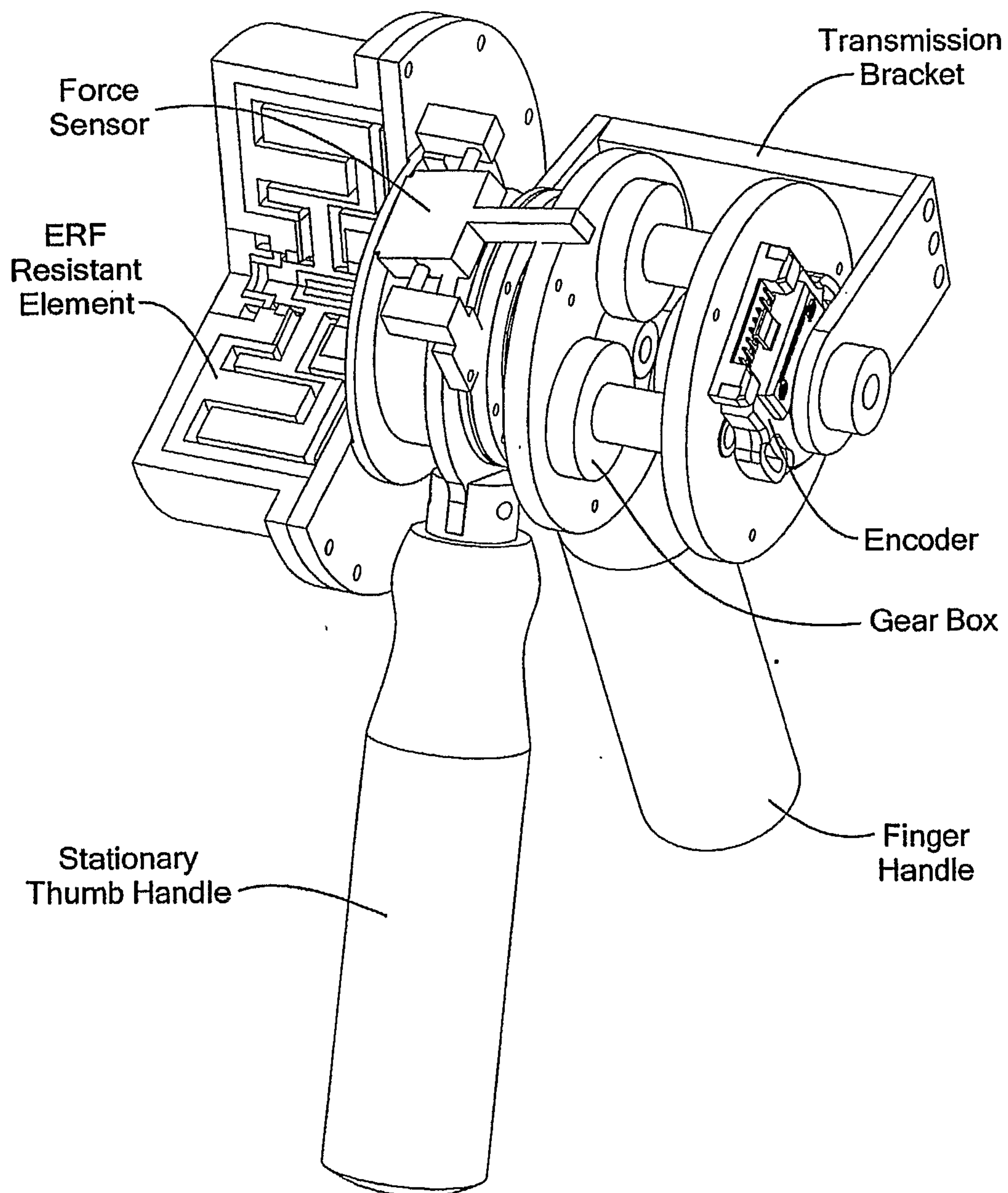
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**FIG. 5A**

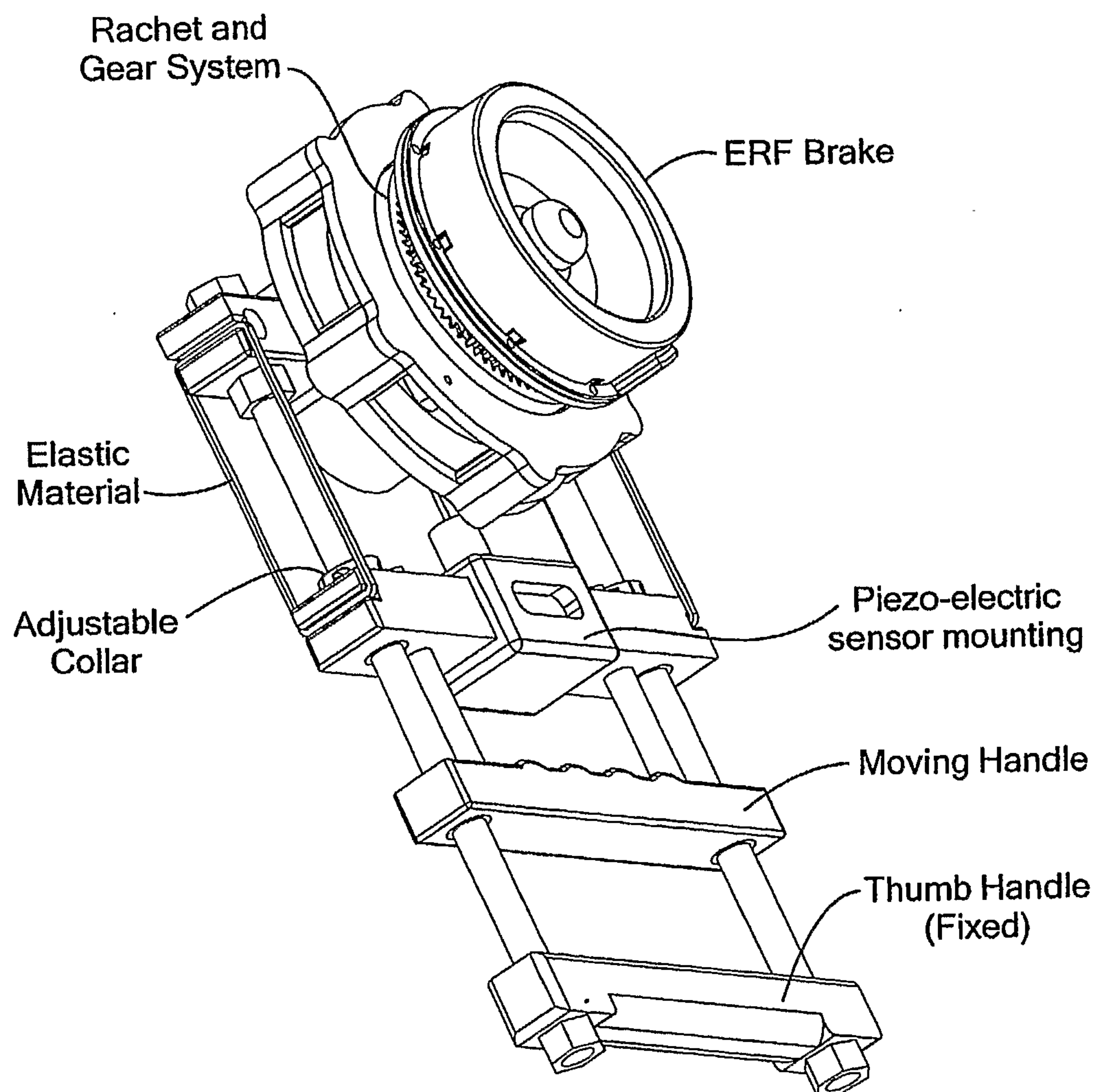
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**FIG. 5B**

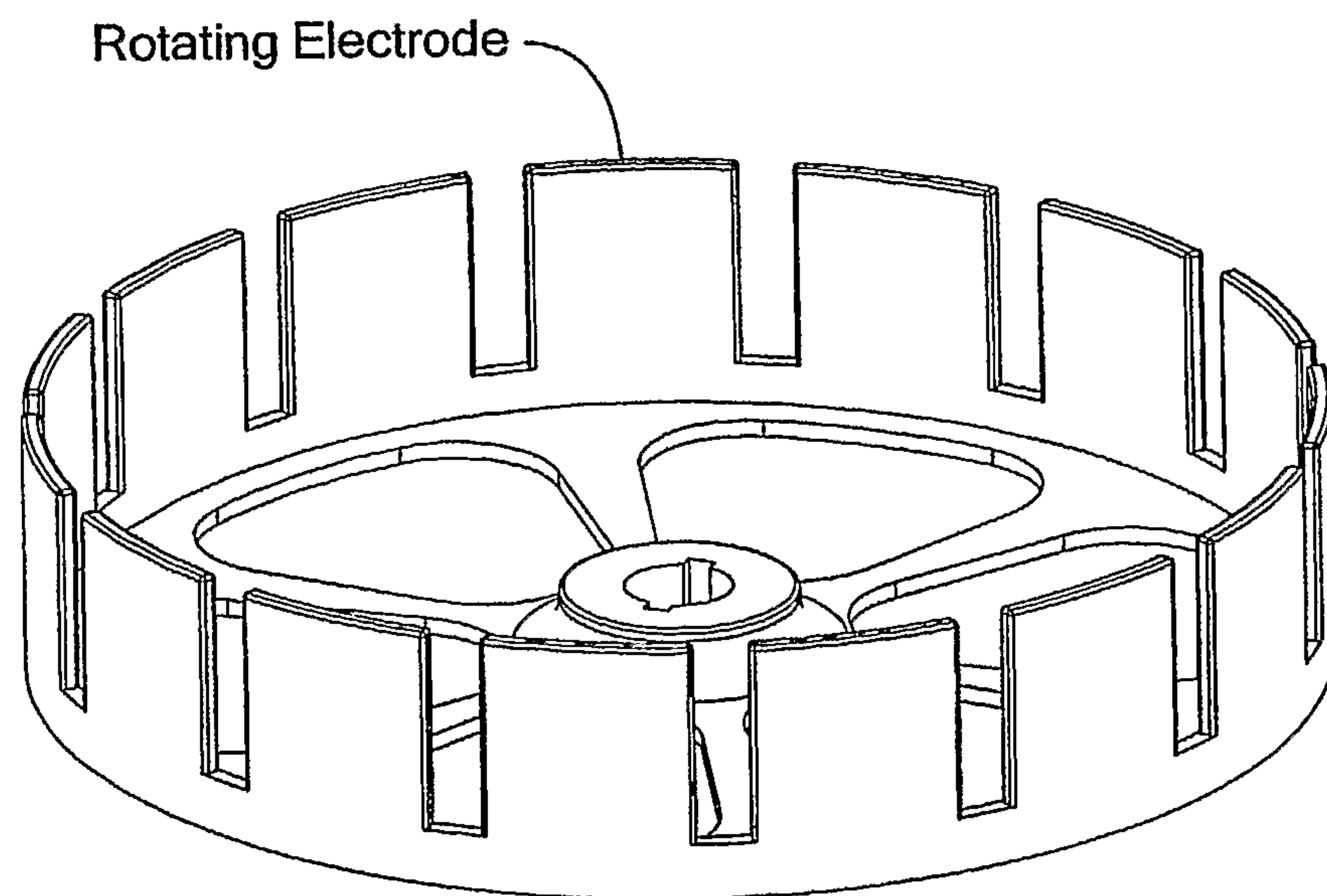
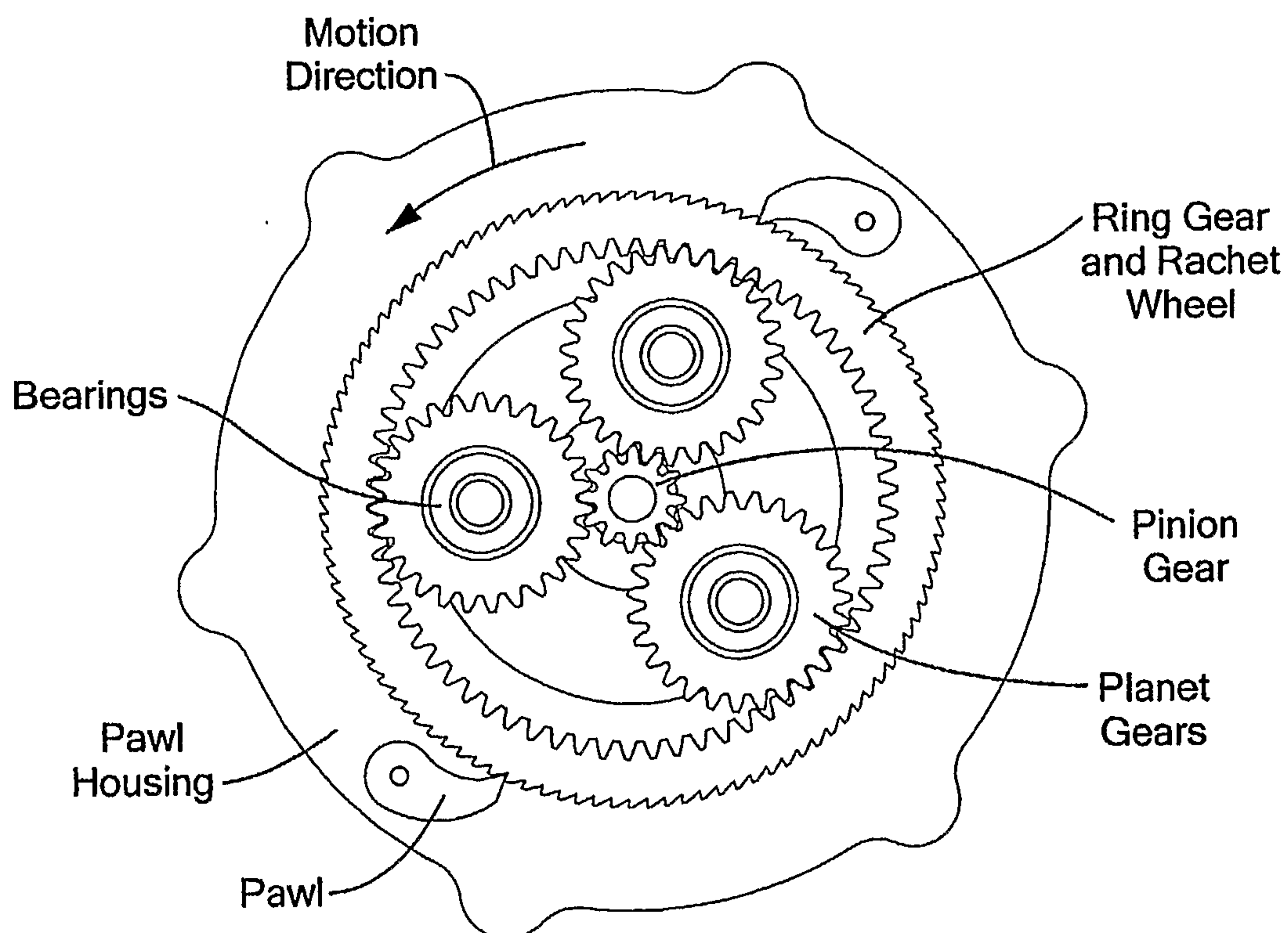
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**FIG. 6**

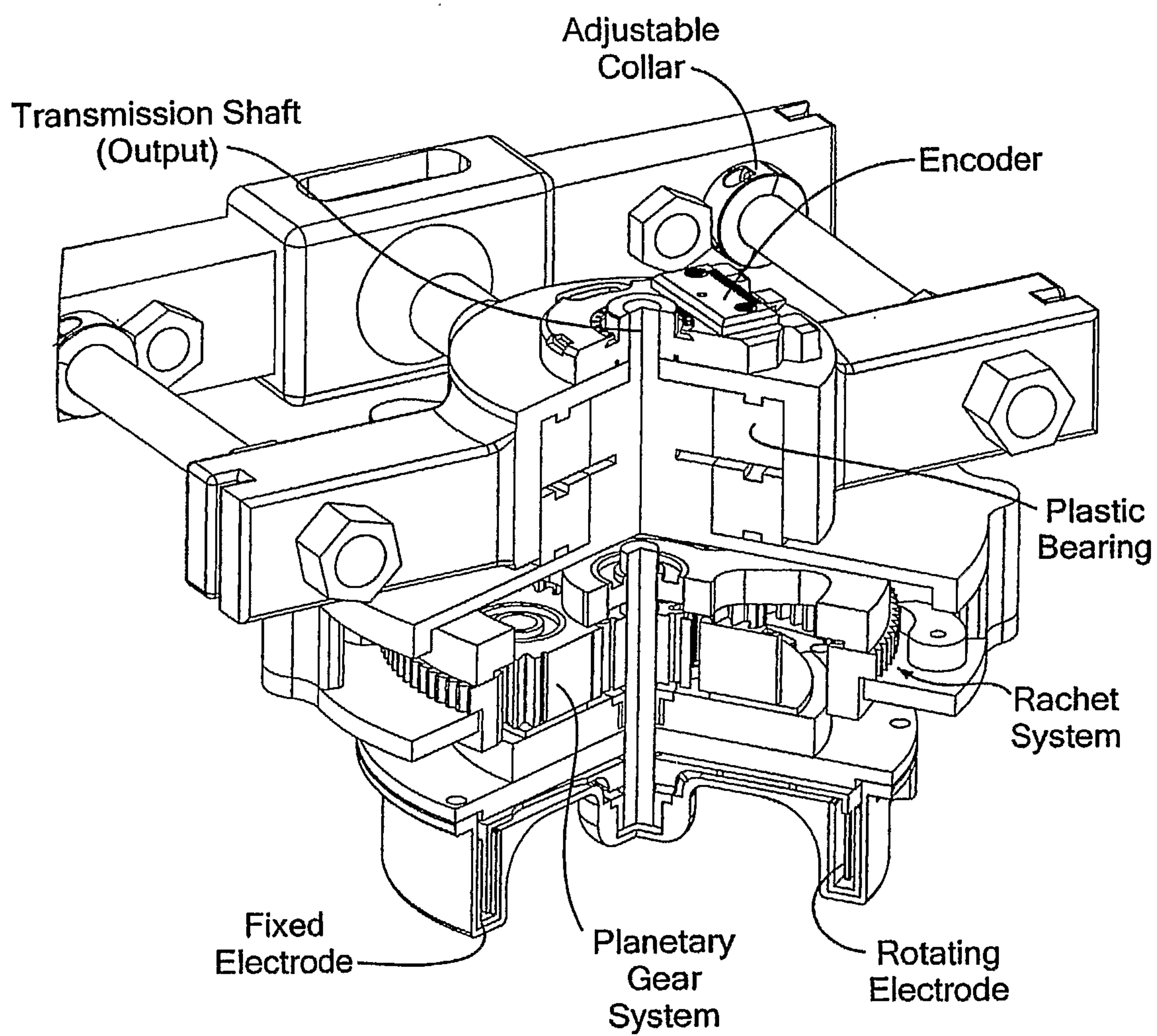
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**FIG. 7**

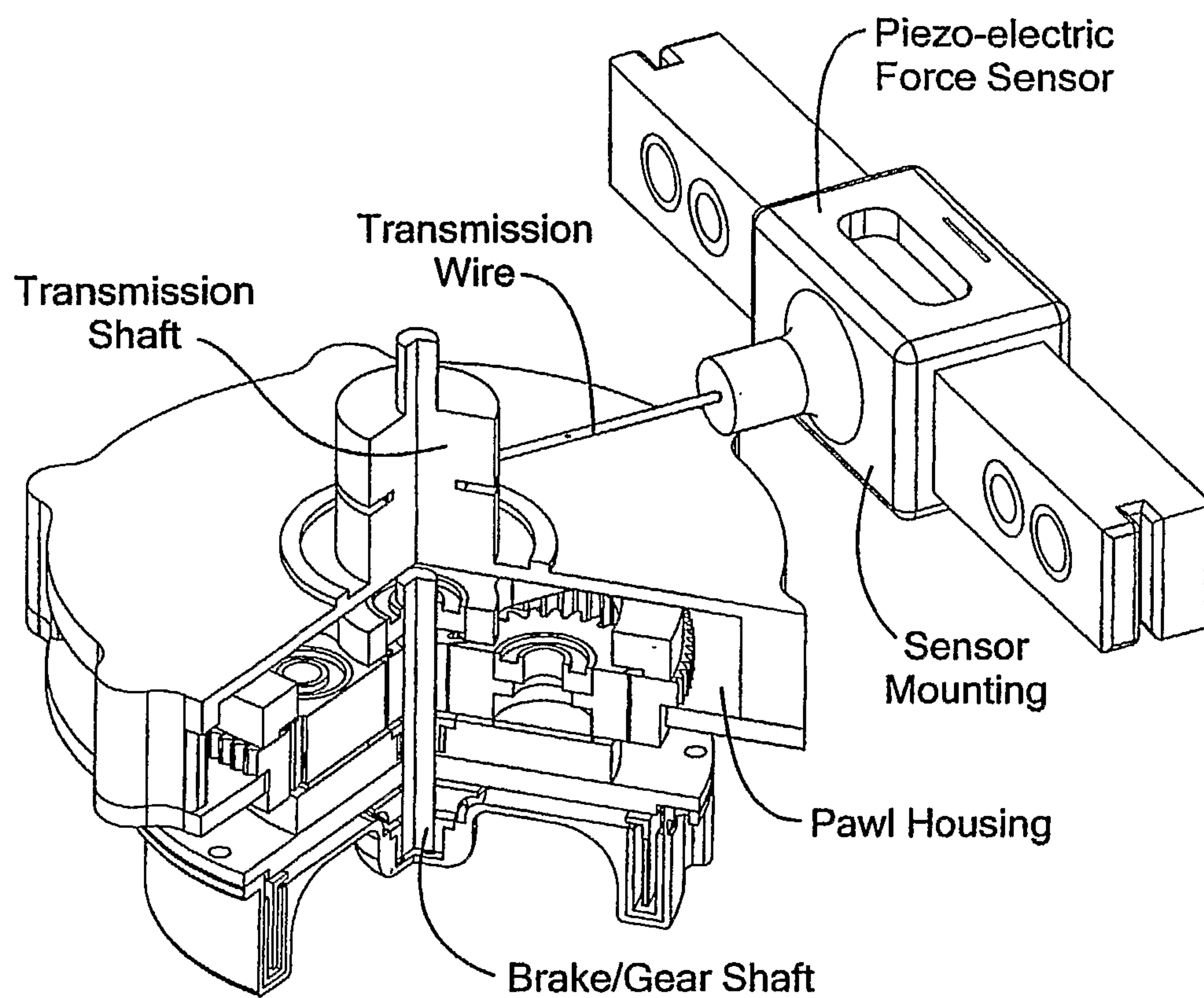
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**FIG. 8****FIG. 9**

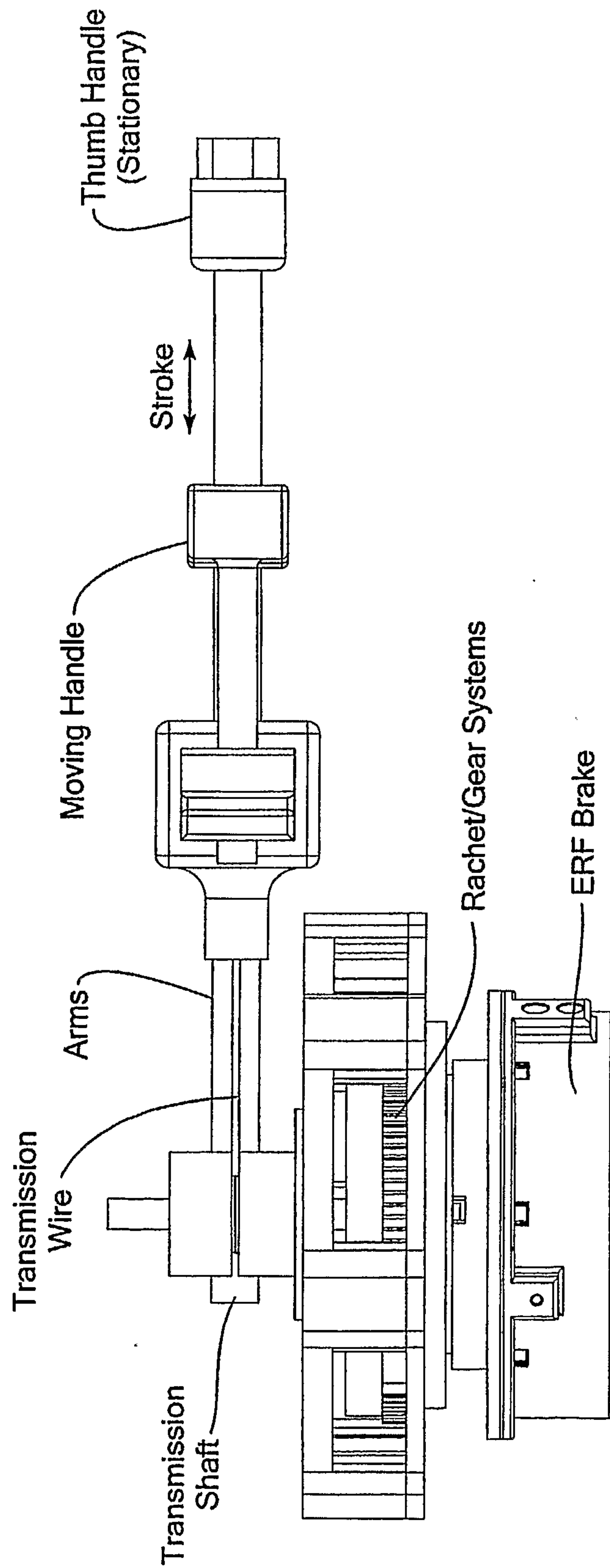
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**FIG. 10A**

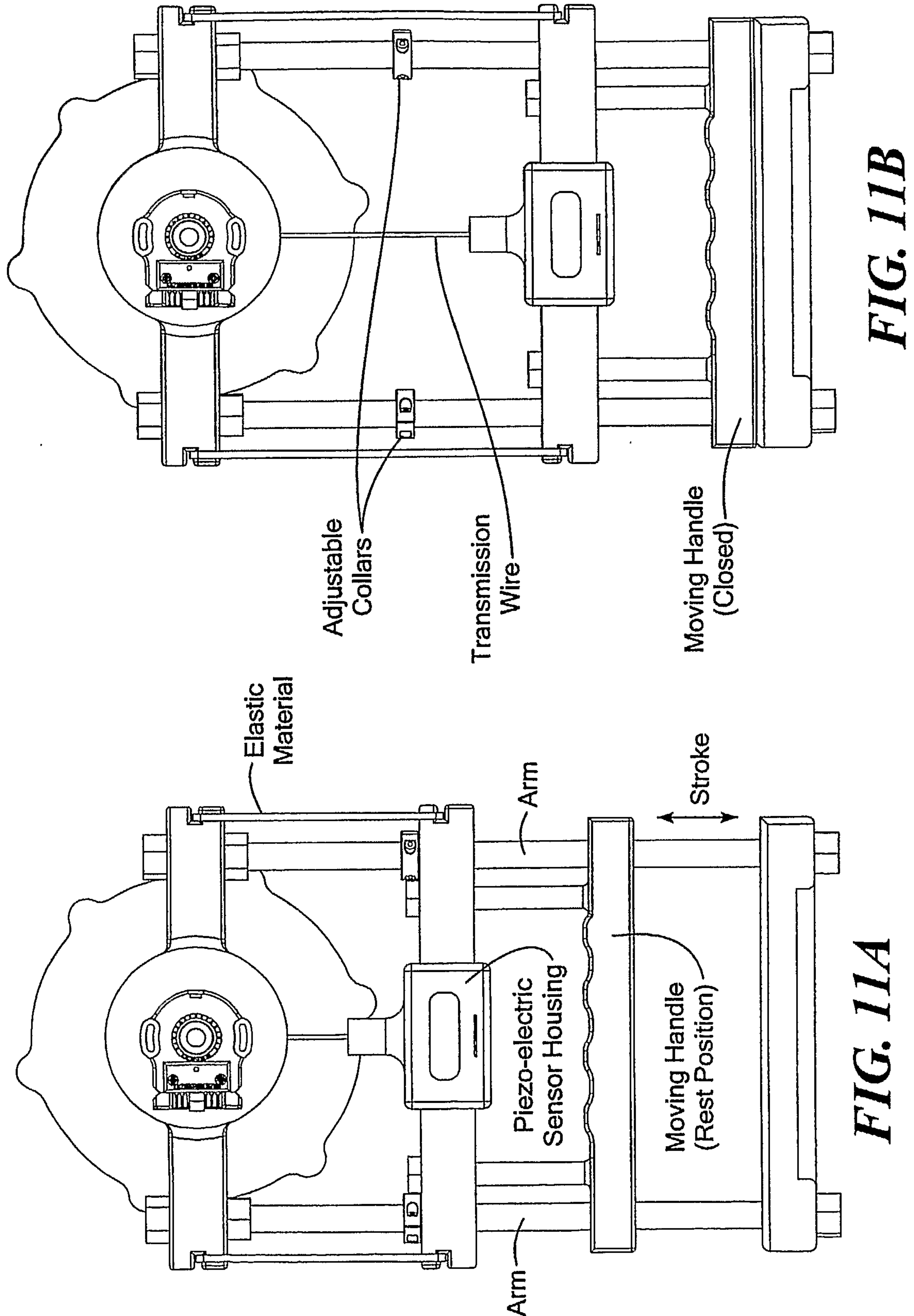
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**FIG. 10B**

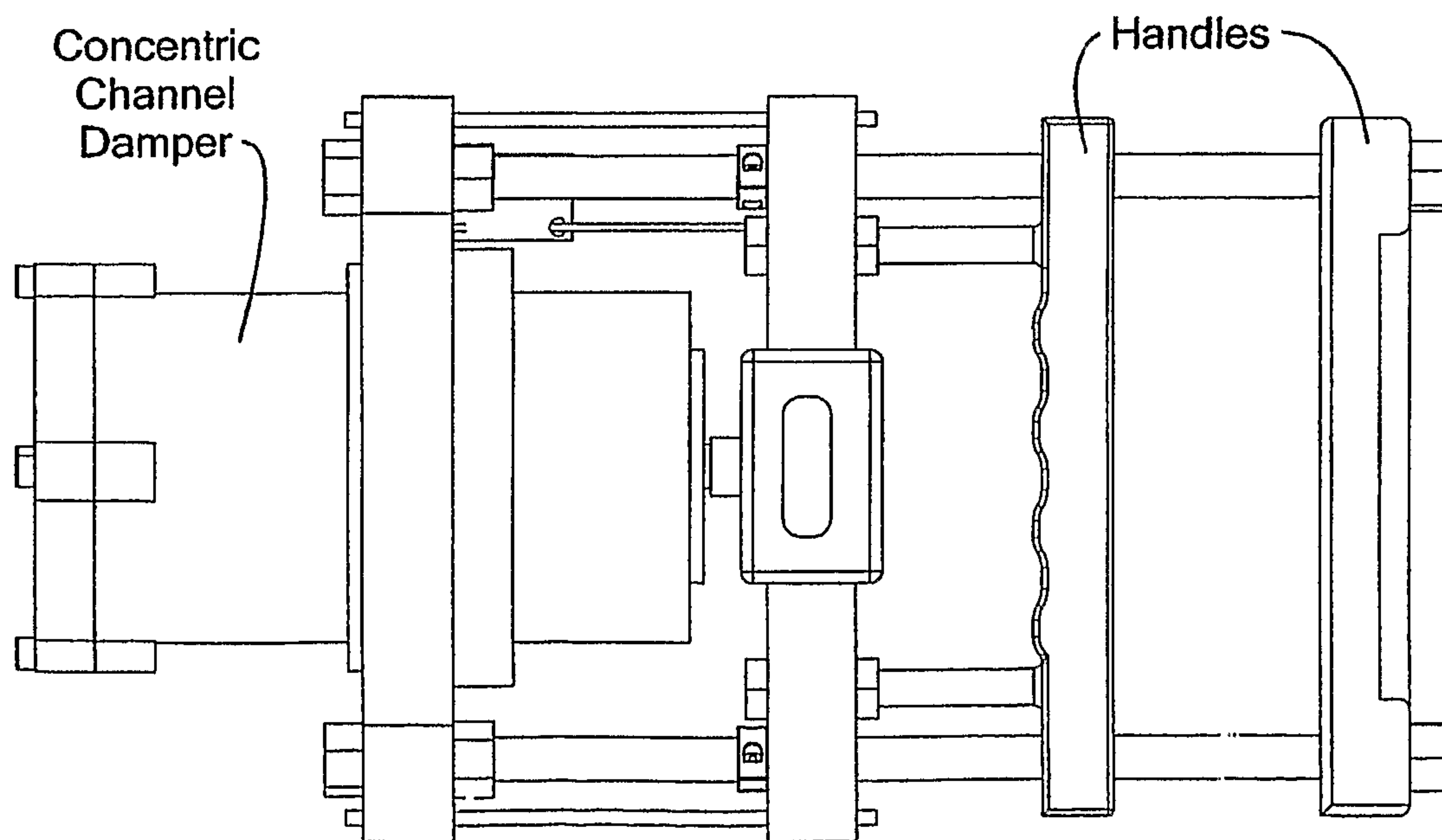
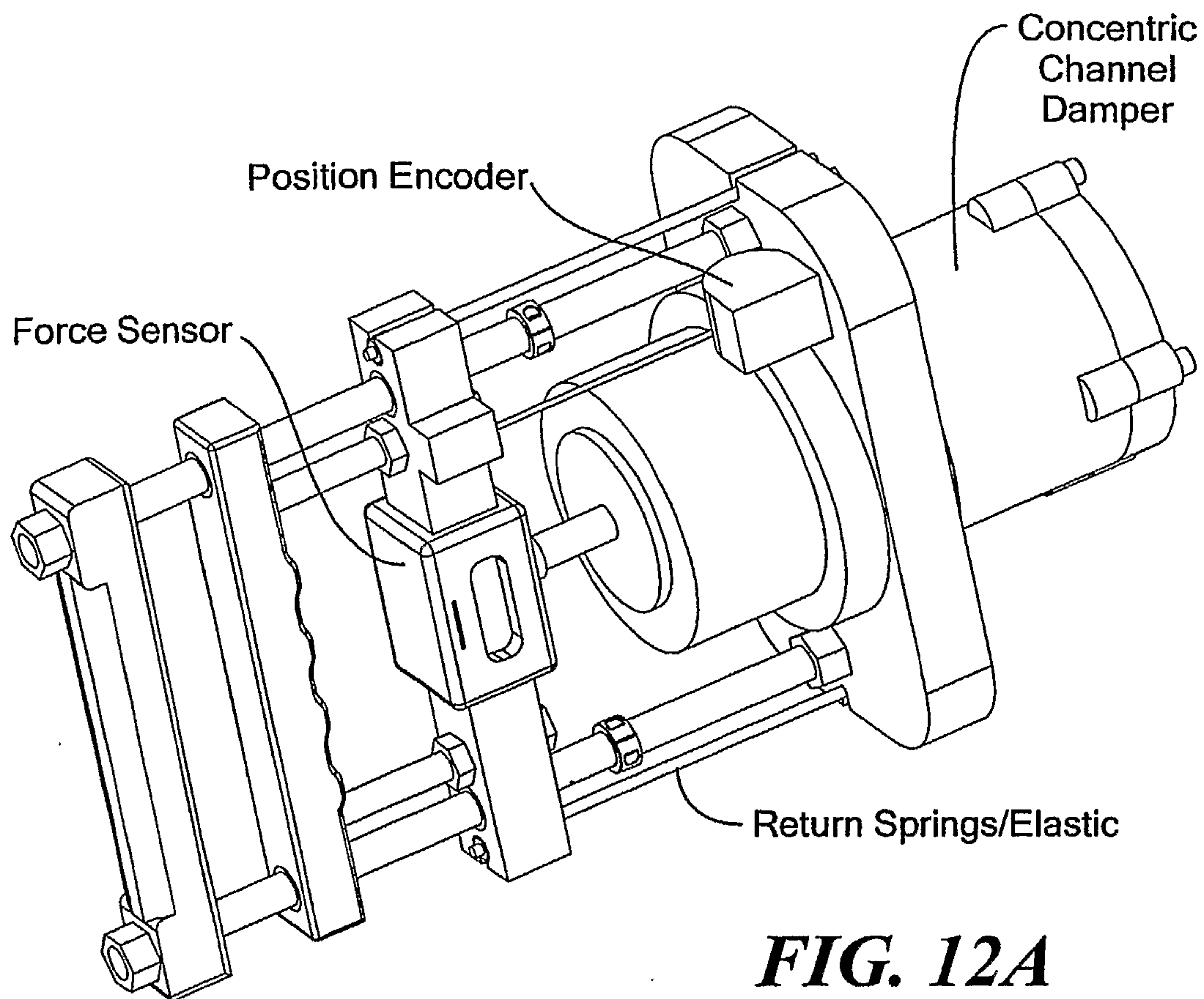
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**FIG. 10C**

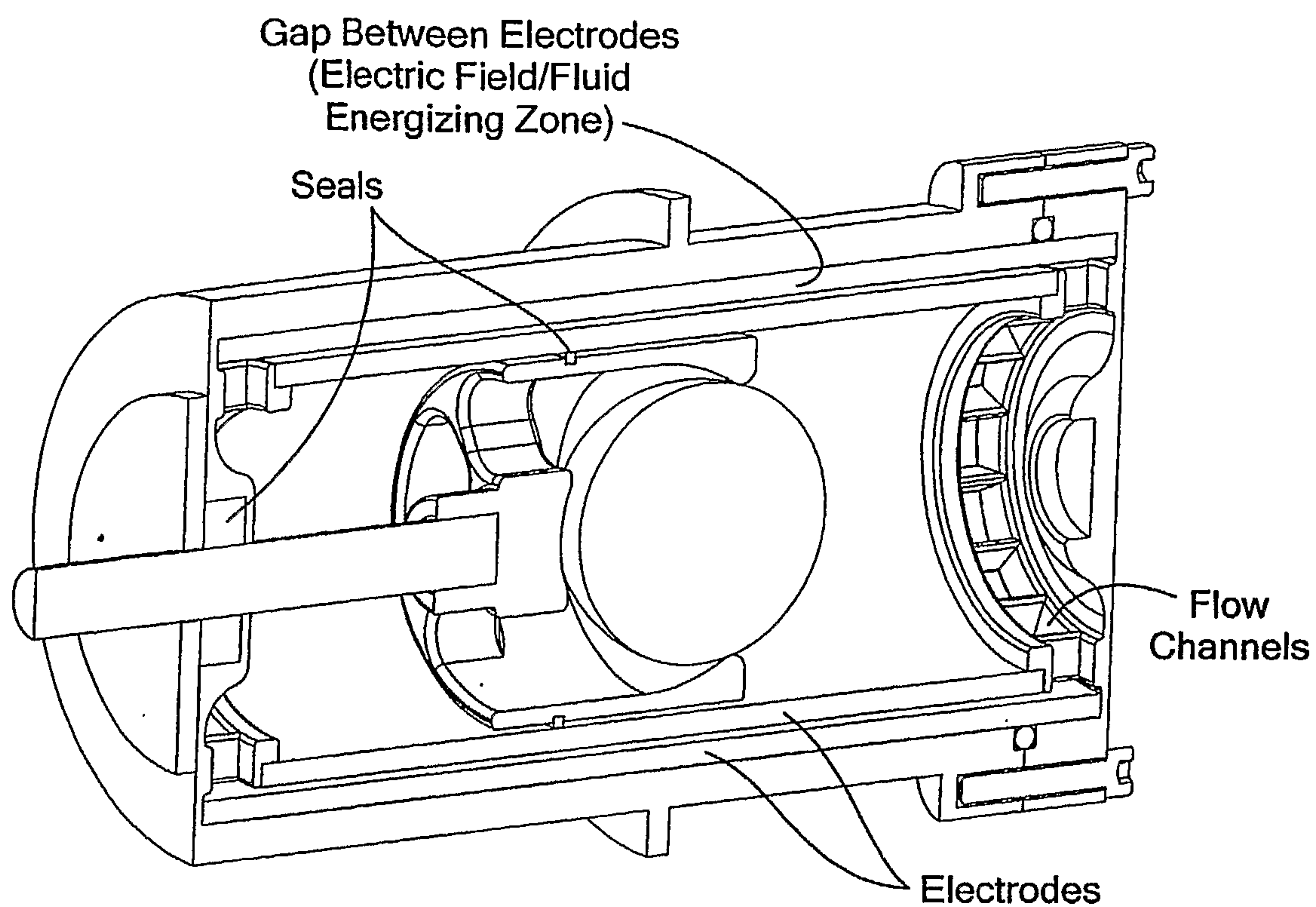
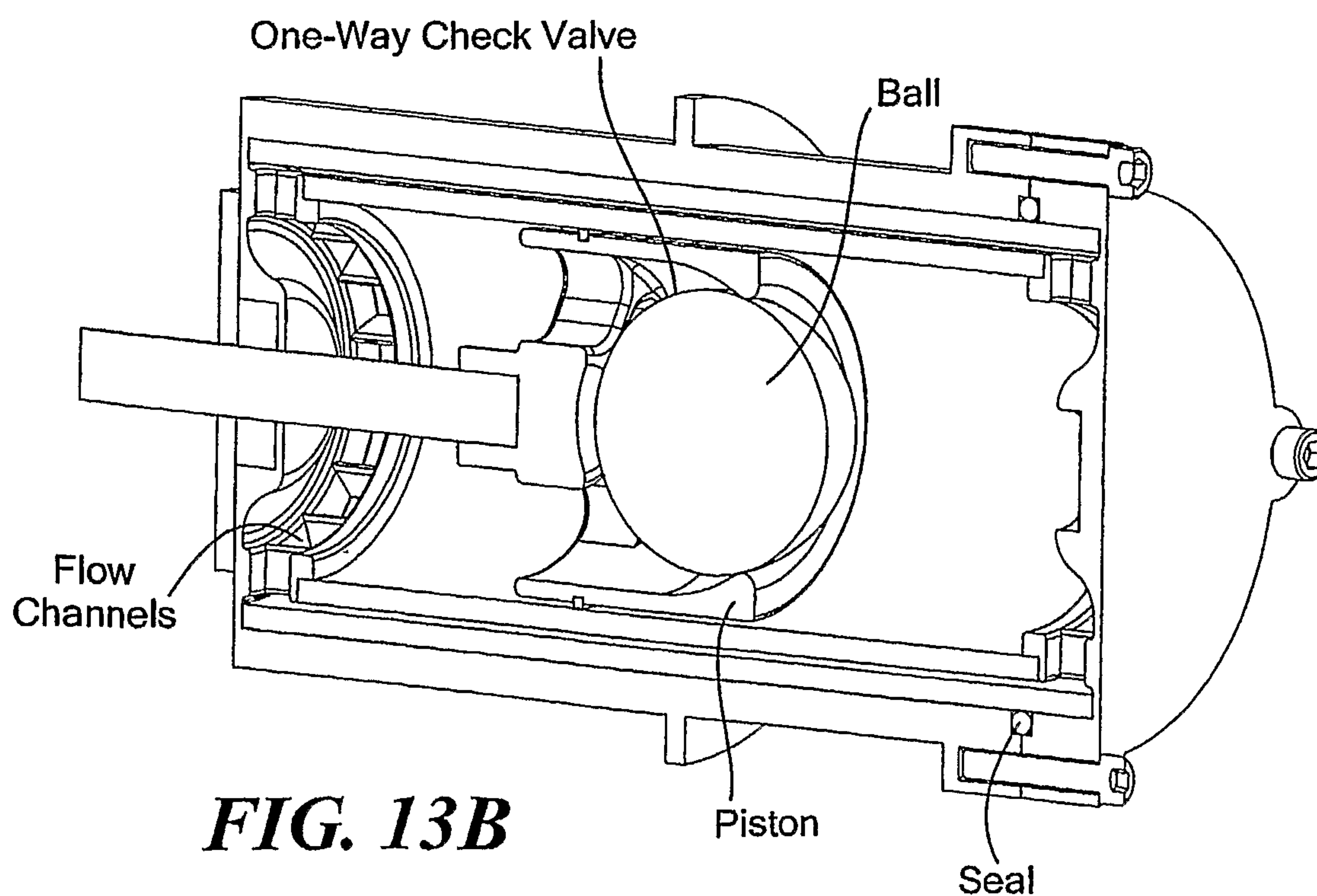
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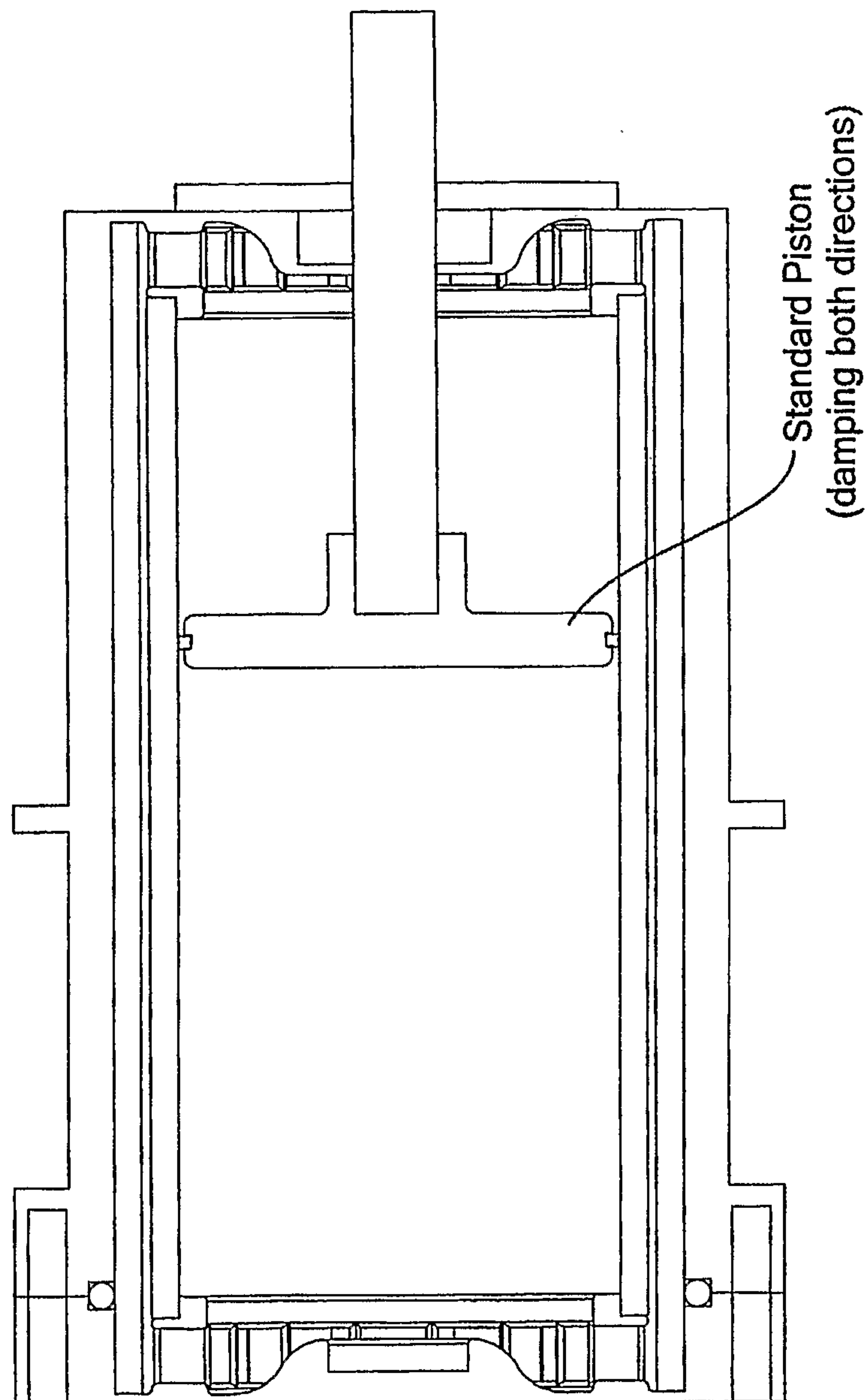
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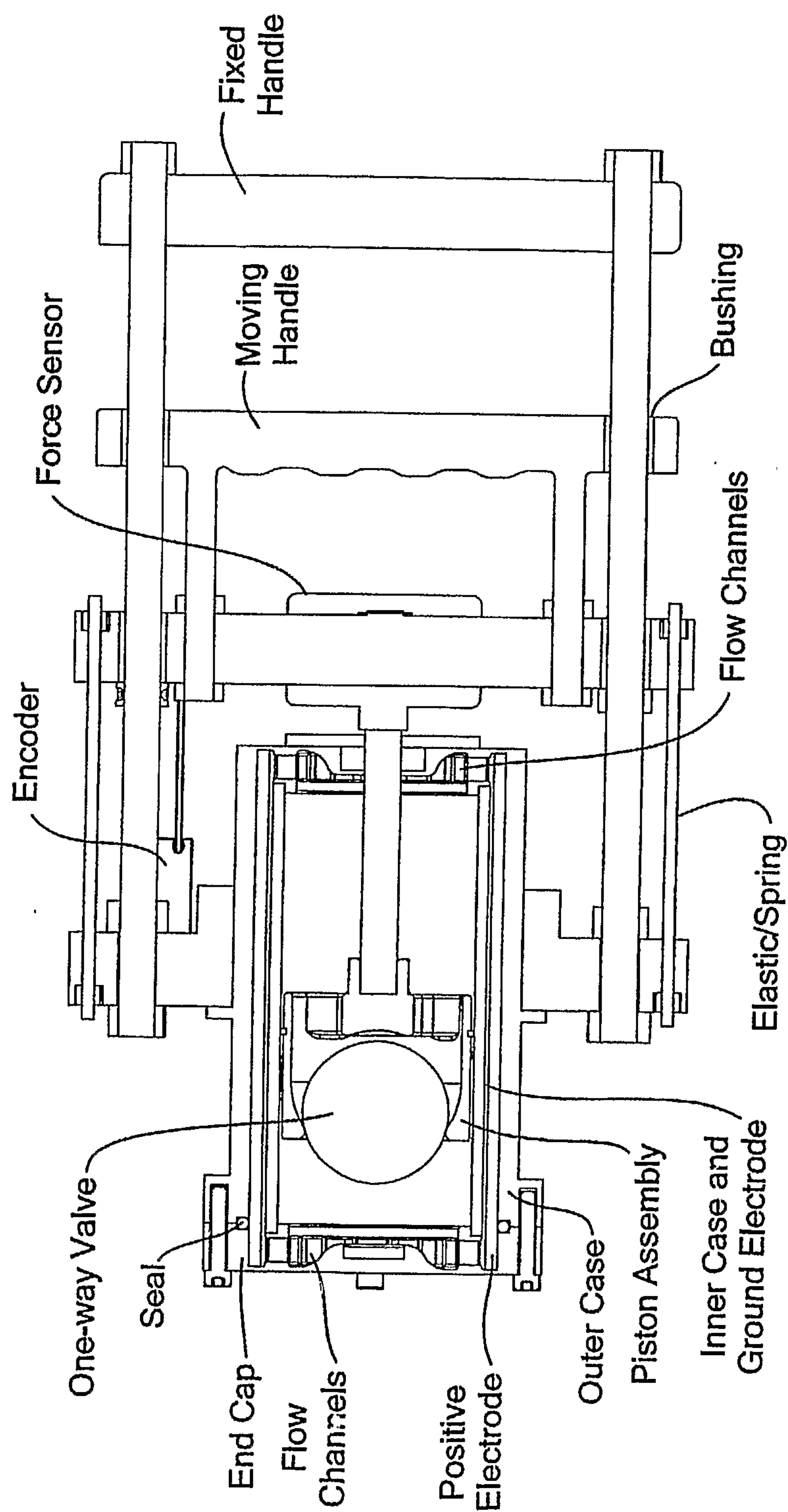
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**FIG. 13A****FIG. 13B**

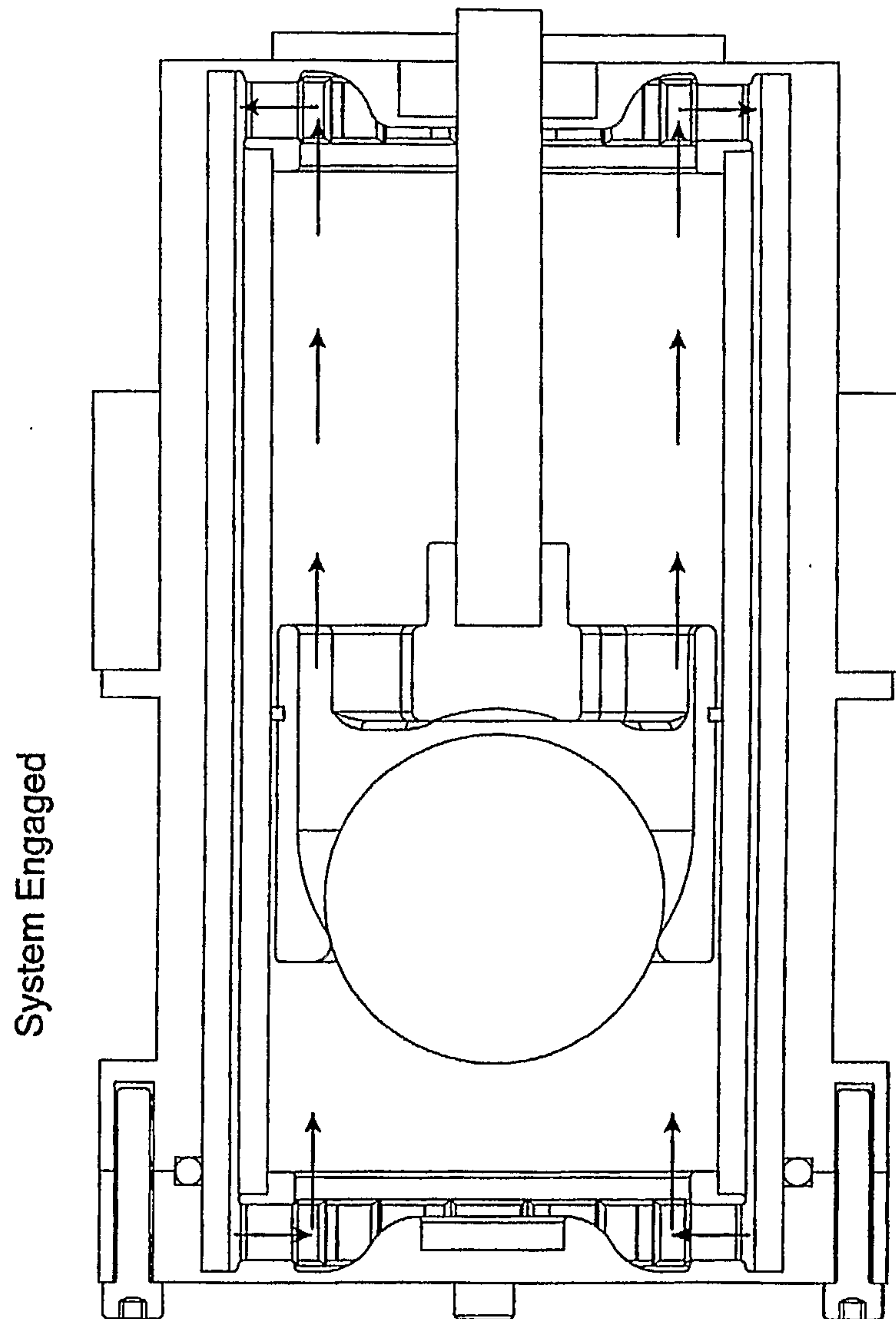
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**FIG. 14**

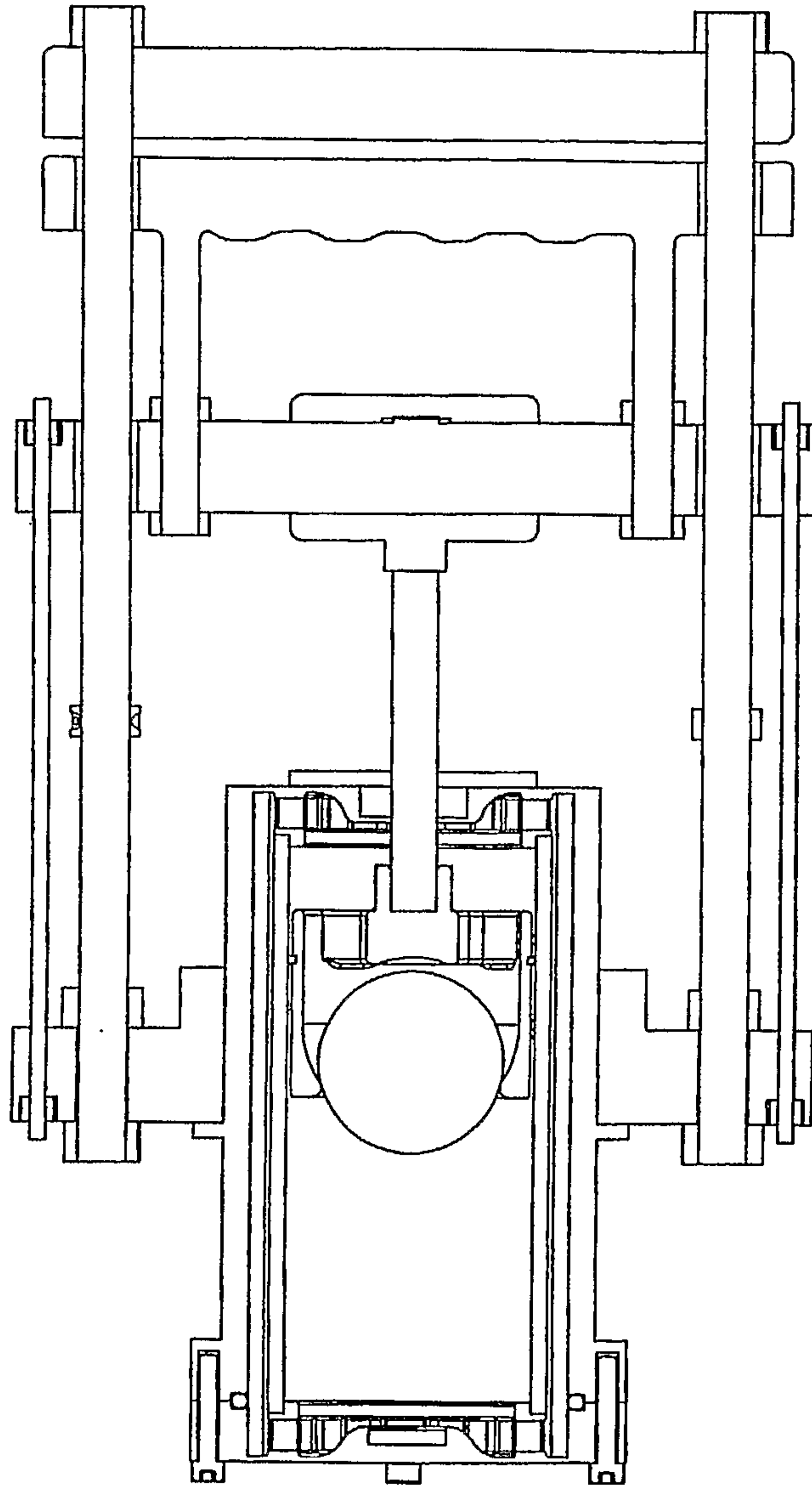
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**FIG. 15A**

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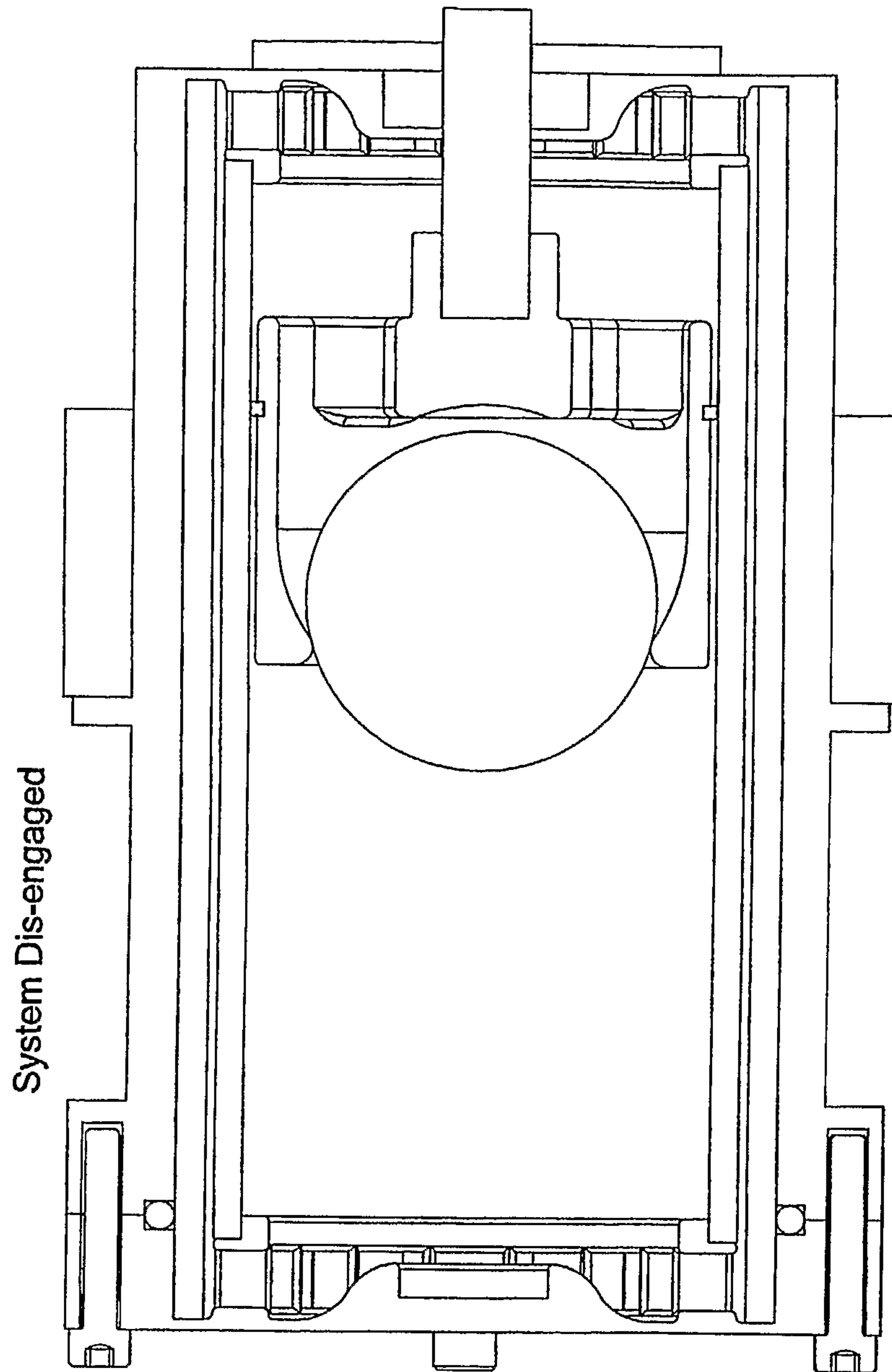
**FIG. 15B**

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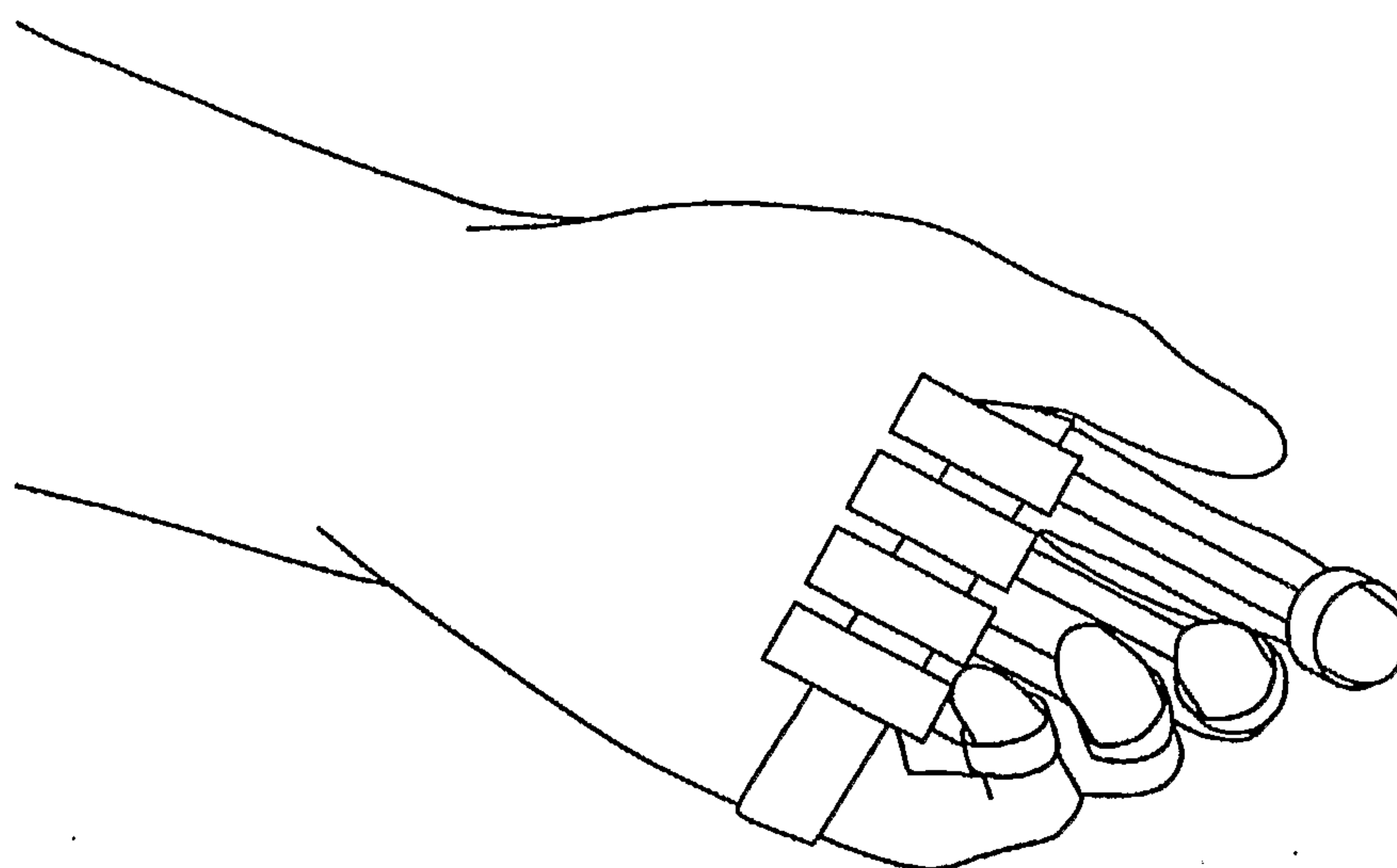


*FIG. 15C*

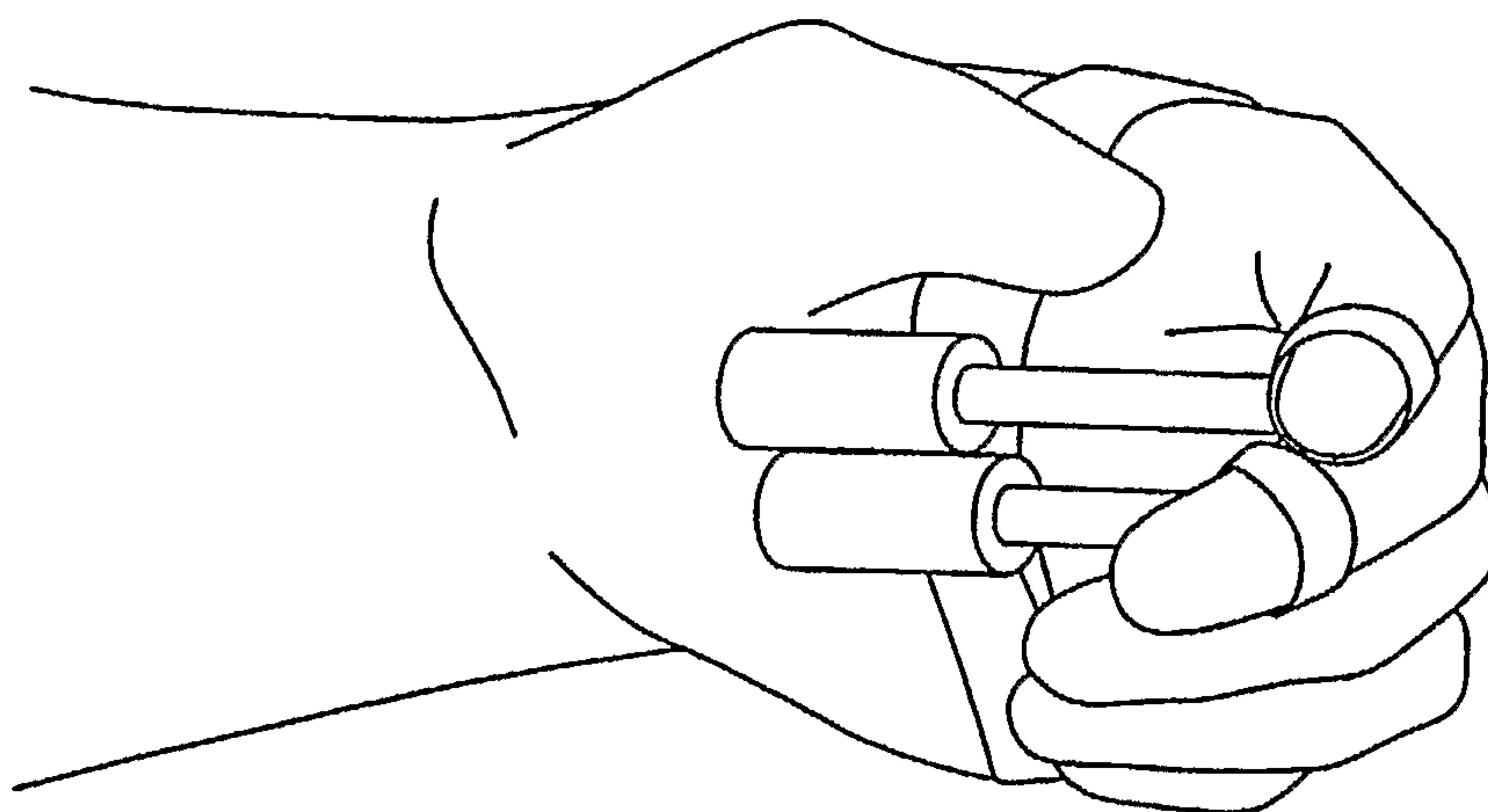
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**FIG. 15D**

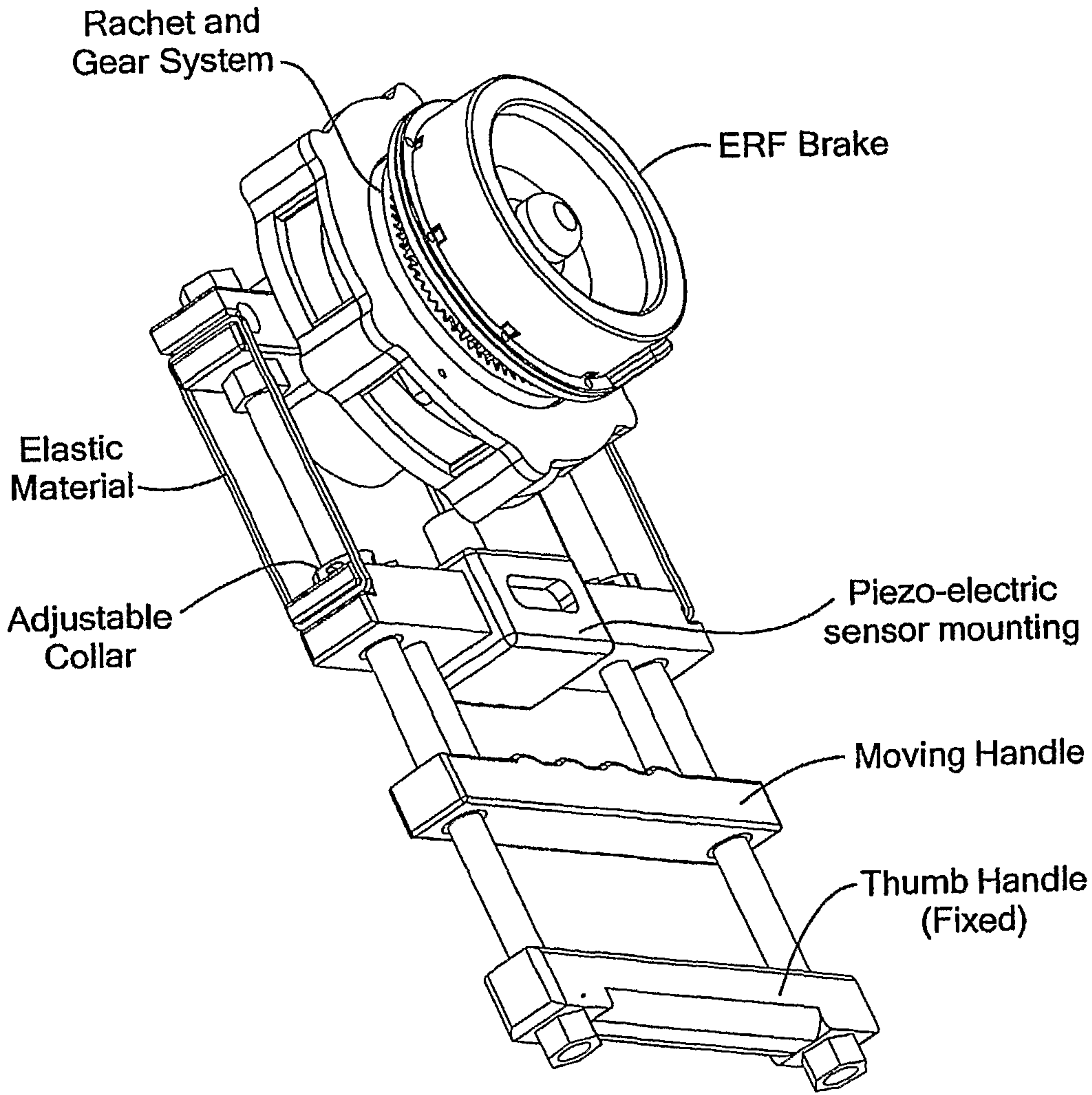
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**FIG. 16A**



**FIG. 16B**



Ratchet and  
Gear System

ERF Brake

Elastic  
Material

Adjustable  
Collar

Piezo-electric  
sensor mounting

Moving Handle

Thumb Handle  
(Fixed)