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(71) Applicant: **MACDONALD DETTWILER & ASSOCIATES INC.** [CA/CA]; 9445 Airport Road, Brampton, Ontario L6S 4J3 (CA).

(72) Inventors: **ROBERTS, Paul;** 20 Maltby Court, Brampton, Ontario L6P 1A5 (CA). **HAY, Gavin;** 103 Durie Street, Toronto, Ontario M6S 3E7 (CA). **WHITE, Jason;** 6 St Marks Road, Toronto, Ontario M6S 2H6 (CA). **SPRAWSON, Geoffrey;** 28 Napier Street, Kleinburg, Ontario L0J ICO (CA).

(74) Agent: **HILL & SCHUMACHER;** 264 Avenue Road, Toronto, Ontario M4V 2G7 (CA).

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(54) Title: SYSTEM AND TOOL FOR ACCESSING SATELLITE FILL/DRAIN VALVES DURING PROPELLANT RESUPPLY

(57) Abstract: Herein is disclosed a tool, system and method for refueling on-orbit spacecraft. The tool and system are configured to allow for resupply of spacecraft configured to be propelled by either a bipropellant (oxidizer and fuel) or a monopropellant (typically hydrazine). The refueling tool is particularly suited for resupply of satellites not originally prepared for refueling but the system may also be used for satellites specifically designed for refueling.

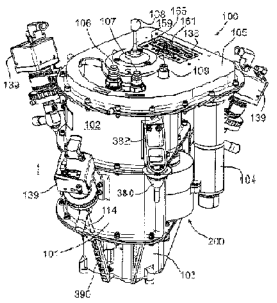

FIG. 1A

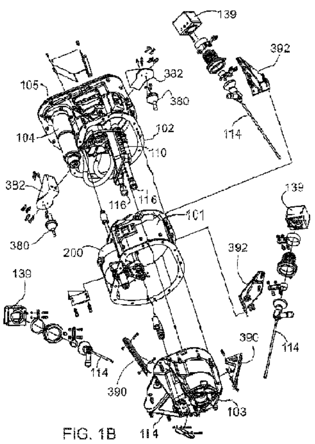

FIG. 1B

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SYSTEM AND TOOL FOR ACCESSING SATELLITE FILL/DRAIN VALVES DURING PROPELLANT RESUPPLY

FIELD OF THE INVENTION

The present disclosure relates to a tool for safely accessing, opening and closing fill/drain valves on artificial satellites during on-orbit propellant resupply operations. More particularly the tool is designed for resupply of satellites with propellant not originally prepared for being resupplied as well as satellites designed for resupply. The tool may be used for accessing other parts of the client satellite other having access component other than fill/drain valves.

BACKGROUND

Many satellites currently in operation were designed with a finite amount of propellant and were not designed for the possibility of being resupplied with propellant. The design philosophy relied upon replacement of the satellites after they had exhausted the on-board propellant supply. In view of the expense of replacing satellites, it would be very advantageous to be able to resupply satellites with propellant which are either near their end of propellant life but otherwise functional, or have suffered an infant propulsion system failure or insertion anomaly, or have been maneuvered more than originally intended for their nominal operations, thereby extending their operational life by several or many years.

It is estimated that as many as half of all GEO communication satellites end their 10 to 15 year life with all or most of their subsystems still functional and it is only the depletion of the carefully budgeted propellant load that drives retirement of the satellite. Using a current economic model, the ability to resupply these end of life satellites in one mission with propellant, would extend each of their useful lives by 3 to 5 years and thereby delay the need to outlay the very high capital costs to launch a replacement for each satellite. Some satellites suffer from primary propulsion system failures or launch vehicle upper stage related failures soon after they are launched. In these cases the entire book value must be written off and compensation paid to the operator by the insurer. The satellite becomes an asset of the insurer and will eventually have to be disposed of in a graveyard or re-entry orbit. If one of these assets can be resupplied with propellant, enabling it to transfer to an orbital station in geosynchronous orbit and extending its life by 5 to 10 years, most or all of the value of the spacecraft can be recovered.

The key technical difficulty is that these satellites were not designed for robotic servicing, and it is not generally accepted that such missions are technically possible. Specifically, most satellites are designed with propellant fill and drain valves that were intended to be filled once prior to launch and never opened or manipulated again. Thus, accessing these fill and drain valves remotely in-orbit presents several major challenges and would involve several operations, each of which is difficult to accomplish robotically including: cutting and removal of the protective thermal blankets, removal of several lockwires hand wrapped around the valves, unthreading and removing outer and inner valve caps, mating a fuel fill line to the valve nipple, mechanically actuating the valve, and when resupply with propellant is complete, replacing the inner valve cap.

On-orbit servicing has been the subject of much study over the past thirty years. The idea of maintaining space assets rather than disposing of and replacing them has attracted a variety of ideas and programs. So far the concept has only found a home in the manned space program where some success can be attributed to the Solar Max and Hubble Space Telescope repair missions, Palapa-B2 and Westar rescue missions and the assembly and maintenance of the International Space Station.

Robotic capture and servicing of operating geostationary spacecraft has never been demonstrated. Until recently there have been no technologies disclosed that can solve the problem of accessing the propellant system of an unprepared satellite for the purpose of replenishing station keeping propellant. The majority of artificial satellites in orbit today were not designed with orbital propellant resupply in mind and access to the propellant system is designed to be accessed by a human on earth before launch. The technologies required to access the client spacecraft's propellant system for the purposes of resupply of propellant still have a very low technology readiness level, and are generally considered to be the main obstacle to a successful servicing mission.

Transferring fuels used for spacecraft propulsion systems from one source to another is very dangerous, due to the corrosive and explosive nature of the liquids involved. For example, inadvertent mixing of fuel and oxidizer in bipropellant systems will cause immediate combustion, so a liquid transfer system for bipropellant based fuels needs to ensure that no accidental mixing occurs.

It would be very advantageous to provide a tool designed for opening and closing of a variety of types/sizes of satellite fill /drain valves during a propellant resupply operation being conducted on an unprepared satellite, such as but not limited to, removal of the sealing cap assembly, coupling/decoupling of propellant hoses to the client satellite, installation of a new sealing cap assembly, to mention just a few.

SUMMARY

The present disclosure relates to a tool for safely accessing, opening and closing fill drain valves on satellites during on-orbit propellant resupply operations. The tool is designed for resupply of satellites not originally prepared for propellant but may also be used for resupplying satellites designed specifically for resupply operations.

An embodiment disclosed herein is a tool mounted on a first satellite for opening a rotationally removable access component of a second satellite, the access component on the second satellite having rotatable and static features coaxially aligned along a first axis, comprising:

a housing including

a motor mounted in said housing, a gear shifter coupled to said motor,

a wrench mechanism mounted in said housing including at least first and second adjustable wrench mechanisms coaxially aligned one on top of the other along a second axis;

a differential gearbox mounted in said housing coupled to said first and second adjustable wrench mechanisms, the gearbox being configured to split the torque received by the gear shifter evenly between the first and second adjustable wrench mechanisms; and

wherein, when the tool is positioned with the wrench mechanism down over the access component with the second axis coincident with the first axis, the first adjustable wrench mechanism engages the rotatable feature of the rotationally removable access component and the second adjustable wrench mechanism engages the static feature of the access component such that the wrench mechanism applies equal and opposite forces to the rotatable feature and the static feature to apply bi-directional torque to the rotatable feature while reacting the torque on the static feature.

There is also provided a method for remotely opening a rotationally removable access component mounted on a client satellite, the access component on the client satellite having rotatable and static features, comprising:

activating a positioning mechanism mounted on a servicer satellite and releasibly coupling an end-effector on the positioning mechanism to a tool mounted on the servicer satellite;

positioning the tool over the rotationally removable access component and aligning a wrench mechanism mounted in the tool over the rotationally removable access component until a rotational axis of the wrench mechanism is aligned with a rotational axis of the rotationally removable access component so that a first adjustable wrench mechanism section of the wrench mechanism is engaged with the rotatable feature of the rotationally removable access component and a second adjustable wrench mechanism section of the wrench mechanism is engaged with the static feature of the rotationally removable access component; and

activating the wrench mechanism for applying equal and opposite forces to the rotatable feature and the static feature to apply bi-directional torque to the rotatable feature while reacting the torque on the static feature.

There is also disclosed a system mounted on a servicing spacecraft for transferring fluid between one or more selected fluid storage tanks on the servicing spacecraft and a client satellite, the client satellite including one or more fluid storage tanks and a fill/drain valve associated with each of the one or more fluid storage tanks, each fill/drain valve having rotatable features and static features, comprising:

a) a positioning mechanism, an end effector mounted on the positioning mechanism, the end effector being coupled to the one or more selected fluid storage tanks;

b) a tool including

a housing,

a fixture mounted on said housing configured to be grasped by said end effector,

a fluid selection and coupling mechanism mounted in said housing and configured to be coupled to the end effector for coupling the one or more fluid storage tanks on the client satellite to the one or more selected fluid storage tanks mounted on the servicing spacecraft,

a wrench mechanism located in said housing and configured for opening and closing each fill/drain valve on the one or more tanks and mating the fluid selection and coupling mechanism to the at least one fill/drain valve on the client satellite;

an actuator mounted in said housing coupled to the fluid selection and coupling mechanism and the wrench mechanism;

c) a sensor system for at least determining a relative displacement between said tool and each fill/drain valve on the one or more fluid storage tanks; and

d) a control system in communication with said sensor, said positioning mechanism, said end effector and said actuator for controlling operation of said positioning mechanism, said end effector and said tool based on feedback from said sensor.

A further understanding of the functional and advantageous aspects of the disclosure can be realized by reference to the following detailed description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the refueling tool will now be described, by way of example only, with reference to the drawings, in which:

Figure 1A is a perspective view of a refueling tool constructed in accordance with the present invention.

Figure 1B is a disassembled view of the refueling tool of **Figure 1.**

Figure 2 is another perspective view of the tool of **Figure 1** upside down relative to the view shown in **Figure 1.**

Figure 3A shows a side elevation view of the upper housing of the refueling tool of **Figure 1.**

Figure 3B shows a side elevation view of the upper housing of the refueling tool of **Figure 1** but opposite to that of **Figure 3A.**

Figure 4 shows a top view of the upper housing of the refueling tool with a vision system attached to the housing.

Figure 5A shows an isometric view of the upper tool housing showing the internal fittings of the housing including fuel/oxidizer exchanger with the propellant hoses.

Figure 5B shows an isometric view of the upper tool housing showing the external fittings of the housing including the grapple fixture and the electrical connections.

Figure 5C shows a top view of similar to **Figure 4** absent the vision system.

Figure 5D is a side elevation view of upper tool housing section showing the Fuel Oxidiser Exchanger (FOE) assembly;

Figure 5E is a side elevation view of upper tool housing section similar to **Figure 5D** but rotated 90°;

Figure 5F is a cross section through line **5F-5F** of **Figure 5C** and line **5F-5F** of **Figure 5D.**

Figure 5G is a cross section through line **5G-5G** of Figure **5C** and line **5G-5G** of **Figure 5D.**

Figure 5H is a disassembled view of the upper tool housing section containing the fuel oxidizer exchanger (FOE).

Figure 5IA is a disassembled view of a fuel oxidizer exchanger (FOE) subsystem forming part of the present refueling tool.

Figure 5IB shows part of the assembled tubing system of the fuel oxidizer exchanger subsystem of **Figure 5IA.**

Figure 6A is a disassembled view of a mid housing section of the refueling tool which houses a differential gearbox.

Figure 6B shows an isometric view of the assembled refueling tool mid housing section showing internal components including a motor shaft used to drive the differential gearbox.

Figure 6C shows an isometric view of the assembled tool mid housing section, flipped over compared to the view of **Figure 6B,** showing the motor shaft engaged in the differential gearbox.

Figure 6D shows a side elevation view of the tool mid housing section showing a gearbox assembly installed in the housing forming part of the invention.

Figure 6E shows a side elevation view of the tool mid housing section similar to **Figure 6D** but rotated 90°.

Figure 6F shows a top view of the mid housing section showing the arrangement of the installed gearbox and cam wrench drive shafts.

Figure 6G is a top view of the mid housing section.

Figure 6H is a view along line **6H-6H** of **Figure 6G.**

Figure 6I is a view along line **6I-6I** of **Figure 6G.**

Figure 7 shows an assembled, external view of a differential gearbox of the present invention.

Figure 8 is an exploded view of a gearbox forming part of the tool drive train.

Figure 9 is a cross section through the gearbox of **Figure 7** taken along the line **9-9.**

Figure 10 is an isometric view of the interior of a cam wrench mechanism **300A** forming part of the refueling tool.

Figure 11 is a cross section view of the cam wrench mechanism taken along line **11-11** of Figure **10.**

Figure 11A is an exploded view of the cam wrench mechanism **of Figure 10.**

Figure 11B shows an exploded view of the various adjustable wrench mechanisms forming the cam wrench mechanism.

Figure **11C** is an exploded view of the lower housing portion and the adjustable wrench mechanism that sits adjacent the bottom of the lower housing portion and showing first and second output gears and a reaction gear located therebetween.

Figure **12A** is a top view of the lower housing portion with the first and second output gears and the reaction gear assembled therewith.

Figures 12B, 12C and **12d** are various sectional views along the corresponding lines of **Figure 12A.**

Figure 12E is an isometric view of the lower housing section.

Figure 12F is an bottom view of the lower housing section.

Figure 13A is a cross section view through the refuelling tool along lines **13A-13A** of **Figure 4** showing the assembled output drive train from the gearbox to the cam wrench mechanisms and, specifically, one output shaft **262 (262A)** to the reaction cam wrench mechanism **300C** forming part of the refueling tool.

Figure 13B is a cross section view through the refuelling tool along lines **13B-13B** of **Figure 4.**

Figure 13C is a cross section view through the refuelling tool along lines **10C-10C** of **Figure 4** showing the assembled input drive train from motor to the gearbox.

Figure 14 is a cross section view through the refuelling tool along lines **14-14** of **Figure 4.**

Figure 15 is a cross section view through the refuelling tool along lines **15-15** of **Figure 4.**

Figure 16A shows how the camera electrical harness and video cable are connected to the camera

Figure 16B shows the various parts of the camera harness and terminating connector.

Figure 16C shows how the camera harness shielding is connected to the connector backshell.

Figure 18 is a block diagram showing those items pertaining to the refuelling of a satellite in addition to the refuelling tool.

Figure 19 shows a client valve located on a client satellite to be resupplied with propellant.

Figure 20A shows the backup fill/drain valve **125** with the secondary seal threaded feature **127,** the backup fill/drain valve actuation nut **132,** the backup fill/drain valve torque reaction feature **129** and the backup fill/drain valve seal fitting **128.**

Figure 20B is an elevation view of a replacement secondary seal fitting used to close the fuel tank on the client satellite once refueling operations have been completed.

Figure 21 shows how the motor leads are connected to the motor harness.

Figure 21A shows a detail of how the motor power leads are spliced into the refuelling tool harness.

Figure 21B shows a detail of how the resolver leads are spliced into the refuelling tool harness.

Figure 22 shows a non-limiting exemplary example of a computer control system that may be used to control the actions of the robotic tool.

Figure 23A shows a perspective view of the front of an end effector configured to be used in conjunction with the refueling tool.

Figure 23B shows perspective view of the back of the end effector of **Figure 23A.**

Figure 23C is another perspective view of the front, side and bottom of the end effector of **Figure 23A.**

DETAILED DESCRIPTION

Various embodiments and aspects of the disclosure will be described with reference to details discussed below. The following description and drawings are illustrative of the disclosure and are not to be construed as limiting the disclosure. The drawings are not to scale. Numerous specific details are described to provide a thorough understanding of various embodiments of the present disclosure. However, in certain instances, well-known or conventional details are not described in order to provide a concise discussion of embodiments of the present disclosure.

As used herein, the terms, "comprises" and "comprising" are to be construed as being inclusive and open ended, and not exclusive. Specifically, when used in this specification including claims, the terms, "comprises" and "comprising" and variations thereof mean the specified features, steps or components are included. These terms are not to be interpreted to exclude the presence of other features, steps or components.

As used herein, the term "exemplary" means "serving as an example, instance, or illustration," and should not be construed as preferred or advantageous over other configurations disclosed herein.

As used herein, the terms "about" and "approximately", when used in conjunction with ranges of dimensions of particles, compositions of mixtures or other physical properties or characteristics, are meant to cover slight variations that may exist in the upper and lower limits of the ranges of dimensions so as to not exclude embodiments where on average most of the dimensions are satisfied but where statistically dimensions may exist outside this region. It is not the intention to exclude embodiments such as these from the present disclosure.

Figure 1 is a perspective view of the tool for removing/replacing fill/drain valves on satellites shown generally at **100** constructed in accordance with the present invention. Tool **100** is comprised of a mid-housing section **101 ,** an upper housing section **102** and a lower housing section **103.** Lower housing section **103** encloses a cam wrench mechanism **300** , not visible in **Figure 1** but shown in **Figure 13A** and which comprises three cam wrench mechanisms which include: secondary seal fitting cam wrench **300A,** valve actuation cam wrench **300B,** and the torque reaction feature cam wrench **300C).** A differential gearbox **200** is partially contained in mid-housing section **101 .** A motor **104** is mounted on the exterior of housing section **102.** A housing cover **105** is bolted to upper housing section **102** and two propellant couplings **106** and **107** are located on cover **105.** A grapple fixture **108** is mounted on housing cover **105** and is designed to be releasibly gripped by a robotic arm. Electrical connectors **161 and 165** are mounted on plates **138** and **159** respectively,

Figure 1B is a disassembled view of the refueling tool of **Figure 1** showing separately the upper housing section **102** containing a Fuel Oxidiser Exchanger **110** (also referred to as a fluid selection and coupling mechanism), the mid-housing section **101** containing the differential gearbox **200,** the lower housing section **103** containing the cam wrench mechanism **300 (Figure 13A)** and a camera vision system which includes cameras **139** shown in **Figure 2** and discussed below and is configured to illuminate and view a bottom portion of the lower housing section **103** which is used to access a fill/drain valve on a client satellite, and optionally attach a backup fill/drain valve to the fuel valve(s) on the client satellite being resupplied with propellant.

Figure 2 shows the tool **100** of **Figure 1A** but upside down to give a view from the bottom of the tool. Three tool cameras **139,** are located at intervals of approximately 120 degrees around, and secured to the mid-housing section **101** with the cameras **139** mounted by brackets **392 (Figure 3B)** to mid-housing section **101 .** Each camera **139** is attached to optics **114** that permit the camera to look under the bottom of the tool **100.** Illumination for the cameras is provided by three pairs of lights **115** located on the bottom face of the tool. The field of view of each cameral **139** will capture the workspace of tool **100** as it engages the various fill-drain valves of the client satellite being refueld which will allow a remote operator to see the entire operation of opening and closing, and attachment of the refueling hoses.

Figure 3A is a vertical elevation of the tool **100** and **Figure 3B** is another vertical elevation of the tool **100.** The view in **Figure 3B** is rotated 90 degrees counter clockwise about the vertical centreline of the tool.

Figure 4 is an overhead or top view of the tool **100** showing the two propellant couplings **106** and **107,** the grapple fixture **108** and the electrical connectors **138** that receive electrical power from the robotic arm **403.** Also seen in **Figure 4** is the vision system including the three (3) cameras **139** which use optical fibers **114 (Figures 3A** and **3B)** (or other light pipe configurations) to pass light received at the bottom of lower section **103** (where the cam wrench mechanism **300 (Figure 13A)** of refueling tool **100** engages the fill/drain valves **402** of the client satellite **401** being refuelled) back to the imager located within the body of camera **139.**

Figures 5A to **5I** show various views of the upper housing section **102** and the various components housed therein. Specifically, **Figure 5A** is an isometric view of the inside of upper housing section **102** showing details of a Fuel Oxidiser Exchanger (FOE) **110,** the propellant delivery hoses **112** and the tips of the propellant delivery tubes **116. Figure 5B** is another isometric view of the upper housing section **102** but now reversed from the view of **Figure 5A** showing exterior details of the upper housing section **102** and the top cover **105** including the grapple fixture **108,** the propellant couplings **106** and **107** protruding through an arcurate slot **320** in top plate **105,** and the electrical (power and data) connectors **138. Figure 5C** is a top view of the upper housing section **102** while **Figures 5D** and **5E** show vertical elevation views, and the sections along lines **5F-5F** and **5G-5G** of both **Figures 5C** and **5D** are shown in **Figures 5F** and **5G** respectively.

Figure 5IA shows a disassembled view of the Fuel Oxidiser Exchanger (FOE) 110. FOE 110 includes a mounting bracket 330 to which propellant couplings 106 and 107 are bolted. The two (2) propellant delivery hoses 112/112' are shown having two sections, a flexible section 112' which is connected to fitting 331 and a rigid pipe section 112. The rigid section 112 is coupled to the flexible section 112' by elbow joints 336 and fittings 338. A spring 340 is located around the outside of rigid section 112. One end of each of the two (2) flexible hose sections 112' are attached to fittings 331 which are mated in turn to associated fittings (not shown) on the bottom of propellant couplings 106 and 107 which are bolted to mounting bracket 330. The other ends of the flexible hose sections 112' are attached to fittings 333 which are coupled to associated elbow joints 336. The elbow joints 336 are mated to associated fittings 338, and first ends of the rigid pipe sections 112 are each connected to one of the fittings 338.

Figure 5IB shows one of the propellant delivery hoses 112/1 12'fully assembled with the spring 340 on rigid pipe section 112, one end of which is connected to coupling 338 which is coupled to elbow joint 336 connected to one end of the flexible hose section 112', and the other end of hose section 112' being connected to propellant coupling 106.

Referring again to **Figure** 51**A,** a bracket 332 is bolted to the mounting bracket 330 and includes features 343 configured to receive the rigid pipe sections 112 which are held in place such that they are free to move vertically against bracket 330 by bushings 344 and brackets 346. In operation, as the FOE 110 is being coupled (and decoupled) to (from) the client satellite being refuelled, (by couplings 116 being connected to associated fill/drain valves on the client satellite), the rigid pipe sections 112 slide up (and down) in bracket 332 facilitated by the bushings 344 which are retained in bracket 332.

The FOE 110 (also referred to as a fluid exchanger subsystem) is designed so that, for cases where bipropellants are being transferred, the fluid exchanger subsystem includes at least two fluid flow pathways having corresponding fool proof coupling features associated with each to mate with the first and second fill/drain valves on the client satellite. This is to ensure no mixing of fuel and oxidizer occurs which would cause an explosion.

Figure 5H is a disassembled view of the upper tool housing section

102 which houses the motor **104,** electrical (power and data) connectors **138** and the fuel oxidizer exchanger (FOE) subsystem **110,** shown assembled in this Figure. Motor **104** includes a motor shaft **162** which passes through the motor mounting plate **151** which in turn is bolted to the housing section **102.** Motor shaft **162** is secured to a motor output gear **155.** The motor output gear **155** transmits the motor torque through an idler gear **154** to a gear shifter input gear **156.** These three gears **155, 154** and **156** are secured in the upper tool housing section **102** by bearings **160.** The fuel oxidiser exchanger **110** rotates within the upper tool housing **102** on journal bearing sleeve **157** and ball bearing **152.** Ball bearing **152** is retained in housing **102** by retaining ring **153.** Journal sleeve bearing **157** is retained in housing **102** by support plate **158.**

Figure 6A shows a disassembled view of the mid-housing section **101** and the assembled gearbox assembly **200** showing that housing section **101** includes a cut-out section **373** of sufficient size to receive therein the differential gearbox assembly **200. Figure 6B** shows an isometric view of the assembled refueling tool mid housing section **101** showing the assembled differential gearbox **200** mounted thereto while **Figure 6C** shows an isometric view of the assembled tool mid housing section and gearbox assembly **200,** flipped over compared to the view of **Figure 6B.**

Referring to **Figure 6A,** three bracket mounts **374** (two of which are visible in **Figure 6B)** are integral to the mid housing section **101** and provide attachment sites to which the three cameras **139 (Figure 1)** of the vision system are bolted. The structure of the gear box assembly **200** is as follows. Shaft **109** is a spline shaft with two spaced toothed drive gears or pinions **118** midway down the shaft and one end of spline shaft **109** is terminated by a spline shaft nose **222** and a screw **224** for retaining nose **222** to the this end of shaft **109.** Spline shaft **109** goes through a switching gear **210** on which a ball bearing **212** is circumferentially mounted. Bearing **212** is positioned within hole **226** located in mid housing section **101 .** Gear box assembly **200** includes two (2) housing sections **201** and **202** and a split bushing **214** bolted to the housing **201** of gear box **200** over the central aperture **228** through which spline shaft **109** is positioned when assembled. An upper support bracket **234** is bolted to a raised pad **230** on one end wall of housing **201** of the gearbox assembly **200** and a lower support bracket **236** is bolted to the opposing end wall onto a raised pad (not shown) on housing **202** similar to pad **230.** Spline shaft **109** extends through split bushing **214** and through differential gear box housings 201 and 202 and through a spring washer **240,** a thrust bearing **242,** three (3) springs **244,** a spring spacer **246** and into a spring housing **248** with the other end of the shaft **109** located in shaft bushing **250** which is secured to spring housing **248.**

A first output gear **262,** a reaction gear **264** and a second output gear **266** have ends supported by upper and lower support brackets **234** and **236** respectively. The ends of the shafts supported by upper support bracket **234** go through thrust washers **268** while the ends supported by lower support bracket **236** each go through a shaft spacer **280,** a bushing **282** and thrust washers **284.** Hard stops **290** are bolted to hard stop bracket **292** which in turn is bolted to mid housing **101** as shown in **Figure 6A.** Gearbox assembly **200** is bolted to midsection housing **101** by means of several socket head bolts **270** and gearbox shims **296.** An assembly gap is closed with a cover **272.**

Figures 6D to **6I** show different views of the assembled mid housing section **101** with the gearbox assembly **200** incorporated therewith.

Figure 8 is an exploded view of the gearbox **200.** It shows the upper gearbox housing **201** and lower gearbox housing **202** plus the valve actuation planet carrier gear **203,** the valve actuation planet gears **204** (three of them), the valve actuation sun gear **205,** the ring gear **206,** the secondary seal fitting sun gear **208,** the secondary seal fitting planet gear **207** and the secondary seal fitting planet carrier gear **209,** first and second bearing retainers **223** and **215,** a reaction bushing **217,** first and second sets of three (3) needle roller bearings **216,** first and second sun gear spacers **225,** two retaining spiral rings **211** and **221**, first and second deep groove, single row ball bearings **213** and **219,** two (2) sets of three retaining rings **226,** two sets of three (3) planet washers **227,** two sets of three (3) thrust washers **228** and two sets of three (3) thrust washers **229.**

Figure 7 shows an external view of the gearbox **200** showing the valve actuation carrier gear **203,** the ring gear **206,** and the secondary seal fitting carrier gear **209.** **Figure 9** is a cross section through the assembled gearbox

200 along line **9-9** of **Figure 7** showing the alignment of the disassembled components of **Figure 8** in the assembled gearbox **200.**

Figure 10 is an isometric view of the interior of cam wrench mechanism **300A.** It shows the nut cams **301,** housing **302,** toothed drive ring **306** in which the outer surface is toothed and inner surface is toothed) cam ring **308,** and the retaining fittings **305.** **Figure 11** is a cross section view of the cam wrench mechanism **300A** taken along the line **11-11** of **Figure 10.**

Figure 11A is an exploded view of a cam wrench mechanism **300A.** It shows the housing **302,** detent spring **304,** drive ring **306,** cam ring **308,** cam locks **303,** cam lock springs **312,** nut cams **301** , retaining fittings **305,** retaining fitting springs **316** and cam wrench mechanism centreline **313.**

Figure 11B shows an exploded view of cam wrench mechanisms **300B** and **300C.** It shows two cam wrench mechanisms **300B** and **300C** are identical to mechanism **300A** except as follows. The two mechanisms are mounted back to back in combination housing **322.** The cam rings **308** of these two mechanisms are retained in combination housing **322** by retaining rings **324.** Also, the nut cams **301 A** do not incorporate features to support retaining fittings **315** and retaining fitting springs **316.**

Figure **11C** is an exploded view of the lower housing **103** and the cam wrench mechanisms **300A, 300B** and **300C** that sits adjacent the bottom of the lower housing **103** and showing the lower extension portions of the first and second output gears **262A** and **266A** and the reaction gear **264A** located between them. The lower extension portions of the output gears **262A** and **266A** and reaction gear **264A** connect to the upper portions of each gear shaft via a spline interface at the top of each lower extension portion that mates with a matching spline on the lower end of each upper portion **286** via a spline union **396** (see **Figure 13A).** Lower extension portions of the output gears and reaction gear rotate within needle bearings **358** at the top and bushings **368** at the bottom. The three shafts are supported by thrust bearings **360** at the top and thrust bearings **366** at the bottom. The shafts and bearings are supported by shaft housing **370** at the bottom, which bolts into combination housing **322** and by shaft housing **356** at the top which bolts into housing **302.**

Lower housing **103** cam wrench mechanism housings **322** and **302** are separated by wrench spacer **364.** The two cam wrench housings **302** and **322** and the wrench spacer **364** have interlocking dogs **376** and slots **378** that prevent the wrench mechanisms rotating under load and also the dog **376** on the bottom of housing **322** interlocks with a matching slot in the lower housing **103** to prevent any of the wrench mechanisms from rotating relative to the lower housing **103.** The three cam wrench mechanisms **300A, 300B** and **300C** are retained in the lower housing **103** by the wrench retaining ring **362** which bolts into the lower housing **103.**

To the top of cam wrench housing **302** are bolted two FOE bearing supports **352R** and **352L** and, on top of them two polymer FOE bearing pads **350R** and **350L.** Thrust washers **354** prevent the spline unions **396** from contacting the shaft housing **356.**

Figure **12A** is a top view of the lower housing portion with the first and second output gears **262A** and **266A** and the reaction gear **264A** assembled therewith. **Figures 12B, 12C,** and **12D** are various sectional views along the corresponding lines of **Figure 12A. Figure 12F** is a bottom view of the lower housing section **103** and **Figure 12E** is an isometric view of the lower housing section **103.**

Figures 13A, 13B and **13C** are cross section views through the refuelling tool **100** of **Figure 4. Figure 13A** showing the gear shifter **109** and the two spaced drive pinions **118** on the gear shifter **109.** It also shows the cam wrench mechanism **300** which includes, as discussed above, three cam wrench mechanisms comprising: the secondary seal fitting cam wrench **300A,** the valve actuation cam wrench **300B,** and the torque reaction feature cam wrench **300C.** There are three output shafts **262 (262A), 264 (264A)** (not visible in **Figure 13A)** and **266 (266A)** (not visible in **Figure 13A)** which are configured to transmit power from the gearbox **200** each to an associated the cam wrench mechanism **300A, 300B** and **300C.** The three shafts are lined up substantially side by side so that they may efficiently engage the differential gearbox **200** at their input end and engage their intended cam wrench mechanism **(300A, 300B** or **300C)** at their output end. Cam wrench mechanisms **300A, 300B** and **300C** are coaxially aligned one on top of the other.

Figure 14 shows a partial section through the refuelling tool along lines

14-14 of Figure 4 and shows how the camera output video cables 163 and their connector 165 are attached to the compliant connector plate 159 with screws (illustrated, but not labelled).

Figure 15 is a partial section through the refuelling tool along lines 15-15 of Figure 4 and shows how the refuelling tool motor power cable 562, motor resolver cable 563 and camera power and data cables 540 and their connector 161 are attached to the compliant connector plate 138 with screws (illustrated, but not labelled).

Figure 16A shows how the camera electrical harness 540 is connected to the camera139 via a connector 542 and video cable 163 is connected to the camera via connector 548.

Figure 16B shows a detail of the various parts of the camera harness 540 and terminating connector 542. The terminating connector includes the connector 541 , the connector backshell 547 and the shielding overwrap 543.

Figure 16C shows how the camera harness shielding 545 is connected to the connector backshell 547 by splicing a small wire 546 to the video cable shielding 545 and then connecting it to the connector backshell 547.

Figure 17 shows four component stowage points and the components stored on each one. Included are: the Fuel Oxidiser Exchanger (FOE) reset post 111 and its tool guide 123, the backup fill/drain valve storage location 126 consisting of back-up fill/drain valve 125 and its tool guide 123, the replacement seal fitting storage location 133 consisting of replacement seal fitting 134 and its tool guide 123 and the secondary seal fitting stowage point 122 and its tool guide 123.

The tool 100 disclosed herein for accessing fill/drain valves 125 on a client satellite may be mounted on a dedicated refuelling or servicer spacecraft 400 (Figure 18) launched directly from earth. The system includes a multifunction tool 540 (see Figure 22) as disclosed in copending US Patent Application Serial No. 13/652,339 (United States Patent Publication 201 3/XXX) to Roberts et al. (which is incorporated herein in its entirety by reference) the purpose of which is to provide tool tips needed to gain access to the fill/drain valves themselves and includes a tool holder and a suite of tool tips which are held by the tool holder and activated by a single motive source under robotic control. The system also includes the propellant transfer system

406 for transferring bi-or mono-propellants from the servicing satellite **400** to the client satellite **401** as disclosed in copending US Patent Application Serial No. 13/678,281 (United States Patent Publication **XXX)** (which is incorporated herein in its entirety by reference) the purpose of which is to provide a propellant transfer system **406 (Figure 18)** for transferring the propellant which is under a combination of remote teleoperator and computer control. Such a dedicated servicer spacecraft **400** may include a spacecraft docking mechanism such as that disclosed in United States Patent No. 6, 969,030 issued November 29, 2005, which patent is incorporated herein in its entirety by reference. Alternatively, or in addition, it may include a second robotic arm **430** for capturing the client spacecraft, as shown in ghost outline in **Figure 18.**

Figure 18 is a block diagram showing those items pertaining to the refueling of a client satellite in addition to the refueling tool **100.** These include the host servicer spacecraft **400,** the client satellite **401** to be refueled, the client fill/drain valve(s) **402,** a robotic arm **403,** an end effector **411** coupled to the robotic arm **403,** the refueling tool **100** releasibly gripped by the end effector **411,** a propellant transfer system **406,** a propellant coupling mechanism **405,** the propellant outlet hose **404,** and a communication system **410** to provide a two-way radio link **407** to Earth **408** (or space station or mother ship-whichever is the location of the teleoperation control). It also shows the stowage points for the backup fill/drain valve **125,** the replacement seal fitting **133,** the secondary seal fitting **122** and the reset post **111 .**

In addition, the servicer spacecraft **400 (Figure 18)** includes an onboard computer control system **500** (see **Figure 22)** which may be interfaced with the tool **100,** in addition to a propellant flow control system, shown at **560** in **Figure 22** so that it can drive all the components that are opened and closed during the propellant transfer operations in a selected sequence depending on which mode of propellant transfer has been selected based on the pressure in the client satellite propellant tank. With the presence of the computer control system **500** interfaced with the propellant flow control system, the propellant transfer process may be autonomously controlled by a local Mission Manager or may include some levels of supervised autonomy so that in addition to being under pure teleoperation there may be mixed teleoperation/supervised autonomy.

Referring now to **Figures 18** and **22,** an example computing system **500** forming part of the propellant resupply system is illustrated. The system includes a computer control system **525** configured, and programmed to control movement of the robotic arm **403** during the entire procedure of accessing the client satellite fill/drain valve **402,** attachment of the backup fill/drain valve **125,** mating of propellant outlet hoses **112** to the backup fill/drain valve **125,** transfer of propellant into the client satellite propellant tanks, demating hoses **112** from backup fill/drain valve **125,** sealing valve **125** and decoupling of the servicer spacecraft **400** from the client satellite **401 .**

The command and control system is also configured to control movement of the robotic arm **403 and** the end effector **411** attached thereto for controlling the action of the refueling tool **100.** This may be the same command and control system mentioned above that is interfaced with the flow control system, for example a computer mounted on the servicer satellite which is programmed with instructions to carry out all operations needed to be performed by the servicer satellite during approach, capture/docking with the client satellite and refueling operations. It may also be a separate computer system. The satellite refueling system includes a vision system for viewing the operation of the refueling tool just prior to engagement or release from the fill-drain valve. Communication system **410** is interfaced with the robotic arm **403** and configured to allow remote operation (from the Earth **408** or from any other suitable location) of the vision system (which may include one or more cameras), the robotic arm **403** and hence the tools. The vision system may include distinct markers mounted on the fluid transfer coupling used to couple the fluid transfer system storage tank and piping system to the fill/drain valve of the client satellite, as well as markings on all tools associated with the fluid transfer operation.

These cameras may be used within a telerobotic control mode where an operator controlling the servicing actions on earth views distinct views of the worksite on display screens at the command and control console. In an alternative mode, the position of elements like the fill drain valve may be determined by either a stereo camera and vision system which extracts 3D points and determines position and orientation of the fill-drain valve or other relevant features on the worksite from which the robotic arm holding tools (multi-function tool, refueling tool) can be driven to these locations according the sensed 6 degree-of-freedom coordinates.

The stereo camera could also be replaced with a scanning or flash lidar system from which desired 6 degree-of-freedom coordinates could be obtained by taking measured 3-D point clouds and estimating the pose of desired objects based on stored CAD models of the desired features or shapes on the refueling worksite. For those applications where the spacecraft was designed with the intention to be serviced, a simple target such as described in Ogilvie et al. (Ogilvie, A., Justin Allport, Michael Hannah, John Lymer, "Autonomous Satellite Servicing Using the Orbital Express Demonstration Manipulator System," Proc. of the 9th International Symposium on Artificial Intelligence, Robotics and Automation in Space (i-SAIRAS '08), Los Angeles, California, February 25-29, 2008) could be used in combination with a monocular camera on the servicing robotics to locations items of interest such as the fill-drain valve. Finally, the robotic arm or device used to position the device may include a sensor or sensors capable of measuring reaction forces between the tools and the work-site (e.g. fill-drain valves). These can be displayed to the operator to aid the operator in tele-operation control or can be used in an automatic force-moment accommodation control mode, which either aids a tele-operator or can be used in a supervised autonomous control mode.

As mentioned above, computer control system **525** is interfaced with vision system **550,** the flow control system **560** of the propellant transfer system, and robotic arm **403.** Previously mentioned communication system **410** is provided which is interfaced with the robotic arm **403** and configured to allow remote operation (from the Earth **408** or from any other suitable location) of the vision system (which may include one or more cameras **550** as separate from the cameras **139** of the refueling tool **100),** the robotic arm **403,** robotic end effector **411 ,** multifunction tool **540,** refueling tool **100** and the flow control system **560.** A system of this type is very advantageous particularly for space based systems needing remote control.

The end effector **411** possesses its own embedded processor (as does the robotic arm **403)** and receives commands from the servicing spacecraft computer. The end effector **411** also passes power and data from the central computer through to the multifunction tool **540** and refuelling tool **100.** The refuelling and multifunction tools do not possess embedded computers/microcontrollers so that they receive actuator commands from the computer control system 525 upstream via the end-effector **411.**

Some aspects of the present disclosure can be embodied, at least in part, in software. That is, the techniques can be carried out in a computer system or other data processing system in response to its processor, such as a microprocessor, executing sequences of instructions contained in a memory, such as ROM, volatile RAM, non-volatile memory, cache, magnetic and optical disks, or a remote storage device. Further, the instructions can be downloaded into a computing device over a data network in a form of compiled and linked version. Alternatively, the logic to perform the processes as discussed above could be implemented in additional computer and/or machine readable media, such as discrete hardware components as large-scale integrated circuits (LSI's), application-specific integrated circuits (ASIC's), or firmware such as electrically erasable programmable read-only memory (EEPROM's).

Figure 22 provides an exemplary, non-limiting implementation of computer control system **525,** forming part of the command and control system, which includes one or more processors **530** (for example, a CPU/microprocessor), bus **502,** memory **535,** which may include random access memory (RAM) and/or read only memory (ROM), one or more internal storage devices **540** (e.g. a hard disk drive, compact disk drive or internal flash memory), a power supply **545,** one more communications interfaces **410,** and various input/output devices and/or interfaces **555.**

Although only one of each component is illustrated in **Figure 22,** any number of each component can be included computer control system **525.** For example, a computer typically contains a number of different data storage media. Furthermore, although bus **502** is depicted as a single connection between all of the components, it will be appreciated that the bus **502** may represent one or more circuits, devices or communication channels which link two or more of the components. For example, in personal computers, bus **502** often includes or is a motherboard.

In one embodiment, computer control system **525** may be, or include, a general purpose computer or any other hardware equivalents configured for operation in space. Computer control system **525** may also be implemented as one or more physical devices that are coupled to processor **530** through one of more communications channels or interfaces. For example, computer control system **525** can be implemented using application specific integrated circuits (ASIC). Alternatively, computer control system **525** can be implemented as a combination of hardware and software, where the software is loaded into the processor from the memory or over a network connection.

Computer control system **525** may be programmed with a set of instructions which when executed in the processor causes the system to perform one or more methods described in the present disclosure. Computer control system **525** may include many more or less components than those shown.

While some embodiments have been described in the context of fully functioning computers and computer systems, those skilled in the art will appreciate that various embodiments are capable of being distributed as a program product in a variety of forms and are capable of being applied regardless of the particular type of machine or computer readable media used to actually effect the distribution.

A computer readable medium can be used to store software and data which when executed by a data processing system causes the system to perform various methods. The executable software and data can be stored in various places including for example ROM, volatile RAM, non-volatile memory and/or cache. Portions of this software and/or data can be stored in any one of these storage devices. In general, a machine readable medium includes any mechanism that provides (i.e., stores and/or transmits) information in a form accessible by a machine (e.g., a computer, network device, personal digital assistant, manufacturing tool, any device with a set of one or more processors, etc.). Examples of computer-readable media include but are not limited to recordable and non-recordable type media such as volatile and non-volatile memory devices, read only memory (ROM), random access memory (RAM), flash memory devices, floppy and other removable disks, magnetic disk storage media, optical storage media (e.g., compact discs (CDs), digital versatile disks (DVDs), etc.), among others. The instructions can be embodied in digital and analog communication links for electrical, optical, acoustical or other forms of propagated signals, such as carrier waves, infrared signals, digital signals, and the like.

The present system is also configured for full autonomous operation. A fully autonomous system is a system that measures and responds to its external environment; full autonomy is often pursued under conditions that require very responsive changes in system state to external conditions or for conditions that require rapid decision making for controlling hazardous situations. The implementation of full autonomy is often costly and is often unable to handle unforeseen or highly uncertain environments. Supervised autonomy, with human operators able to initiate autonomous states in a system, provides the benefits of a responsive autonomous local controller, with the flexibility provided by human teleoperators.

Figure 19 shows the client fill/drain valve **402,** the secondary seal fitting **117,** (also referred to as a B-nut cap or "valve access cap") the valve actuation nut **131 ,** the torque reaction features **121** and the client valve centreline **140.**

Figure 20A shows the backup fill/drain valve **125** with the secondary seal threaded feature **127,** the backup fill/drain valve actuation nut **132,** the backup fill/drain valve torque reaction feature **129** and the backup fill/drain valve seal fitting **128.**

Figure 20B shows the replacement secondary seal fitting **134** with the seal fitting threaded feature **137,** the replacement secondary seal fitting torque reaction feature **135** and the seal fitting **136.**

Figures 23A to **23C** show different views of end effector **411**. The perspective view of **Figure 23A** shows the end effector includes a housing **413,** two (2) cameras **415,** a grapple mechanism **417** for grappling grapple fixture **108 (Figure 1),** and two (2) propellant couplings **419** which couple with propellant couplings **106** and **107 (Figure 1).** Mounted in the end effector **411** is an actuator **421** (preferably a linear actuator) for actuating gearbox shifter **109** in the tool **100.** Doors **423** and **425** cover electrical connectors for the electrical connections **161** and **165** located on tool **100 (Figure 1).** A hex nut drive **429** is included in end effector **411** for other servicing tasks unrelated to client valve actuation. One of these is the actuation of the tilting mechanism within the multifunction tool **540.** Cameras **415** are provide views of operations and the client satellite to the teleoperators to permit them to control various end effector actions. **Figure 23B** shows a perspective view of the back of the end effector **411** showing coupling **427** for coupling the end effector **411** to the end of the robotic arm **403.**

The end effector **411** includes at least two fluid couplings **419,** but it will be understood that if the system is designed to transfer only monopropellant then only one coupling is needed. Mounted in end effector **411** is a coupling actuator (not shown) for moving the fluid coupling(s) into engagement with the couplings **106** and **107** on the tool **100 (Figure 1).** Similarly, mounted in the end effector **411** is a coupling actuator (not shown) for moving the hex socket on the hex-nut drive **429** into engagement with hex-nuts suitably positioned on compatible servicing tools such as the multifunction tool **540.** There is a third coupling actuator (not shown) for moving the electrical and data connectors behind doors **423 and 425** forward to mate with the electrical (power and data) connectors **161 and 165.**

As discussed above, the fluid selection and coupling mechanism **110** includes at least one fluid coupling **(106, 107)** attached on an exterior of the housing section **102,** and the end effector **411** and the housing section **102** of tool **100** are configured such that when the end effector **411** grips the grapple fixture **108** and the coupling actuator is activated fluid couplings **419** on the end effector **411** mate with fluid couplings **106, 107** on the exterior of the housing section **102.**

Further, the end effector **411** and housing section **102** are configured so that when end effector grips the tool grapple fixture **108,** the electrical connectors behind doors **423** and **425** mate with electrical connectors **161 and 165 (Figure 1)** on tool housing section **102** thereby connecting the tool **100** to a source of power and data on the servicer satellite **400.** An actuator (not shown) mounted in end effector **411** drives the two connectors behind the doors **423** and **425** into the tool connectors **161** and **165.**

The electrical connectors on the end effector **411** may be both a data and power connectors and the electrical connectors on the housing **102** may also be power and data connectors. The connector **161** on the end effector **411** is connected to the motor **104** in addition to the various sensor systems located on tool **100,** including, but not limited to rangefinders, cameras **139,** switches, position sensors, temperature sensors, etc. The connector **161** enables commands to be sent to the tool **100** and for telemetry of all sensors to be sent back to the control system. Examples of commands is the voltage demand to the motor **104** and examples of telemetry are status of position switches, measured position, temperature levels and other health monitoring functions and other built-in test function status.

Once the servicer satellite **400** has captured or docked with the client satellite **401 ,** the process for refuelling a client satellite involves first removing any thermal blanket, lockwire and outer cap (or tertiary seal) that may be in place and then using refuelling tool **100** to access and operate the client's propellant valves. Removal of the thermal blanket, lockwire may be achieved using for example the multifunction tool **540** and once access has been achieved, the multifunction tool **540** is sequestered.

Referring briefly to **Figure 18,** for all tool **100** operations, the refueling tool **100** is connected to a robotic arm **403** that provides the structural connection to the host spacecraft **400,** the electrical power for the tool, the connections to the propellants contained in the host satellite **400** refuelling system **406** via the propellant coupling mechanism **405,** the propellant hose **404** leading from the satellite refueling system **406** to coupling mechanism **405** and the mechanical actuation of the gear shifter **109 (Figure 10).**

To open, refuel and close the client satellite fill/drain valve **402,** the refuelling tool **100** performs four functions, each function being selected by positioning the gearbox shifter **109** in a selected position. These positions are named here, for convenience, Gear 1, Gear 2, Gear 3 and Gear 4 and each gear position corresponds to the gearbox shifter 109 having been linearly moved to position the two drive pinions **118** to specific locations. Linear actuator **421 ,** that is part of the end effector **411 (Figure 23A),** moves the gearbox shifter **109** forwards and backwards allowing the control software in the host spacecraft **400** to select the appropriate gear to perform the tasks as needed. In an alternative embodiment, the gearbox shifter **109** can be linearly actuated by an actuator physically mounted within the refuelling tool **100.** In this form, this actuator would be commanded with the electrical connectors **161 and 165.**

The first function that must be performed is to ensure that the correct propellant will be provided to the satellite **401 .** The Fuel Oxidiser Exchanger (FOE) **110 (Figure 5A-5E)** is the mechanism that is used to switch between the several propellants that the tool **100** can manage. After the robotic arm **403** has grappled the refueling tool **100** using the grapple fixture **108** and made all mechanical and electrical connections, the operator establishes which propellant will be provided to the client satellite **401 .**

There is a nominal stowage position for the FOE **110** and if the propellant to be supplied matches the nominal FOE position, no further action is required. If the nominal FOE position does not match that of the propellant to be supplied, then, the refuelling tool **100** is moved onto the Reset Post **111** by the robotic arm **403.** The linear actuator **421** is commanded to move the gear shifter **109** to the Gear 1 position which is located such that the upper drive pinion **118** on the gear shifter **109** engages the FOE drive gear **168** on the upper FOE housing **330** (shown in **Figure 5H).** The motor **104** is commanded to move the FOE **110** such that the correct propellant delivery tube **112** is located concentric with the cam wrench centreline **313 (Figures 11A** and **13A)** The refuelling tool **100** is then moved off of the reset post **111 (Figures 17** and **18),** the correct propellant delivery tube slides down into the centre of the cam wrench mechanism **300** driven by spring **340** as the tool **100** moves off the rest post **111** and manoeuvred over the client valve **402.**

The ability of the tool **100** to perform four distinct functions, two of which involve splitting the motor torque equally between two cam wrench mechanisms **(300A** and **300C** or **300B** and **300C)** is a key factor in permitting tool **100** to work. The torque splitting is performed using the differential gear train **200.** While individual differential gear trains are not unique, the ability of the refuelling tool gearbox **200** design to shift between several differential and non-differential gear trains is unique. These four gear trains are described while defining each of the gear states: Gear 1, Gear 2, Gear 3 and Gear 4. While the gearbox **200** in this example of a refuelling tool switches between a total of four separate gear trains, there is nothing inherent in the design that would prevent the number of gear trains from being some other number from two trains up to the limit of the space available and the amount of linear motion available to the gear shifter **109** due to actuator **421** on the end effector **411.**

Using detailed knowledge of the client satellite, the robotic arm **403** manoeuvres the tool **100** to a position very near the client fill/drain valve **402** and then the operator uses the three cameras **139** and their associated optics **114** and lights **115** to provide final and fine guidance to move the tool **100** down over the valve **402** until the refueling tool **100** comes in contact with the surface of the client satellite **401** with the client valve **402** located within the tool **100.** At this point the tip **116** of the propellant delivery pipe **112** is in gentle contact with the top of the secondary seal fitting on the client valve **402.**

The first step in servicing the client satellite drain/fill valve **402** is to remove the secondary seal fitting **117.** To do so the linear actuator **411** moves the gearbox shifter **109** to the Gear 2 position. In this position, the lower drive pinion **118** on the gear shifter **109** engages the secondary seal sun gear **208.** The refueling tool **100** is commanded to rotate the secondary seal fitting **117** in a counter-clockwise direction. With the gear shifter in the above noted Gear 2 position, torque from the motor **104** passes to the gear shifter **109,** which is also the main input drive shaft, via motor output gear **155** idler gear **154** and gear shifter input gear **156.** The torque then passes from the upper pinion **118** to the lower pinion **118** which is engaged in the secondary seal sun gear **208.** The well understood differential arrangement of the secondary seal sun gear **208,** secondary seal planet gears **207,** secondary seal fitting planet carrier gear **209** and the ring gear **206** splits the input torque from the lower pinion **118** and causes both the ring gear **206** and the secondary seal fitting planet carrier gear **209** to rotate in opposite directions. The secondary seal fitting planet carrier gear **209** is connected to output shaft **266,** which is then connected to lower output shaft **266A** via a spline coupling **396** and then to cam wrench mechanism **300A**.**The** ring gear **206** is connected to the reaction gear **264,** which is then connected to lower reaction gear **264A** via a spline coupling **398** and then to cam wrench mechanism **300C.**

It will be appreciated that while the present disclosure shows three (3) different cam wrench mechanisms **300A, 300B** and **300C** stacked coaxially one on top of the other, it will be understood that some applications may require only two (2) cam wrench mechanisms coaxially stacked one on top of each other depending on the number of the nuts on the client satellite they are engaging for the application at hand.

When in the Gear 2 position as described above, torque is supplied to the cam wrench mechanism **300A** that engages the secondary seal fitting and to the cam wrench mechanism **300C** that engages the torque reaction features on the client valve **402.** The differential action of the gearbox **200** causes both cam wrench mechanisms **300A** and **300C** to activate and the cams to close on and engage the flat surfaces of the secondary seal fitting **117** and the torque reaction features **121 .** As torque is applied to the cam wrenches **300A** and **300C** (described in more detail below) they both rotate around the client valve **402** in opposite directions and the nut cams **301** of the wrench close in providing an action that both "hunts" for the optimal seating position for the nut cams **301** to apply torque to the client valve **402** and centres the valve within the refuelling tool **100** to provide the correct alignment between the tool **100** and the client valve **402** for further functions.

Once the mechanism has found its optimum position, further application of motor torque causes cam wrench mechanism **300A** to apply a loosening torque to the secondary seal fitting **117** and the other cam wrench mechanism **300C** to apply an equal and opposing reaction torque to the valve reaction features **121 .** This contains all of the servicing torques within the valve **402** and the tool **100** and virtually eliminates any torque being applied to the structure of the client spacecraft **401,** which it may not be designed for. It also eliminates torques being applied to the servicing spacecraft robotic arm **403** allowing it to be significantly lighter.

The torque applied to the secondary seal fitting **117** is increased until it overcomes the torque with which it was installed and then the fitting is rotated in the counter-clockwise direction until it is completely free of the client valve **402.** The secondary seal fitting cam wrench **300A** has attached to it, via an axis and spring, a pair of seal fitting retainers **305** and when the secondary seal fitting is completely loose from the client valve **402,** these fitting retainers **305,** driven by their springs **316,** become engaged with the underside of the seal fitting **117.** Contained at the sides by the cam wrench jaws **301** of cam wrench **300A,** from the top by the propellant delivery pipe **112** and from below by the fitting retainers, the secondary seal fitting **117** is ready to be removed from the client valve **402.**

To remove the secondary seal fitting **117** from the client valve **402,** the gear shifter **109** is advanced to the Gear 3 position. In the Gear 3 position the lower drive pinion 118 is disengaged from the secondary seal sun gear 208 and moved such that it directly engages the ring gear 206. In this position, the lower drive pinion **118** is disengaged from the secondary seal fitting cam wrench **300A** but remains engaged with the torque reaction cam wrench **300C** via reaction gear **264** and **264A.** The motor **104** is then commanded to rotate such that the torque reaction cam wrench **300C** opens. Mechanical drag within the machine leaves the jaws of the secondary seal fitting cam wrench **300A** engaged with the fitting. With the jaws of the torque reaction wrench **300C** fully withdrawn the way is clear for the refuelling tool **100** to be withdrawn from contact with the client valve **402** taking the secondary seal fitting **117** with it.

The refuelling tool **100** is manoeuvred away from the client satellite **401** and back to the host spacecraft **400** where there is a storage point for the removed secondary seal fitting **117.** The storage point **122** includes a guide **123** for the refuelling tool **100** and a threaded fitting that matches the configuration of the client valve **402.**

The refuelling tool **100** manoeuvres over the guide **123** and, using the cameras **139,** optics **114** and lights **115,** engages the tool **100** into the guide. Once engaged, the tool **100** is commanded down over the storage point **122.** Once the tool **100** is fully seated into the storage point, the storage fitting **122** is inside the tool in the same location as the client valve **402** occupied and the retained secondary seal fitting **117** comes in contact with the top of the storage fitting **122.** The springs on the retaining fittings are moved out of the way by the action of lowering the refuelling tool **100** over the storage fitting **122** leaving the threads of the secondary seal fitting **117** to engage with the treads on the top of the storage fitting **122.**

To store the secondary seal fitting **117** onto the secondary seal fitting stowage point **122,** the gear shifter **109** is retracted to the Gear 2 position, see above. The motor **104** provides torque to both the secondary seal fitting cam wrench **300A** and to the torque reaction cam wrench **300C.** The motor **104** is then commanded to rotate the secondary seal fitting **117** in the clockwise direction, installing it onto the storage fitting **122.** Once a satisfactory installation torque has been reached, the motor direction is reversed and the cam wrench nut cams **301** are retracted to the fully open position. The refuelling tool **100** is retracted from the secondary seal fitting stowage point **122.**

The refuelling tool **100** is then manoeuvred to the stowage point for a backup fill/drain valve **125.** The backup fill/drain valve **125** provides a method to close off the client valve **402** in case the client valve's own sealing mechanism fails to work properly after refuelling. It is installed at the interface between the secondary seal fitting which has been removed and the exposed threaded interface on the client valve **402** and, if need be, is left behind to seal the client satellite's propellant system in the event that fuel is found to be leaking from the valve **402** even with the valve actuation nut **131** closed. The backup fill/drain valve **125** has interfaces at the top and bottom that match the configuration of the client valve **402** being serviced.

The backup fill/drain valve **125** stowage point has refuelling tool guides similar to those on the secondary seal fitting storage point **122.** After being manoeuvred over the backup fill/drain valve **125** the guide positions the refuelling tool **100** properly with respect to the backup fill/drain valve **125** and the refuelling tool **100** is lowered down over the backup fill/drain valve **125.** Once properly positioned within the refuelling tool **100,** the top of the backup fill/drain valve **125** becomes engaged with the tip of the propellant delivery pipe **112.** The tip of the propellant delivery pipe **112** contains a seal fitting **116** similar to the secondary seal fitting **117** of the client fill/drain valve **402.**

Once the backup fill/drain valve **125** is properly positioned within the refuelling tool **100,** the tool is retracted by the arm **403** to an intermediate position where the secondary seal fitting cam wrench **300A** can engage the seal fitting **116** on the propellant delivery pipe **112.** At that point the torque reaction cam wrench **300C** is aligned with torque reaction features **129** on the backup fill/drain valve **125.** The gearbox shifter **109** is commanded to the Gear 2 position, see above, (or verified that it has remained in the Gear 2 position) and the motor **104** is commanded to rotate the seal fitting **116** of the propellant delivery pipe **112** so that it is installed onto the top threaded feature **127** of the backup fill/drain valve **125.** Once the proper torque is reached to ensure a good seal, the motor **104** is commanded to open the two cam wrenches to the fully open position and the arm moves the tool **100** downward so that the backup fill/drain valve **125** protrudes further into the tool **100** and the secondary seal fitting cam wrench **300A** on the tool **100** aligns with the seal fitting **128** on the base of the backup fill/drain valve **125.** At that point the torque reaction cam wrench **300C** is aligned with torque reaction features **431** on the base of the backup fill/drain valve **125** stowage point.

With the gear shifter still in the Gear 2 position, the motor **104** on the tool **100** is commanded to rotate the seal fitting at the base of the backup fill/drain valve **125** in the counter-clockwise direction thereby disengaging the backup fill/drain valve **125** from the backup fill/drain valve stowage point. At this point the backup fill/drain valve **125** is fully installed in tip **116** of the propellant delivery tube **112** and free of the backup fill/drain valve stowage point **126.** The refuelling tool **100** is manoeuvred off of the backup fill/drain valve **125** stowage point **126** and then back over the client valve **402.** Again using the refuelling tool cameras **139,** optics **114** and lights **115,** the refuelling tool **100** is manoeuvred down to the client valve **402** until the seal fitting at the base of the backup fill/drain valve **125** can be seen engaging the threaded feature at the top of the client valve **402** where the client secondary seal fitting **117** had been threaded previously before removal. Once this has taken place the refuelling tool **100** is commanded downwards until the refuelling tool again contacts the surface of the client satellite **401.**

With Gear 2 still engaged, and the seal fitting **128** of the backup fill/drain valve **125** engaged with the threads on the client valve **402** the motor **104** is commanded to turn the seal fitting **128** clockwise, installing the backup fill/drain valve **125** and propellant delivery pipe **112** onto the client satellite **401 .** Once the correct sealing torque has been achieved, the motor **104** is commanded to open cam wrenches **300A** and **300C** to the fully open position.

With the backup fill/drain valve **125** installed on the client valve **402** the propellant hose(s) **404 (Figure 18)** in the robotic arm **403** is advanced until the fluid couplings **419** and **419'** on the hose mechanism on end effector **411** fully engages with the fittings **106** and **107** on the refuelling tool **100.** The mechanical arrangement of the hose couplings and the refuelling tool **100** fittings **106** and **107** is such that it is impossible to incorrectly mate hose couplings **419** and **419'** to the desired fittings **106** and **107** on the tool **100.**

The valve within the backup fill/drain valve **125** is nominally closed and in this position, and with the propellant hose **404** to the host spacecraft attached, the propellant hose **404** is pressurised by the propellant transfer system **406** on the servicer satellite **400** so that it can be verified that the backup fill/drain valve **125** to propellant delivery pipe connection is pressure tight. Once this has been verified the refuelling tool **100** is raised to the point where the torque reaction cam wrench **300C** is in contact with the torque reaction features **129** on the backup fill/drain valve **125.** The gear shifter **109** is advanced to the **Gear 4** position by the linear actuator **421.** In this position, the lower pinion **118** on gear shifter **109** is aligned with the valve actuation sun gear **205.** With the gear shifter **109** in the above noted Gear 3 position, torque from the motor **104** passes to the gear shifter **109,** via motor output gear **155** idler gear **154** and gear shifter input gear **156.** The torque then passes from the upper pinion **118** to the lower pinion **118** which is engaged in the valve actuation sun gear **205.** The well understood differential arrangement of the valve actuation sun gear **205,** secondary seal planet gears **204,** valve actuation planet carrier gear **203** and the ring gear **206** splits the input torque from the lower pinion **118** and causes both the ring gear **206** and the valve actuation planet carrier gear **203** to rotate in opposite directions. The valve actuation planet carrier gear **203** is connected to output shaft **262,** which is then connected to lower output shaft **262A** via a spline coupling **396** and then to cam wrench mechanism **300B.** As before, the ring gear **206** is connected to the reaction gear **264,** which is then connected to lower reaction gear **264A** via a spline coupling **398** and then to cam wrench mechanism **300C.** The motor **104** is commanded to rotate the backup fill/drain valve actuation nut **132** to the open position. In the **Gear 4** position, when torque is applied to the input pinion **118** on the gear shifter **109** the selected differential gear stage splits the torque between the torque reaction cam wrench **300C** and the valve actuation cam wrench **300B.** Similar to the action when removing or installing the seal fitting, the motor torque is supplied to the valve actuation cam wrench mechanism **300B** that engages the valve actuation nut **132** and to the torque reaction cam wrench mechanism **300C** that engages the torque reaction features **129** respectively on the backup fill/drain valve **125.** The differential action of the gear train causes both cam wrench mechanisms **300B** and **300C** to activate and the nut cams **301** to close on and engage the flat surfaces of the backup fill/drain valve **125** actuation nut **132** and the backup fill/drain valve **125** torque reaction features **129.** As torque is applied to the cam wrenches **300B** and **300C** they both rotate around the backup fill/drain valve **125** in opposite directions and the nut cams **301** of the wrench mechanism **300B** and **300C** close in providing an action that both "hunts" for the optimal seating position for the cams to apply torque to the backup fill/drain valve **125** and centres the backup fill/drain valve **125** within the refuelling tool **100** to provide the correct alignment between the tool **100** and the backup fill/drain valve **125** for further functions.

Once the mechanism has found its optimum position, further application of motor torque causes cam wrench **300B** to apply a loosening torque to the actuation nut on the backup fill/drain valve **125** and the other cam wrench **300C** to apply a reaction torque to the reaction features **129** of the backup fill/drain valve **125.** Again, this contains all of the servicing torques within the backup fill/drain valve **125** and the tool **100** and virtually eliminates any torque being applied to the structure of the client spacecraft **401 .**

The torque applied to the backup fill/drain valve **125** actuation nut **132** is increased until it overcomes the torque with which it was installed and then the nut rotates in the counter-clockwise direction until the backup fill/drain valve **125** aperture is completely open. Once the backup fill/drain valve **125** actuation nut **132** is open, the seal between the backup fill/drain valve **125** and the client satellite is pressure checked by the host satellite refuelling system **406.**

Once the pressure checks have been passed, the cam wrenches **(300B** and **300C)** are commanded to open fully and the refuelling tool **100** is translated back down until it again contacts the surface of the client satellite **401 .** In this location, and with Gear 4 (see above) still engaged, the motor **104** is commanded to open the valve actuation nut **131** on the client fill/drain valve **402** using the valve actuation nut cam wrench **300B** while cam wrench **300C** is engaged with torque reaction feature **121** on valve **402.** Once the valve **402** is fully opened, the refuelling system on the servicer spacecraft **400** directs new propellant from the servicer spacecraft **400** to the client spacecraft **401** through the propellant hose **404.** When the desired amount of propellant has been transferred to the client satellite **401 ,** the motor **104** is commanded to close the valve actuation nut **131** using the valve actuation nut cam wrench **300B** and the torque reaction cam wrench **300C** is engaged with torque reaction feature **121** on valve **402.**

With the backup fill/drain valve **125** still in the open position, the integrity of the closed client valve **402** seal is pressure checked by the host satellite refuelling system **406.** If the seal is acceptable, the process skips on to the removal of the backup fill/drain valve **125** step, below. If the seal is inadequate, the backup fill/drain valve **125** is left behind as the client's primary seal. In that case, the refuelling tool **100** is translated away from the client spacecraft **401** until the refuelling tool valve actuation nut cam wrench **300B** can access the actuation nut **132** on the backup fill/drain valve **125** and, with the tool in Gear 4 (see above), the motor **104** is commanded to close the backup fill/drain valve **125** actuation nut **132** and, when closed, the seal is pressure checked by the host satellite refuelling system **406.** When the seal is acceptable, the propellant hoses **112** are decoupled from the refuelling tool **100,** cam wrenches **300B** and **300C** are commanded top fully open and the tool is translated to where the secondary seal fitting cam wrench **300A** can access the seal fitting **116** between the propellant delivery pipe and the backup fill/drain valve **125.** The gear shifter **109** is moved to the Gear 2 position (see above) and the motor **104** is commanded to disconnect the seal fitting **116** from the top of the backup fill/drain valve **125** using cam wrenches **300A** and **300C.** With seal fitting **116** completely loosened from the backup fill/drain valve **125,** the refuelling tool **100** is manoeuvred away from the client fill/drain valve **402** leaving the backup fill/drain valve **125** behind.

Assuming the client valve **402** seal was acceptable, then, with the client spacecraft **401** resupplied with propellant, the backup fill/drain valve **125** is removed from the client fill/drain valve **402** by reversing the installation procedure. First, the propellant hoses **112** are decoupled from the refuelling tool **100.** Then, with the gear shifter in the Gear 2 position (see above) the secondary seal fitting cam wrench untorques the seal fitting **128** between the backup fill/drain valve **125** and the client valve **402** allowing the tool to back away from the client satellite taking the backup fill/drain valve **125** with it. The tool **100** and backup fill/drain valve **125** are manoeuvred back to the stowage point on the servicer satellite **400.** Once the tool **100** has been guided back down over the backup fill/drain valve **125** stowage point the secondary seal fitting cam wrench **300A** reinstalls the backup fill/drain valve **125** seal fitting onto the stowage point.

The cam wrenches **300A** and **300C** are positioned to the fully open position and the tool **100** is free to translate upwards to where the secondary seal fitting cam wrench **300A** detaches the seal fitting **116** at the tip of the propellant pipe **112** from the top of the backup fill/drain valve **125.** The cam wrenches **(300A** and **300C)** are opened again and the refuelling tool **100** is now free from the backup fill/drain valve **125.**

The tool **100** translates to the replacement secondary seal fitting stowage point **133** on the servicer satellite **400.** With the gear shifter **109** still in the Gear 2 position (see above), the refuelling tool **100** picks up a replacement secondary seal fitting **134** in the same way as it picked up the backup fill/drain valve **125.** The seal fitting **116** on the end of the propellant delivery pipe **112** is torqued onto the threaded feature **137** on the top of the replacement fitting **134** and then the seal fitting **136** at the base of the replacement fitting **134** is detached using the secondary seal fitting cam wrench **300A** allowing, once the cam, wrenches **300A** and **300C** are opened the replacement secondary seal fitting **134** to be lifted away from the servicer satellite **400** and manoeuvred over the client satellite fill/drain valve **402.**

With the gear shifter still in Gear 2, the replacement secondary seal fitting **134** is installed onto the client valve **402** by using the secondary seal fitting cam wrench **300A** to install the seal fitting **136** of the replacement fitting **134** onto the threaded feature on top of either the client valve **402** or the backup fill/drain valve **125** depending upon whether the backup fill/drain valve **125** is to remain on the client satellite **400.** Once the replacement secondary seal fitting **134** has been torqued to the correct value, the tool **100** is translated such that the seal fitting **116** on the propellant delivery pipe **112** can be removed from the top of the replacement seal fitting, leaving the tool **100** free and leaving the replacement seal fitting installed on the client satellite **401 .**

This completes the tool activities to provide one propellant to a client satellite **401 .**

As mentioned above, the cam wrench mechanisms **300A, 300B** and **300C** for opening and closing the fill/drain valves **402** are aligned coaxially one on top of the other. The cam wrench mechanism **300** and the gearbox **200** are configured so that the torque is substantially equally split between the two output shafts **262 (262A)** and **264 (264A)** or **266 (266A)** and **264 (264A)** of selected pairs of cam wrench mechanisms **(300A, 300C,** or **300B, 300C)** which are being employed as pairs to avoid applying torque to the client satellite **401** or to the robot arm **403** during fluid transfer operations. It will be understood that the torque may not be split exactly equally due to the mechanical nature of the system but they are substantially equal.

Replenishing a client satellite **401** may require the provision of several types of propellants to several different sized fill/drain valves. To accomplish this without requiring the use of multiple refuelling tools required the invention of the present cam wrench mechanism **300.** The cam wrench mechanism **300** allows torque to be applied to a wide range of nut sizes that may be at any rotational orientation around the nut axis and can be reversed to permit the application of torques in both the clockwise and counter-clockwise directions using the same cam wrench.

All three cam wrenches **300A, 300B** and **300C** in the refuelling tool **100** work essentially the same way and may be comprised of identical parts if the client valve **402** specifications permit it. The cam wrench mechanisms comprise the following principle components: a housing, which supports the components of the cam wrench via bearings and is anchored to the tool lower housing structure **103** to prevent its rotation under torque load, a drive ring which is geared on its exterior surface to accept the torque input from the gearbox output shaft, a cam ring, which is coaxial with the drive ring, supports two cam locks and resides within the drive ring, two nut cams which are free to rotate each within a hole in a cam lock, two cam locks, each of which supports one nut cam and is free to translate radially within the cam ring and a detent spring which resides between the cam ring and the housing which provides the initial resistance to motion so that the cams start to rotate before the cam ring is rotated by the drive ring. Other fasteners and covers may be present in order to build a reliable mechanism, but they are not critical to the operation of the cam wrench mechanism.

The physical manifestation of the cam wrench mechanism **300** is quite compact and takes up little space perpendicular to the axis of the client valve **402** so that several mechanisms **(300A, 300B, 300C)** may be stacked coaxially on top of each other to apply torque at several locations along the axis of rotation without moving the tool **100.** Each cam wrench mechanism **300A, 300B** and **300C** must be supplied with torque from an external source, such as output and reaction shafts **262 (262A), 264 (264A)** and **266 (266A)** from a gearbox **200.** Usually, the cam wrench mechanisms **300A, 300B, 300C** are utilized only in pairs with the wrenches of each pair being rotated in opposite directions.

A key feature of each of the adjustable cam wrench mechanisms is the presence of the cam locks **303.** Referring to **Figure 11A,** each adjustable wrench mechanism **(300A, B** and **C)** includes housing **302** having a rotational axis **313,** the pair of opposed nut cams **301** pivotally mounted each to toothed cam lock **303.** The nut cams **301** each include a pawl member **307,** with the cam locks **303** being translationally mounted to cam ring **308.** The cam ring **308** is coaxially mounted in the housing **302** and is rotationally movable with respect to the housing **302.** A detent spring **304** is mounted between the cam ring **308** and the housing **302** to restrict movement of the cam ring. The toothed drive ring **306** having an inner tooth surface **315** and and outer toothed surface and is mounted in the housing **302** and is rotatable with respect to the housing **302.** The cam pawls **307** are engaged with the toothed drive ring **306** so that when the toothed drive ring is rotated by an output shaft from the differential gear box **200,** the opposed nut cams **301** are rotationally driven until they contact opposing outer surfaces of a faceted rotatable element (such as fill/drain valve **402),** at which point the toothed cam locks **303** slide radially outward to engage the toothed inner surface **315** of the drive ring 306 thereby locking the drive ring **306** and the cam ring **308** together to permit torque applied by the output shaft to be transmitted to the faceted surface.

More specifically, referring to **Figures 10, 11** and **12,** to operate a cam wrench **300A, 300B** or **300C,** torque is input to the mechanism via the drive ring **306,** which turns on the bearing **317** in the housing **302.** As the drive ring **306** turns, the detent spring **304** keeps the cam ring **308** rotationally fixed to the housing **302.** The nut cams **301 (301 A)** are attached to the cam rings **308** yet have pawls **307** that engage slots **309** in the drive ring **306.** As these pawls **307** are moved by the drive ring **306,** and given that the cam ring **308** is not rotating, the nut cams **301** start to rotate. The nut cams **301 (301 A)** continue to rotate as the drive ring **306** rotates until their interior surfaces **310** contact the object or nut to be rotated. At that point a moment or torque is established that tries to rotate the axis **311** of the nut cams **301 (301 A)** away from the axis **313** of the nut being acted upon.

The axis **311** of the nut cams **301** is supported within the cam locks **303** and these cam locks are free to slide radially inwards and outwards, a spring **312** being used to keep them nominally positioned closer to the cam wrench axis of rotation **313.** As cam nut **301 (301 A)** contacts the nut face **310,** the resultant moment pushes the cam lock outward to the point where the spline segment **314** on the exterior of the cam lock **303** engages with the spline segments **315** on the interior of the drive ring **306.** This locks the cam ring **308** and the nut cams **301 (301 A)** rotationally to the drive ring **306** and from that point onward additional torque applied to the drive ring **306** is resolved as torque applied to the nut that is to be rotated.

Changing the direction of rotation of the drive ring **306,** usually, but not necessarily, by changing the direction of rotation of the tool motor **104,** rotates the drive ring **306** in the opposite direction. The nut cam **301 (301 A)** rotates out of contact with the nut or object being rotated and the moment that moved the cam lock **303** radially outward and into contact with the drive ring disappears. The spring **312** attached to the cam lock **303** moves the cam lock **303** back to its original position thereby unlocking the cam ring **308** from the drive ring **306** and the drive ring **308** starts to rotate in the other direction. It will continue to rotate in that direction until the contact faces **310** of the nut cams **301 (301 A)** again come into contact with the nut and the contact force moment is re-established. At that point the cam lock **303** again moves outward and locks the cam ring to the drive ring and the wrench mechanism can apply torque in the opposite direction to before. Thus the same mechanism can apply torque in the clockwise and counter-clockwise directions.

As drive ring **306** rotates around axis **313** it pushes on pawl **307.** Pawl

307 pushes nut cam **301** to rotate around axis **311** until cam face **310** comes into contact with something solid. The drive ring **306** continues to rotate and the push force on the pawl **307** is resisted by whatever surface face **310** is in contact with. The combination of the force on pawl **307** and the resistance by **310** creates a moment within the nut cam **301,** but cam nut **301** is not held rigidly and does not resist the radial component of the forces developed because the axis **311** sits in the nut cam **303** which is free to slide radially. The forces on the axis **311** force the nut cam **303** to slide radially outward until the teeth on the nut cam **314** engage the inner teeth **315** on the drive ring **306.** These teeth intermesh and lock the two rings **306** and **308** together. The locked pair of then rings resist the resultant force on **311** and then can transmit torque to the feature.

The size adjustability comes about because the locking of the two rings does not occur until the face **310** actually contacts something solid creating the radial force vector that moves the cam lock out into engagement with the drive ring **306.** For a larger feature, the nut cam **301** does not rotate as much when pawl **307** is pushed before contacting the larger feature and the mechanism locks up soon after torque is applied. For smaller features, the nut cam **301** has to rotate further before contact and only after the contact is made after this larger rotation does the cam lock **303** move outwards to lock the two rings **306** and **308** together.

The use of backup fill/drain valve **125** is very advantageous for several reasons. If the client fill drain valve cannot be properly closed (i.e., if it leaks), then propellant would leak from the client propulsion subsystem as soon as the refueling tool is disconnected. This situation is not acceptable and the risk of its occurrence could dissuade potential customers from consider propellant resupply of their spacecraft. This risk is mitigated through the use of the backup fill/drain valve **125.** The system may be configured in such a way that backup fill/drain valve **125** also functions as a throttling valve. If the backup fill/drain valve **125** is only partially opened, then it has increased flow resistance and so can be used to regulate the flow rate of propellant. This is useful for the direct transfer method as otherwise the flow rate would be determined solely by the pressure difference between the client propellant tank and the servicer spacecraft propellant storage tank. The backup fill/drain valve **125** provides a secondary sealing of the principal flow path from the client storage tank to the vacuum of space.

Tool **100** may include passive thermal control means such as thermal insulation blankets or surface coatings and may include active temperature control means for sensing and controlling the temperature of the housing and the mechanisms therein such as thermistors, thermal switches, heaters and heat pipes.

The tool **100** may include sensors for sensing and reporting the locations of designated moving parts. Said sensors may include switches, proximity sensors, miniature cameras or visual indications on or inside the tool. Portions of the tool housings **(101 , 102, 103, 105)** may have openings to permit cameras external to the tool to view and report on mechanism positions.

An advantage of the present tool is that the gear shifter shaft **109** is also the torque input shaft for the gearbox **200** so that the present system does not require a separate drive input and separate gear shifter, the present system accomplishes both using one shaft.

It will be understood that the present tool may be used not just for refueling operations but in any operation for opening a rotationally removable access component of the client satellite, i.e., not just fill/drain valves but any other the access component on the client satellite having rotatable and static features. Such a tool is useful for accessing other areas of the client satellite rather than specifically the propellant system. Such a tool would not require the fluid exchanger subsystem per se and as such in this embodiment of the tool the fluid exchanger subsystem would be optional.

The specific embodiments described above have been shown by way of example, and it should be understood that these embodiments may be susceptible to various modifications and alternative forms. It should be further understood that the claims are not intended to be limited to the particular forms disclosed, but rather to cover all modifications, equivalents, and alternatives falling within the spirit and scope of this disclosure.

THEREFORE WHAT IS CLAIMED IS:

1. A tool mounted on a first satellite for opening a rotationally removable access component of a second satellite, the access component on the second satellite having rotatable and static features coaxially aligned along a first axis, comprising:

a housing including

a motor mounted in said housing, a gear shifter coupled to said motor,

a wrench mechanism mounted in said housing including at least first and second adjustable wrench mechanisms coaxially aligned one on top of the other along a second axis;

a differential gearbox mounted in said housing coupled to said first and second adjustable wrench mechanisms, the gearbox being configured to split the torque received by the gear shifter evenly between the first and second adjustable wrench mechanisms; and

wherein, when the tool is positioned with the wrench mechanism down over the access component with the second axis coincident with the first axis, the first adjustable wrench mechanism engages the rotatable feature of the rotationally removable access component and the second adjustable wrench mechanism engages the static feature of the access component such that the wrench mechanism applies equal and opposite forces to the rotatable feature and the static feature to apply bi-directional torque to the rotatable feature while reacting the torque on the static feature.

2. The tool according to claim 1 wherein said differential gearbox is coupled to said at least two adjustable wrench mechanisms via at least first and second shafts, the gear shifter being coupled to said gearbox, the gear shifter being configured to transmit torque from said motor to said gearbox, said gearbox being configured to transmit said torque received from said gear shifter to said at least first and second output shafts.

3. The tool according to claim 2 wherein said tool is a tool for exchanging

one or more fluids between first and second satellites in orbit, the robotic tool being mounted on said first satellite, the rotationally removable access component on the second satellite including at least one fill/drain valve having the rotatable features and static features, including a fluid exchanger subsystem mounted in said housing and configured to mate with one or more fluid sources on the first satellite and to selectively pass fluid between the first and second satellites, wherein the gear shifter is coupled to said fluid exchanger subsystem.

4. The tool according to claim 3 wherein the at least one fill/drain valve includes a rotationally removable secondary seal fitting with an associated rotatable feature coaxially aligned with the rotatable and static features of the fill/drain valve, wherein said wrench mechanism includes at least a third adjustable wrench mechanism being aligned coaxially with the first and second wrench mechanisms, said differential gear box including a third output shaft, said third output shaft being coupled to said third wrench mechanism, said third wrench mechanism being configured to engage the associated rotatable features of the secondary seal fitting to apply bi-directional torque thereto while the second adjustable wrench mechanism reacts this bi-directional torque on the static features on the fill/drain valve.

5. The tool according to claim 4 wherein said third adjustable wrench mechanism is configured to grasp said secondary seal fitting and to secure it once the applied torque has disengaged it from the fill/drain valve.

6. The tool according to claim 4 wherein said differential gear box is a shifting differential gear box in which an operator can selectively shift between differentially paired output shafts.

7. The tool according to claim 4 wherein said differential gear box is a shifting differential gear box in which an operator can selectively shift between said first and second output shafts and said second and third output shafts.

8. The tool according to claim 7 including an actuator configured to

selectively engage said gear shifter for shifting between gear positions in said differential gear box.

9. The tool according to claim 8 wherein said actuator is a linear actuator mounted on said end effector and is configured for remote teleoperator control which, when commanded by an operator, engages said gear shifter to move said gear shifter between selected gears of the gearbox.

10. The tool according to claim 8 wherein said actuator is mounted on said housing and is configured for remote teleoperator control which, when commanded by an operator, engages said gear shifter to move said gear shifter between selected gears of the gearbox.

11. The tool according to claim 3 wherein the second satellite is configured to receive at least two different fluids and includes at least a first fill/drain valve and a second fill/drain valve each having different fool proof coupling features, and wherein said fluid exchanger subsystem mounted in said housing includes at least two fluid flow pathways having corresponding fool proof coupling features associated with each to mate with the first and second fill/drain valves.

12. The tool according to claim 11 wherein fluid exchanger subsystem is configured to be movable between at least two positions in said housing such that when in a first position a first of the at least two fluid flow pathways is coupled to a first fluid source on the first satellite and the first fill/drain valve then the second of said at least two fluid flow pathways is disengaged from the second fill/drain valve and from a second fluid source on the first satellite, and wherein when in a second position the second fluid flow pathway is coupled to the second fluid source on the first satellite and the second fill/drain valve then the first fluid flow pathway is disengaged from the first fill/drain valve and from the first fluid source on the first satellite, and wherein said fluid exchanger subsystem includes an interface adapted to be engaged by said actuator for moving said fluid exchanger subsystem between said first and second positions.

13. The tool according to any one of claims 1 to 12 wherein each adjustable wrench mechanism includes a housing having a rotational axis, a pair of opposed nut cams pivotally mounted each to a toothed cam lock, said nut cams each including a pawl member, said cam locks being translationally mounted to a cam ring, said cam ring coaxially mounted in said housing and being rotationally movable with respect to said housing, a detent spring mounted between said cam ring and said housing to restrict movement of said cam ring, a toothed drive ring having inner and outer toothed surfaces mounted in said housing and being rotatable with respect to said housing, said cam pawls being engaged with said toothed drive ring so that when said toothed drive ring is rotated by an output shaft from said differential gear box, said nut cams are rotationally driven until they contact opposing outer surfaces of a faceted rotatable element, at which point said toothed cam locks slide radially outward to engage said toothed inner surface of said drive ring thereby locking the drive ring and the cam ring together to permit torque applied by said output shaft to be transmitted to said faceted surface.

14. The tool according to any one of claims 1 to 13 wherein said wrench mechanism is mounted adjacent to a first end of said housing, said first end of said housing being configured to allow engagement of said wrench mechanism with said rotationally removable access component, and including a vision system mounted on said housing disposed, and having a field of view, to observe a region around said first end of said housing to observe the engagement of the wrench mechanism with the rotationally removable access component to allow remote operator control of said wrench mechanism.

15. The tool according to any one of claims 1 to 14 including features mounted on said housing to allow the tool to be grasped and manipulated by an end effector mounted on a distal end of a robotic arm, said features includes a grapple fixture.

16. The tool according to claim 15 wherein said housing includes at least one power and data connector, at least one fluid coupling connected to at least one fluid flow path from at least one fluid storage tank on said first

satellite, and wherein said at least one power and data connector, and said at least one fluid coupling are positioned to mate with corresponding power and data connector and fluid flow coupling on said end effector.

17. The tool according to claim 16 wherein said power and data connector on said housing is connected to said actuator for providing power to said actuator, and for providing power and a data connection to various sensors including a vision system mounted to said housing for transmitting image data from said vision system to a communication system on said first satellite for transmitting the image data to a remote operator and for receiving instructions from said remote operator for commanding said actuator, said vision system disposed, and having a field of view, to observe a region around said first end of said housing to observe the engagement of the wrench mechanism with the rotationally removable access component to allow remote operator control of said wrench mechanism.

18. The tool according to claim 17 wherein said end effector includes at least a first actuator configured such that when the tool is grasped by the end effector and said first actuator is activated, said at least one electrical connector on said end effector is advanced and plugged into said at least one electrical connector on said housing, and including a second actuator configured such that when the tool is grasped by the end effector and said second actuator is activated, said at least one data connector on said end effector is advanced and plugged into said at least one data connector on said housing, and including a third actuator configured such that when the tool is grasped by the end effector and said third actuator is activated said at least one fluid coupling on said end effector is advanced and mated to said fluid exchanger subsystem.

19. The tool according to any one of claims 1 to 18 wherein said housing includes thermal insulation and temperature controllers for controlling a temperature of the housing.

20. The tool according to to any one of claims 1 to 19 including sensing

means incorporated into said housing for sensing locations of designated moving parts.

21. The tool according to claim 11 wherein said each nut cam includes a cam face, and wherein when said adjustable wrench mechanism is rotated within said housing over a fill/drain valve the cam faces on the two nut cams move towards each other until they contact the features on the fill/drain valve.

22. A system mounted on a servicing spacecraft for transferring fluid between one or more selected fluid storage tanks on the servicing spacecraft and a client satellite, the client satellite including one or more fluid storage tanks and a fill/drain valve associated with each of the one or more fluid storage tanks, each fill/drain valve having rotatable features and static features, comprising:

a) a positioning mechanism, an end effector mounted on the positioning mechanism, the end effector being coupled to the one or more selected fluid storage tanks;

b) a tool including

a housing,

a fixture mounted on said housing configured to be grasped by said end effector,

a fluid selection and coupling mechanism mounted in said housing and configured to be coupled to the end effector for coupling the one or more fluid storage tanks on the client satellite to the one or more selected fluid storage tanks mounted on the servicing spacecraft,

a wrench mechanism located in said housing and configured for opening and closing each fill/drain valve on the one or more tanks and mating the fluid selection and coupling mechanism to the at least one fill/drain valve on the client satellite;

an actuator mounted in said housing coupled to the fluid selection and coupling mechanism and the wrench mechanism;

c) a sensor system for at least determining a relative displacement between said tool and each fill/drain valve on the one or more fluid storage tanks; and

d) a control system in communication with said sensor, said positioning mechanism, said end effector and said actuator for controlling operation of said positioning mechanism, said end effector and said tool based on feedback from said sensor.

23. The system according to claim 22 wherein said actuator includes

a motor,

a gear shifter, the motor being coupled to the gear shifter,

a differential gearbox mounted in said housing coupled to said gear shifter and at least first and second output shafts, the gear shifter being configured to transmit torque from said motor to said differential gearbox, said differential gearbox being configured to transmit said torque received from said gear shifter to said at least first and second output shafts, the gear shifter being configured to be engaged to said fluid selection and coupling mechanism for moving said fluid selection and coupling mechanism between at least two positions in said housing,

said wrench mechanism including at least first and second adjustable wrench mechanisms aligned coaxially, said first wrench mechanism being coupled to said first output shaft for transmitting torque received by said first output shaft from said gearbox to a first object engaged by the first adjustable wrench mechanism, said second adjustable wrench mechanism being coupled to said second output shaft for transmitting torque received by said second output shaft from said gearbox to a second object engaged by the second wrench mechanism, the gearbox being configured to split the torque received by the gear shifter evenly between the first and second wrench mechanisms to apply equal and opposite forces to said first and second objects; and

wherein said first object is the rotatable feature of a fill/drain valve such that the first adjustable wrench mechanism configured to engage the rotatable features of the fill/drain valve of the second satellite to apply bi-directional torque to the rotatable features, and the second object is the static feature of the fill/drain valve such that the second adjustable wrench mechanism reacts the torque on the static features on the fill/drain valve.

24. The system according to claim 23 wherein the at least one fill/drain valve includes a secondary seal fitting with associated rotatable features, wherein said cam wrench mechanism includes at least a third adjustable wrench mechanism being aligned coaxially with the first and second adjustable wrench mechanisms, said gear box including a third output shaft, said third output shaft being coupled to said third adjustable wrench mechanism, said third adjustable wrench mechanism being configured to engage the associated rotatable features of the secondary seal fitting to apply bi-directional torque thereto while the second of the adjustable wrench mechanisms reacts this bi-directional torque on the static features on the fill/drain valve.

25. The system according to claim 24 wherein said differential gear box is a shifting differential gear box in which an operator can selectively shift between differentially paired output shafts.

26. The system according to claim 24 wherein said differential gear box is a shifting differential gear box in which an operator can selectively shift between said first and second output shafts and said second and third output shafts.

27. The system according to any one of claims 22 to 26 wherein each adjustable wrench mechanism includes a housing having a rotational axis, a pair of opposed nut cams pivotally mounted each to a toothed cam lock, said nut cams each including a pawl member, said cam locks being translationally mounted to a cam ring, said cam ring coaxially mounted in said housing and being rotationally movable with respect to said housing, a detent spring mounted between said cam ring and said housing to restrict movement of said cam ring, a toothed drive ring having inner and outer toothed surfaces mounted in said housing and being rotatable with respect to said housing, said cam pawls being engaged with said toothed drive ring so that when said

toothed drive ring is rotated by an output shaft from said differential gear box, said nut cams are rotationally driven until they contact opposing outer surfaces of a faceted rotatable element, at which point said toothed cam locks slide radially outward to engage said toothed inner surface of said drive ring thereby locking the drive ring and the cam ring together to permit torque applied by said output shaft to be transmitted to said faceted surface.

28. The system according to claim 27 wherein said each nut cam includes a cam face, and wherein when said adjustable wrench mechanism is rotated within said housing over a fill/drain valve the cam faces on the two nut cams move towards each other until they contact the features on the fill/drain valve.

29. The system according to any one of claims 22 to 28 wherein the positioning mechanism is configured to carry one or more fluid lines which are coupled to the one or more selected fluid storage tanks, and wherein the end effector is coupled to the one or more fluid lines on the positioning mechanism.

30. The system according to claim 29 wherein the end effector includes at least one fluid coupling and a coupling actuator for moving the at least one fluid coupling, and said fluid selection and coupling mechanism includes at least one fluid coupling attached on an exterior of the housing, and wherein the end effector and the housing are configured such that when the end effector grips the grapple fixture and the actuator is activated the at least one fluid coupling on the end effector mates with at least one fluid coupling on the exterior of the housing.

31. The system according to claim 30 wherein the end effector includes at least one electrical connector connected to a power source on the servicer satellite, and wherein said housing includes at least one electrical connector located on an exterior of the housing, and wherein the end effector and the housing are configured such that when the end effector grips the grapple fixture and the actuator is activated the at least one electrical connector on the end effector mates with at least one electrical connector on the exterior of the

housing to provide power to the robotic tool.

32. The system according to claim 31 wherein the at least one electrical connector on the end effector is a data and electrical connector, and wherein the at least one electrical connector on the housing is an electrical and data connector, and wherein the data connector on the end effector is connected to the control system, and wherein the data connector on the tool is connected to said sensor system and said actuator.

33. A method for remotely opening a rotationally removable access component mounted on a client satellite, the access component on the client satellite having rotatable and static features, comprising:

activating a positioning mechanism mounted on a servicer satellite and releasibly coupling an end-effector on the positioning mechanism to a tool mounted on the servicer satellite;

positioning the tool over the rotationally removable access component and aligning a wrench mechanism mounted in the tool over the rotationally removable access component until a rotational axis of the wrench mechanism is aligned with a rotational axis of the rotationally removable access component so that a first adjustable wrench mechanism section of the wrench mechanism is engaged with the rotatable feature of the rotationally removable access component and a second adjustable wrench mechanism section of the wrench mechanism is engaged with the static feature of the rotationally removable access component; and

activating the wrench mechanism for applying equal and opposite forces to the rotatable feature and the static feature to apply bi-directional torque to the rotatable feature while reacting the torque on the static feature.

34. The method according to claim 33 including a step of transferring fluid between the servicer satellite and the client satellite, wherein the rotationally removable access component is a fill/drain valve, engaging the wrench mechanism with a fluid coupling to attach the fluid coupling to the fill/drain valve, wherein the fluid coupling is in flow communication with a fluid source on the servicer satellite, engaging the wrench mechanism to the fill/drain valve

to open it and pass fluid between the servicer and client satellites, and once fluid has been transferred, engaging the wrench mechanism to the fill/drain valve to close it, and once closed engaging the wrench mechanism to the decoupling to remove it from the fill/drain valve.

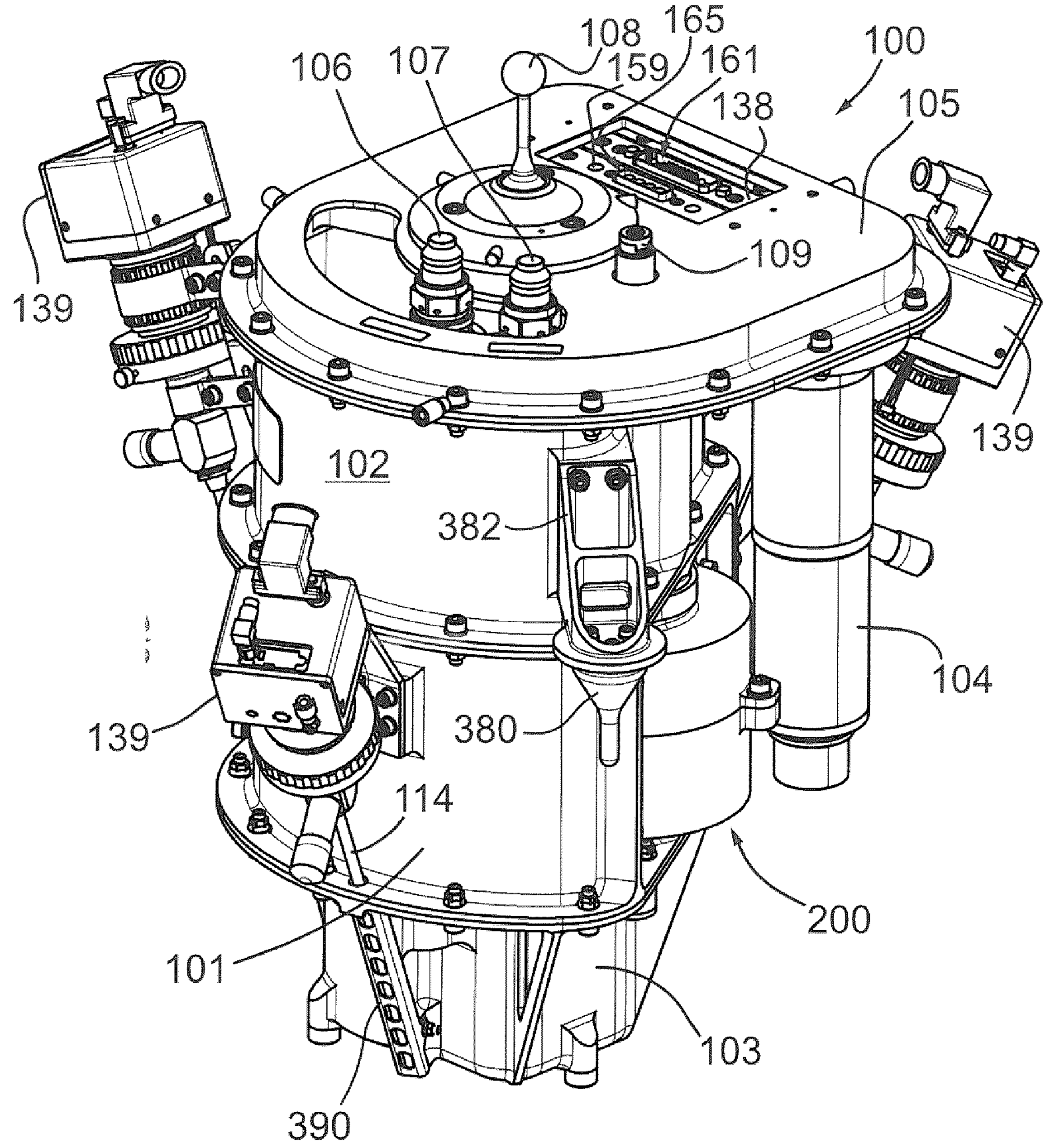

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FIG. 1A

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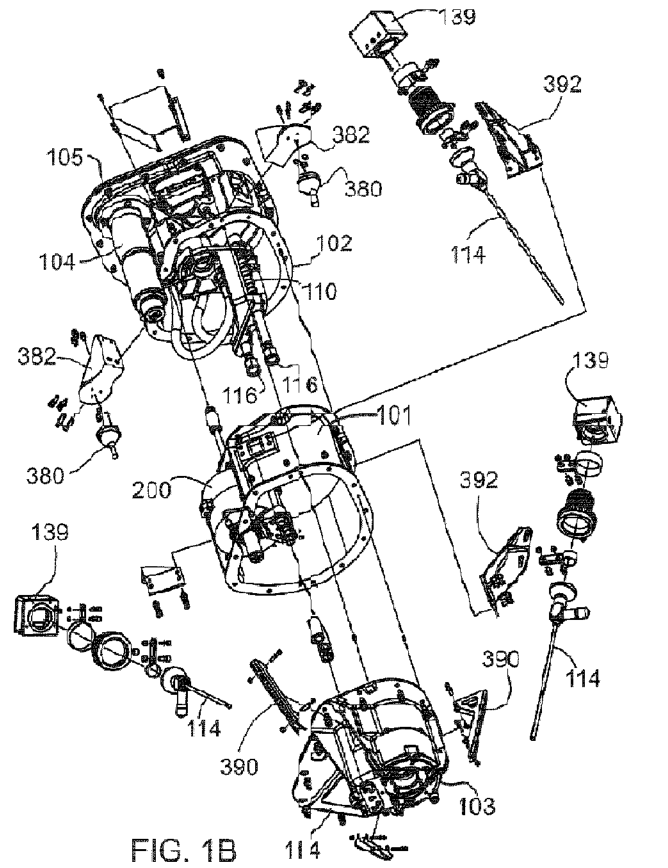

FIG. 1B

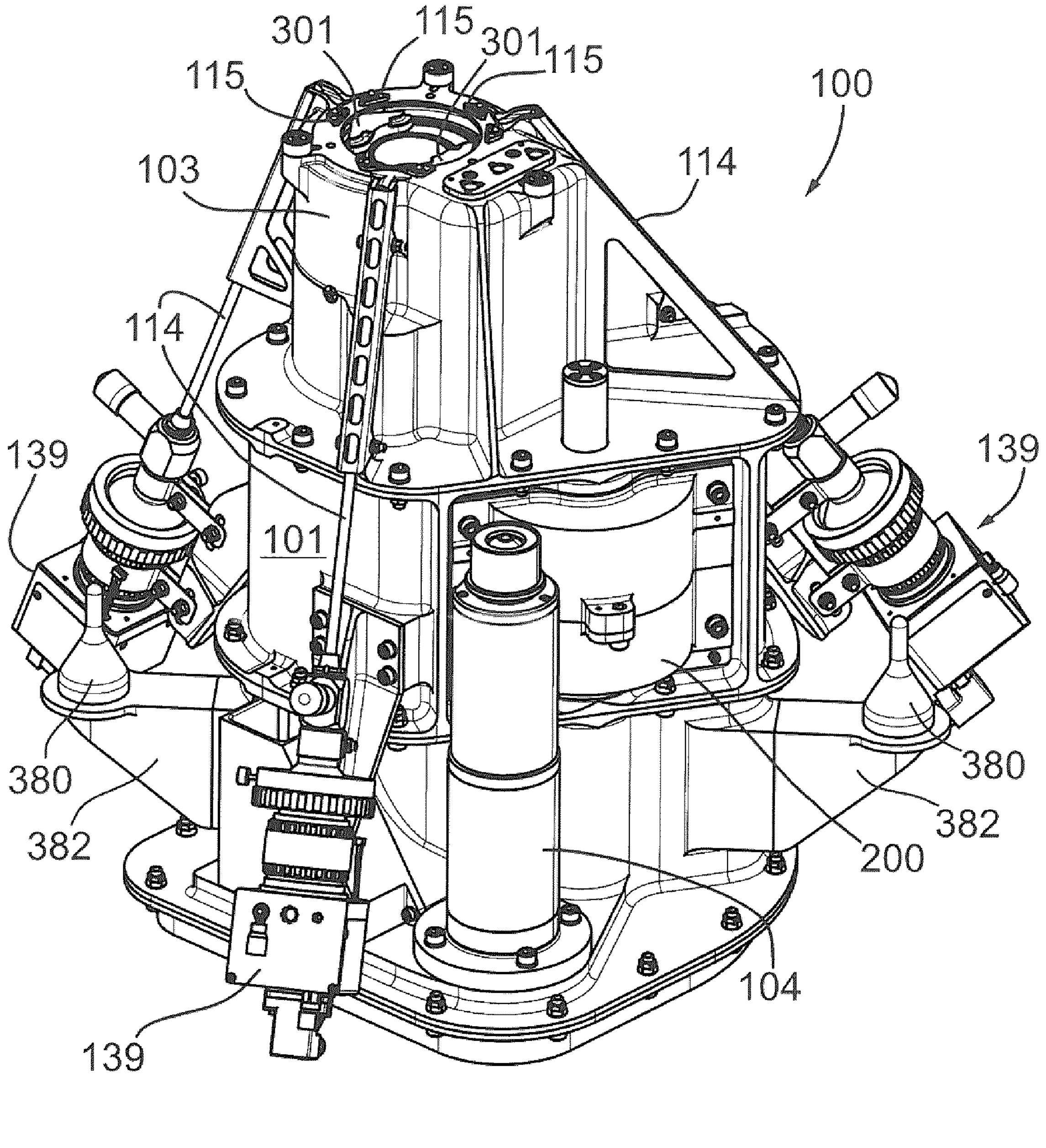

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FIG. 2

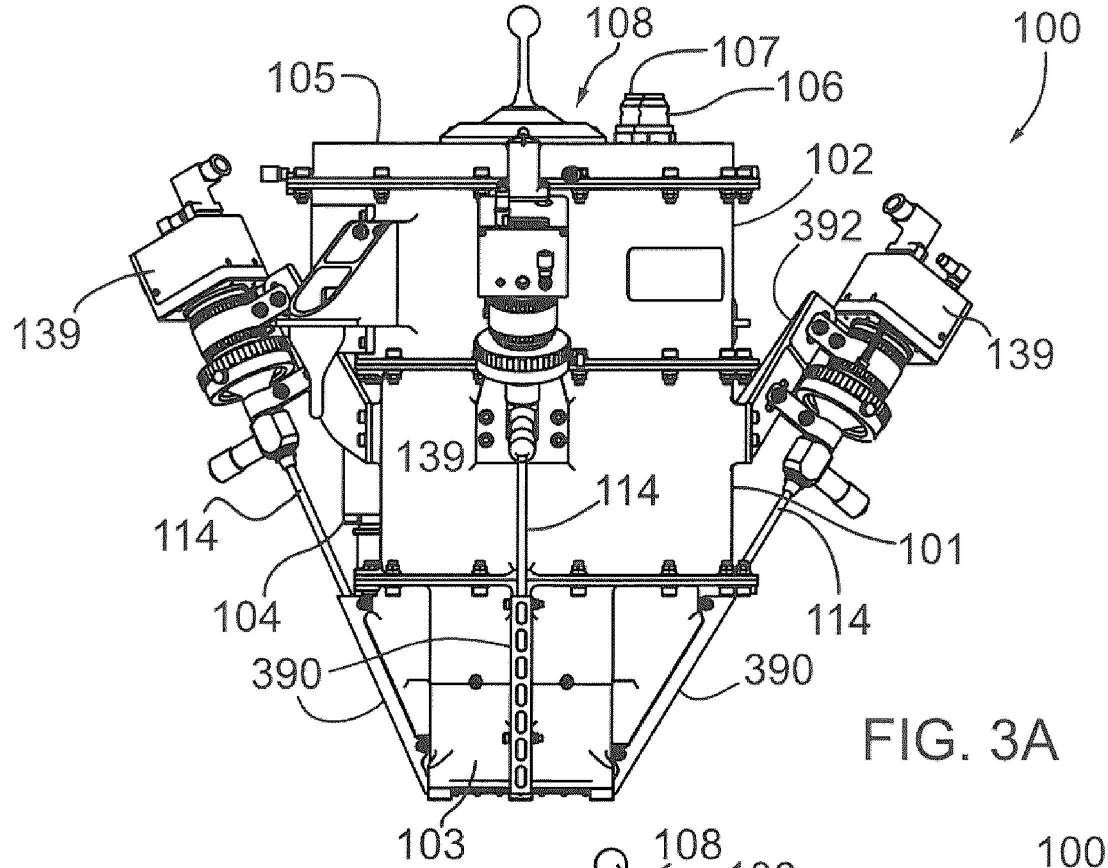
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FIG. 3A

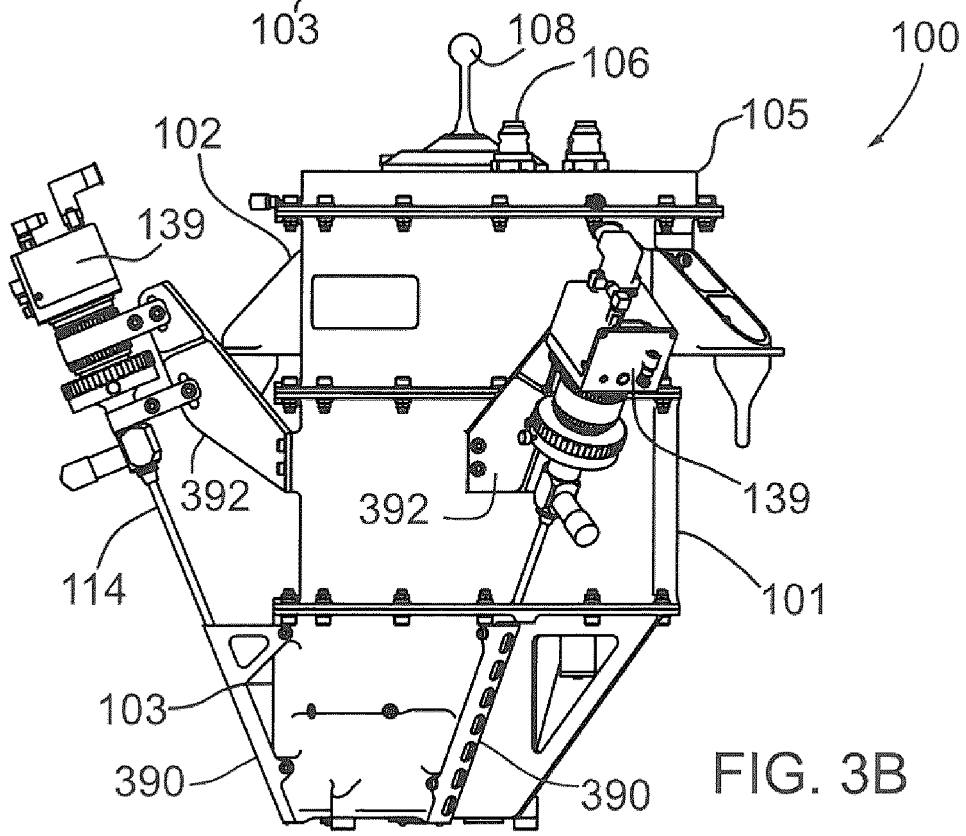
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FIG. 3B

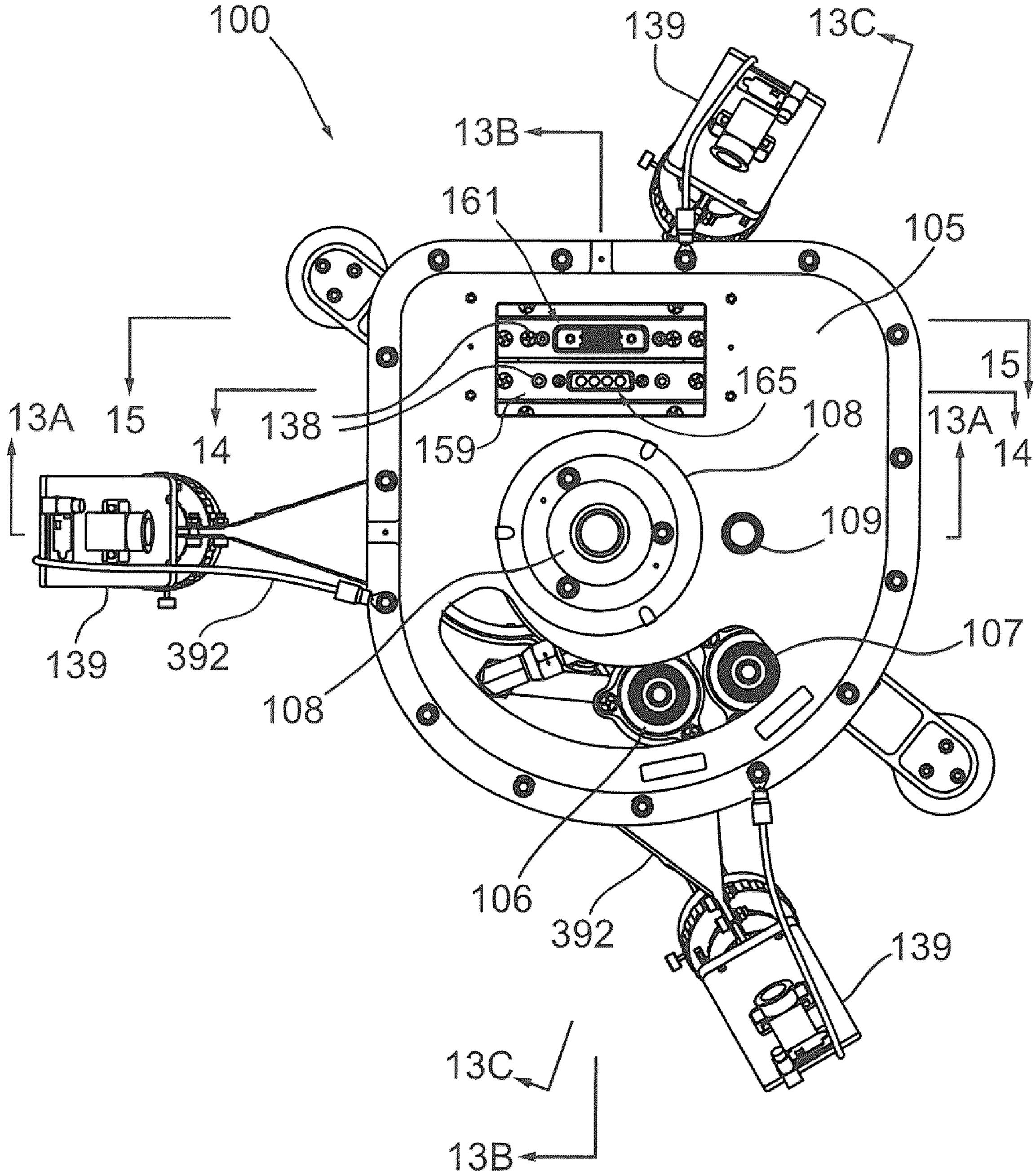
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FIG. 4

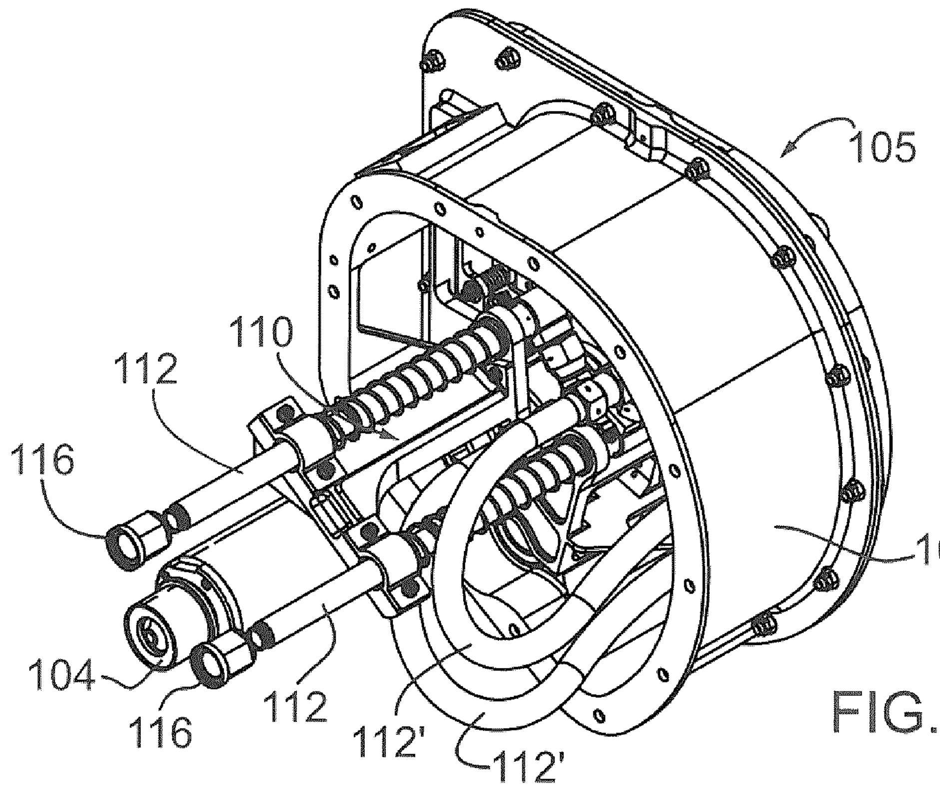
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FIG. 5A

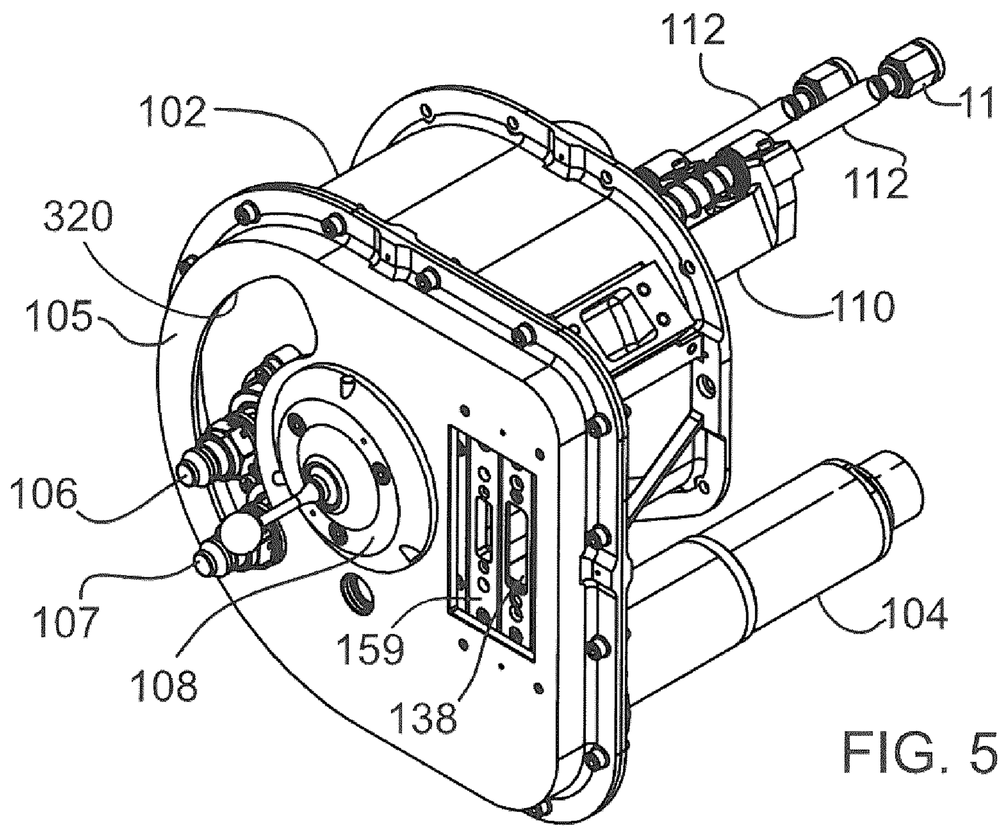
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FIG. 5B

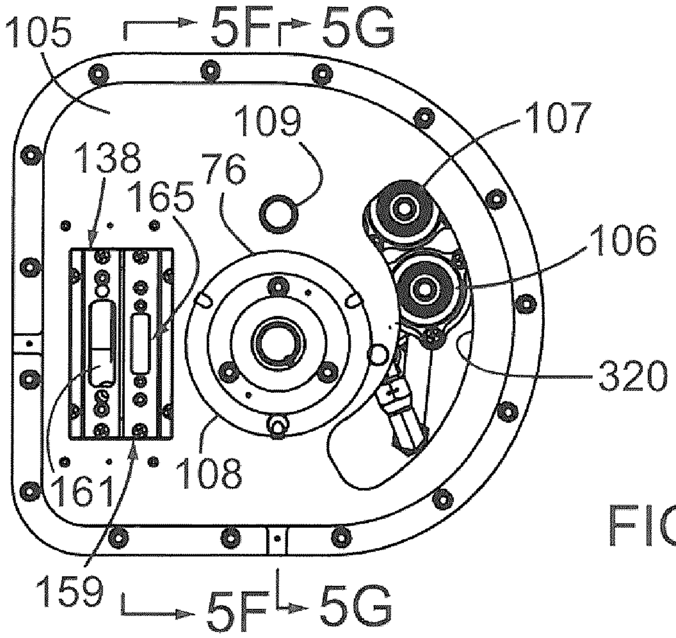

FIG. 5C

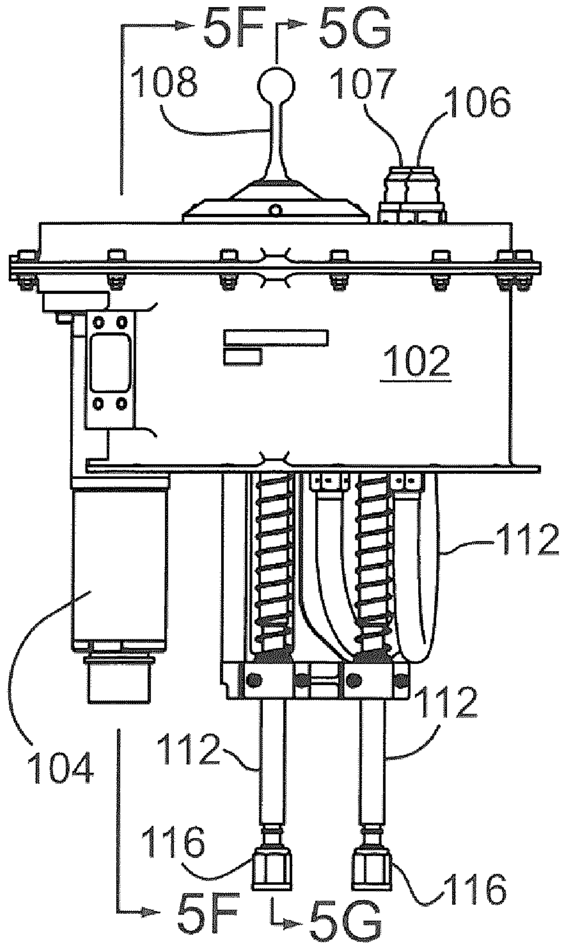

FIG. 5D

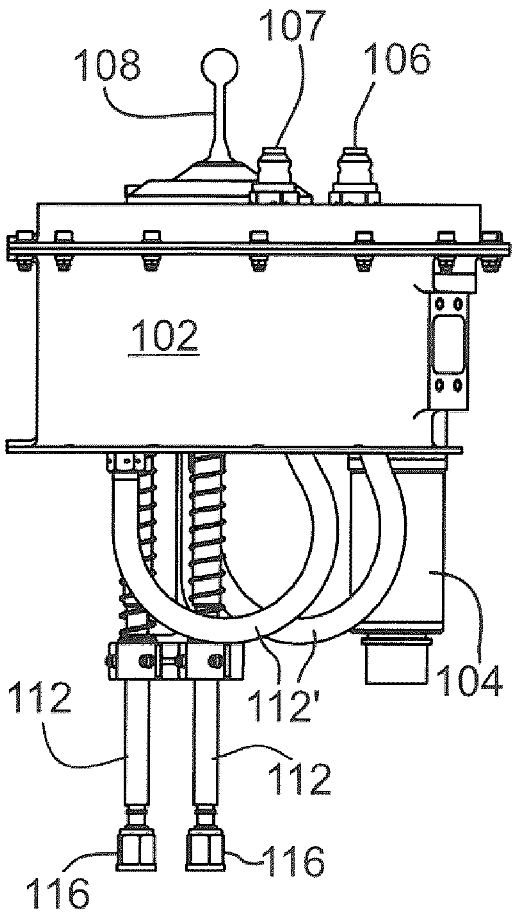

FIG. 5E

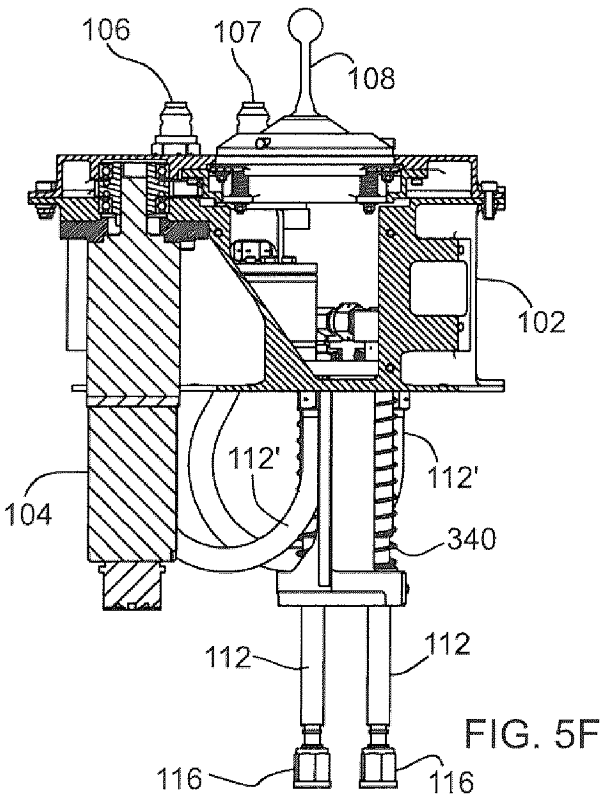
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FIG. 5F

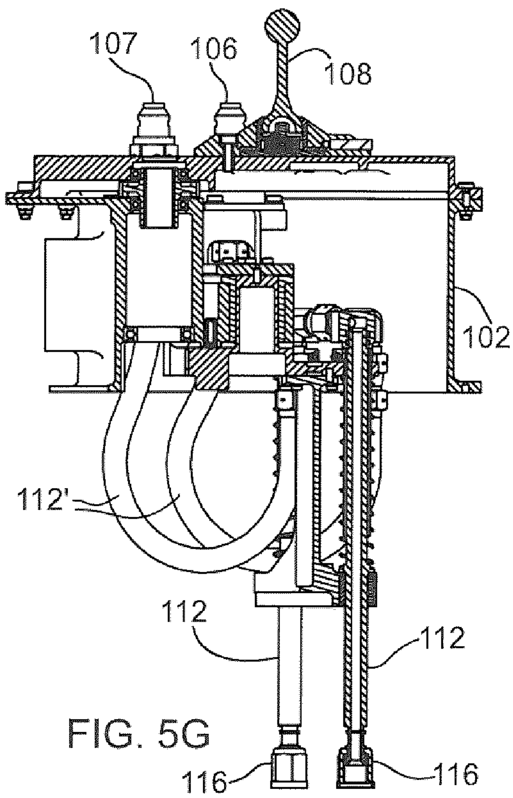
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FIG. 5G

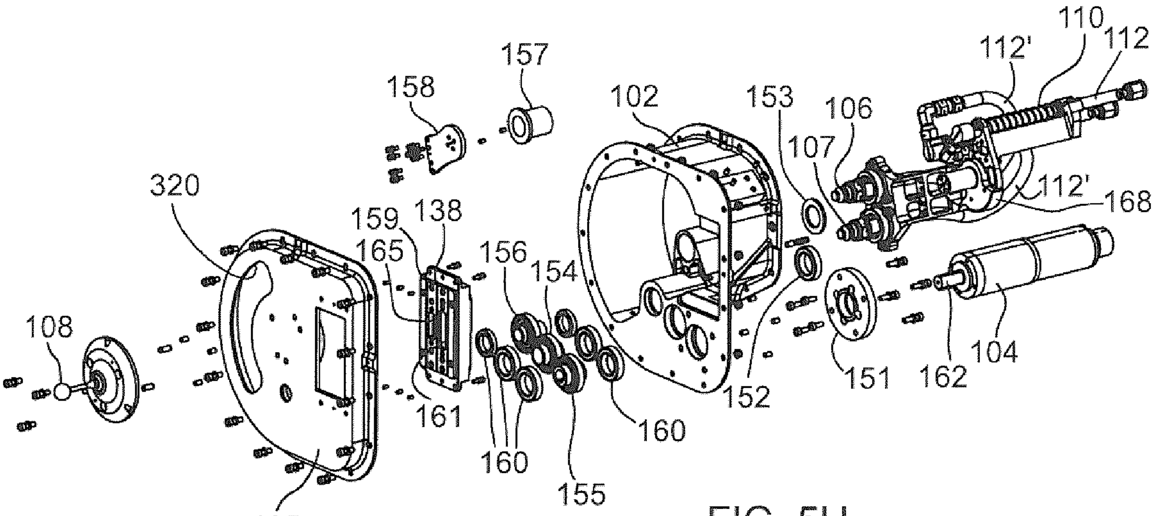
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FIG. 5H

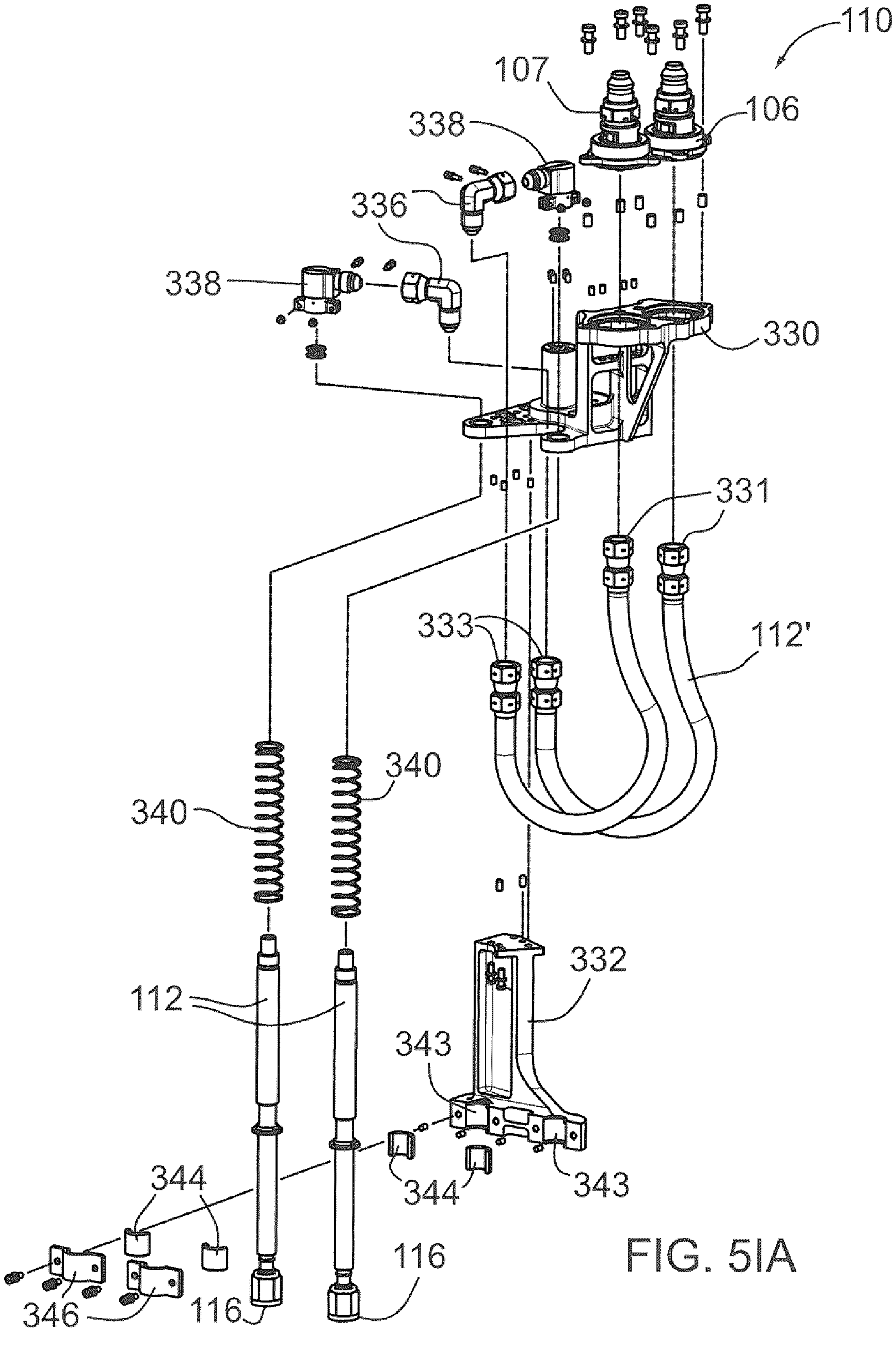
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FIG. 5IA

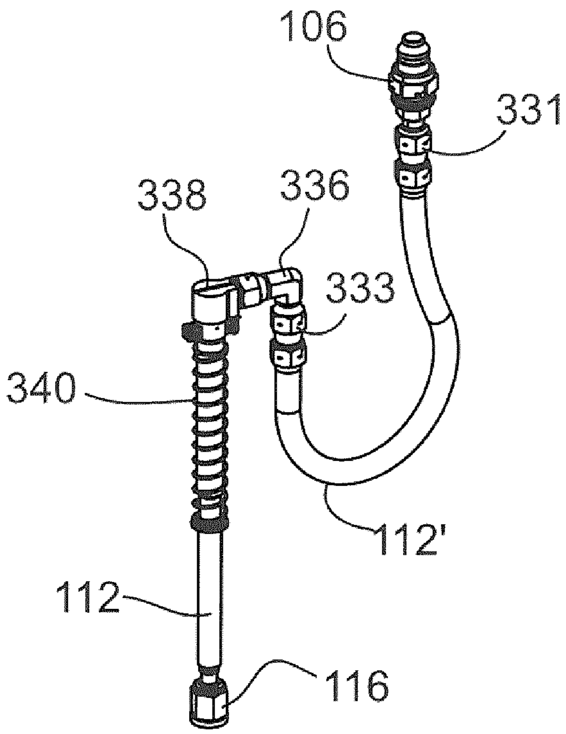

FIG. 5IB

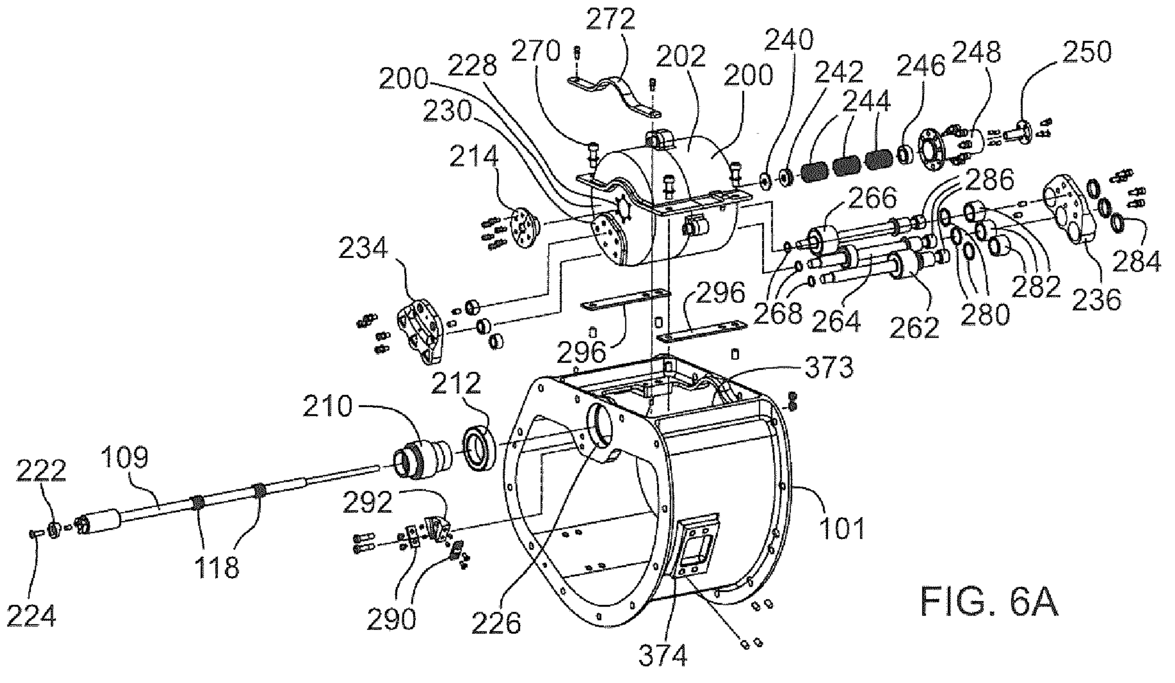
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FIG. 6A

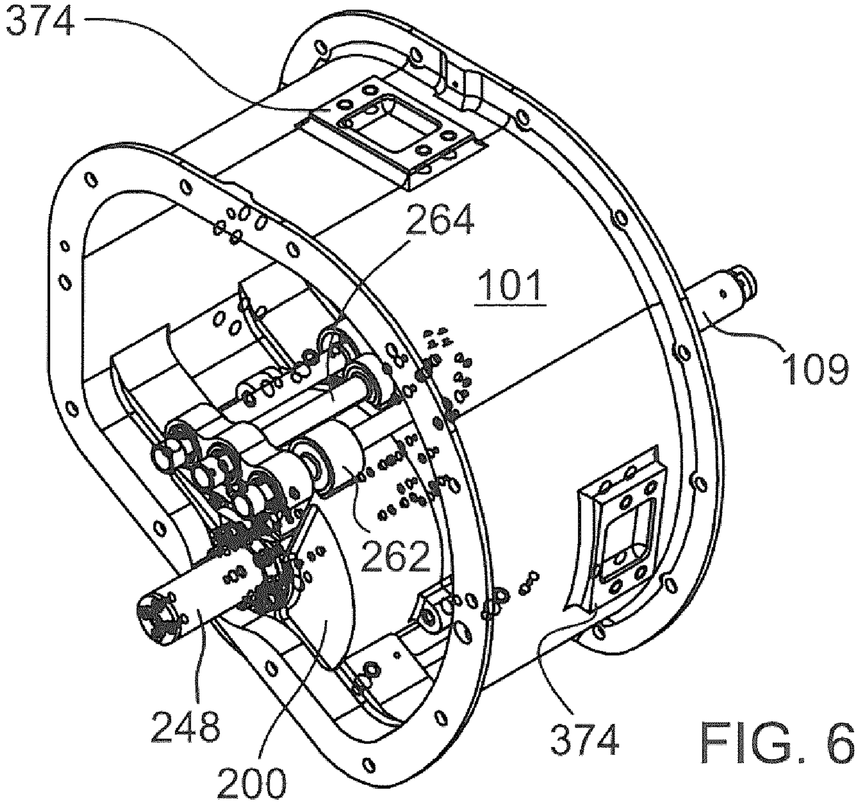

FIG. 6B

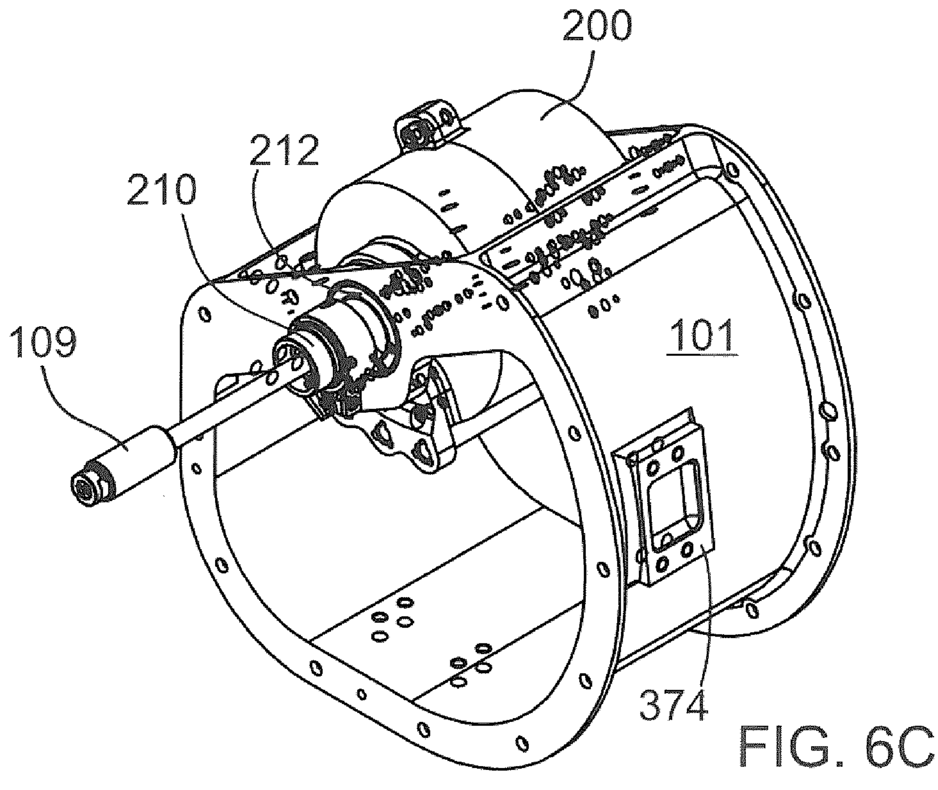

FIG. 6C

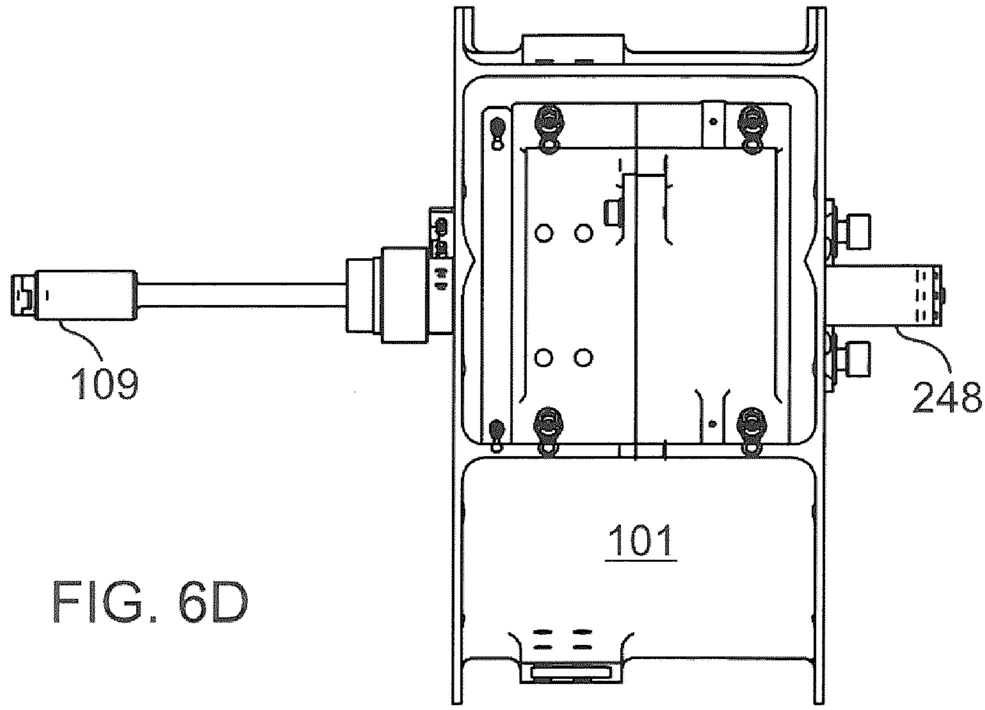

FIG. 6D

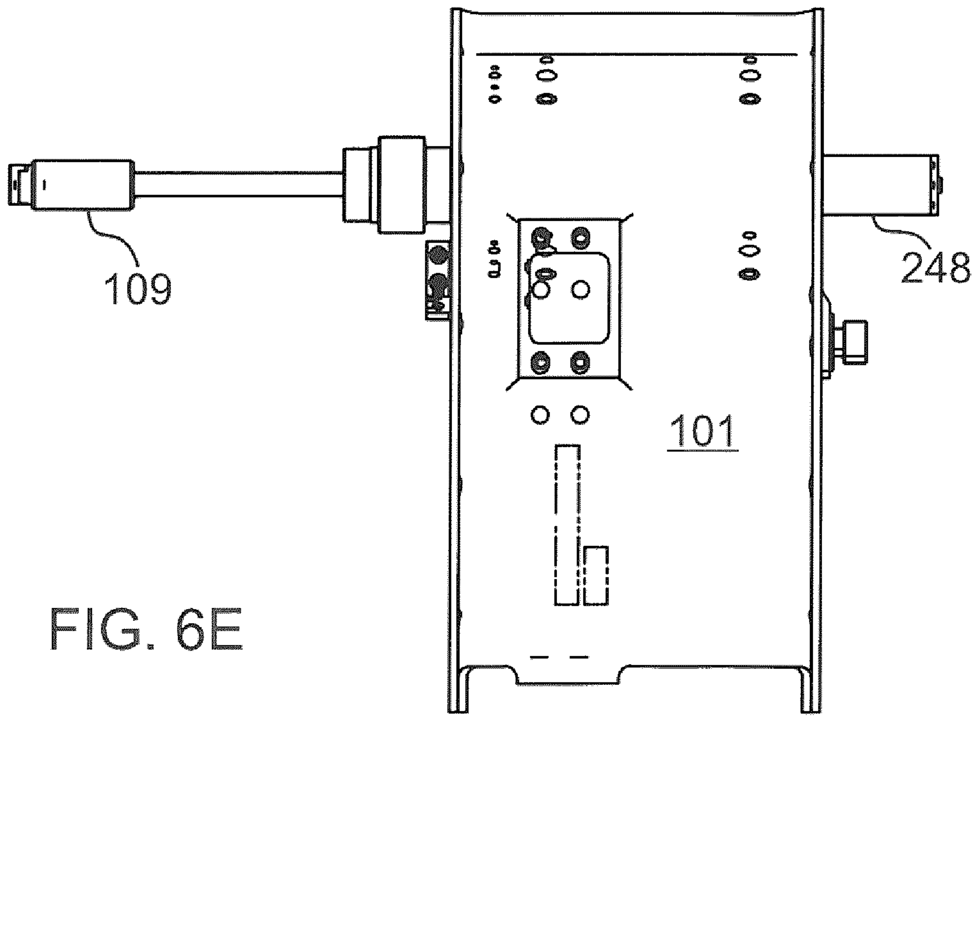

FIG. 6E

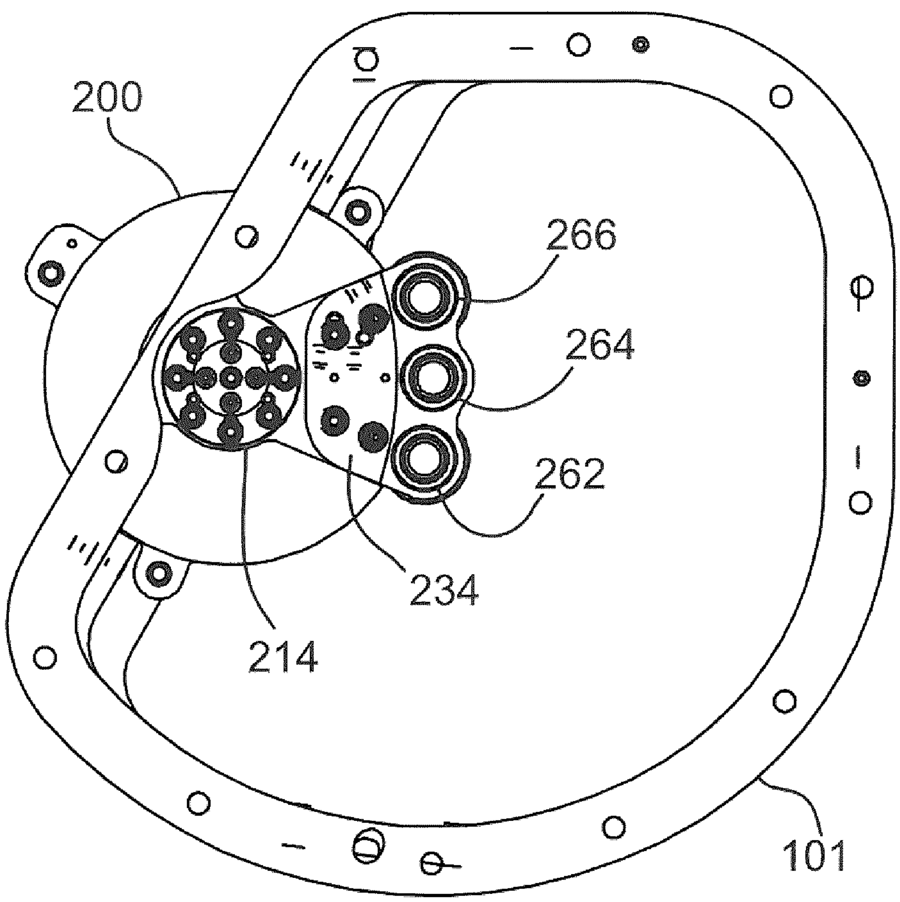

FIG. 6F

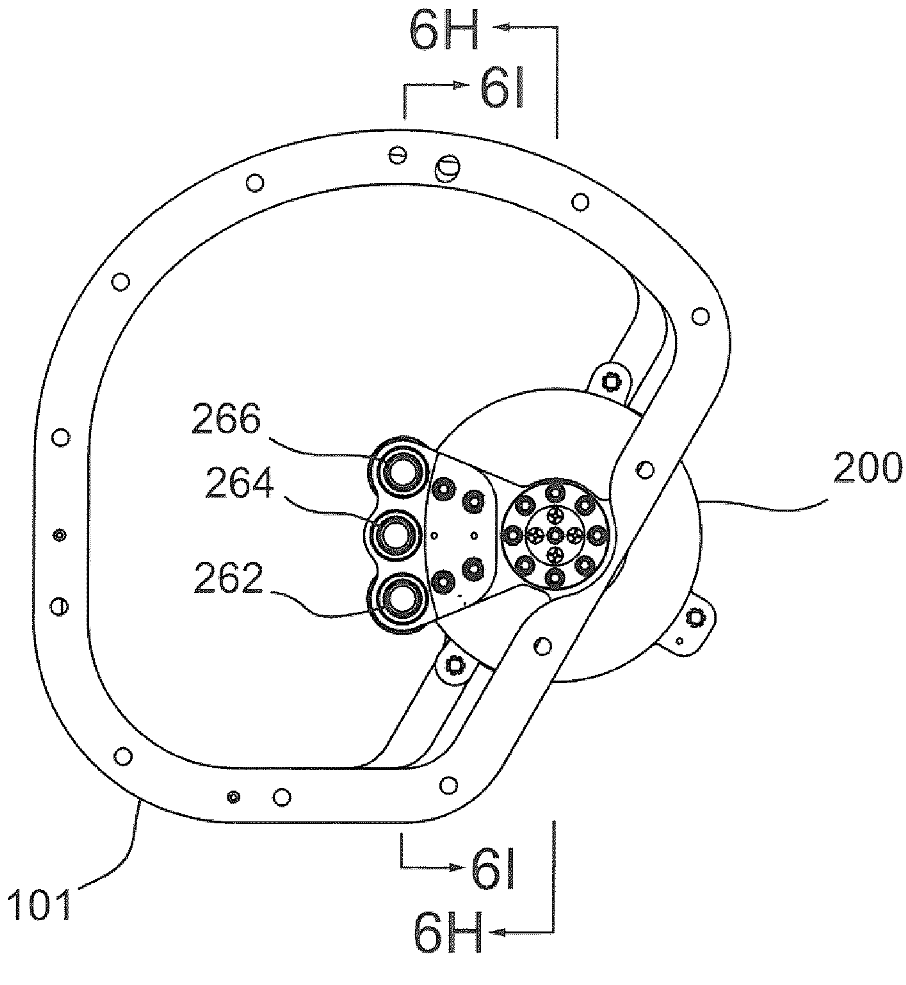

FIG. 6G

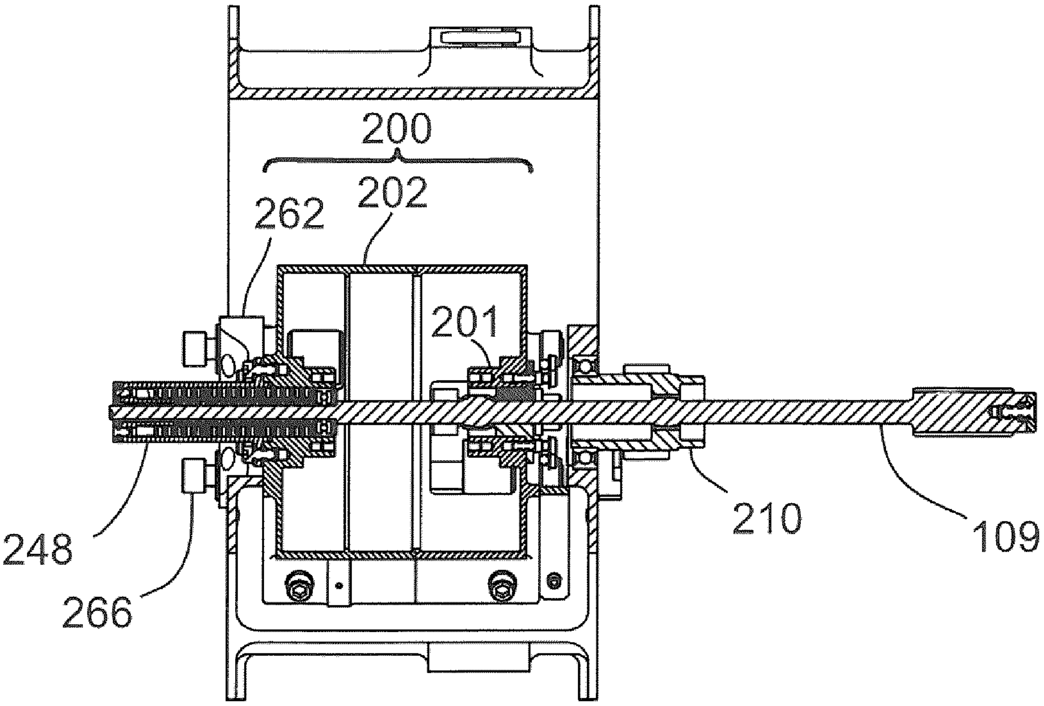

FIG. 6H

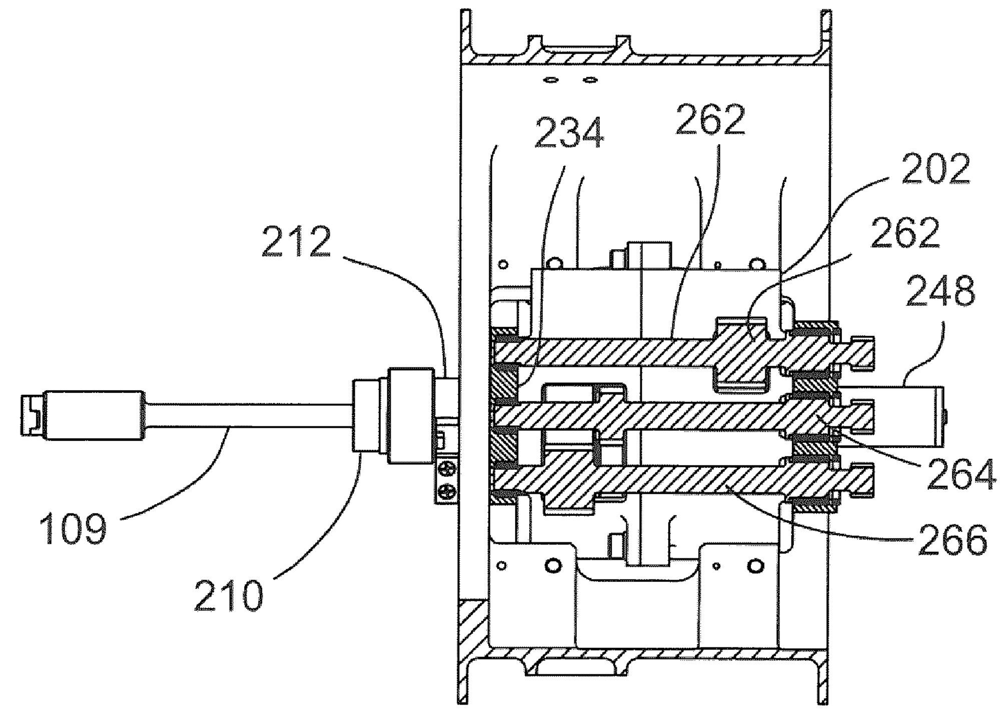

FIG. 6I

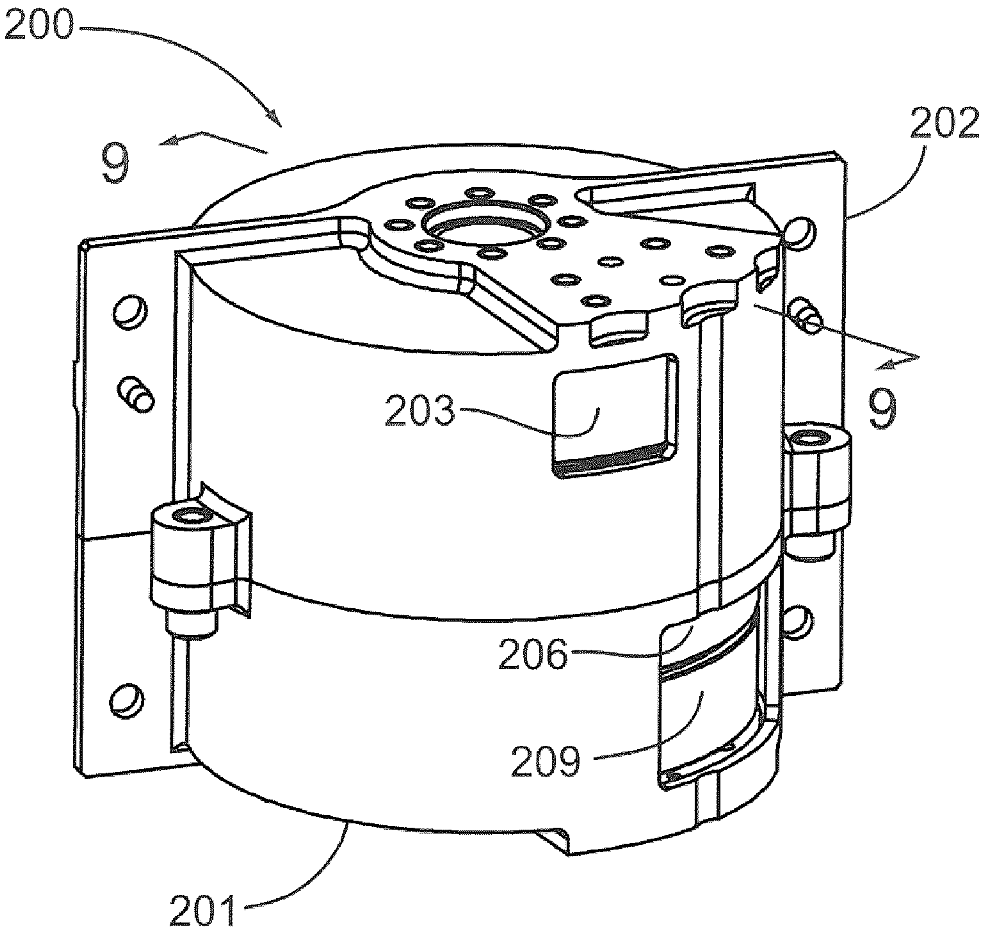

FIG. 7

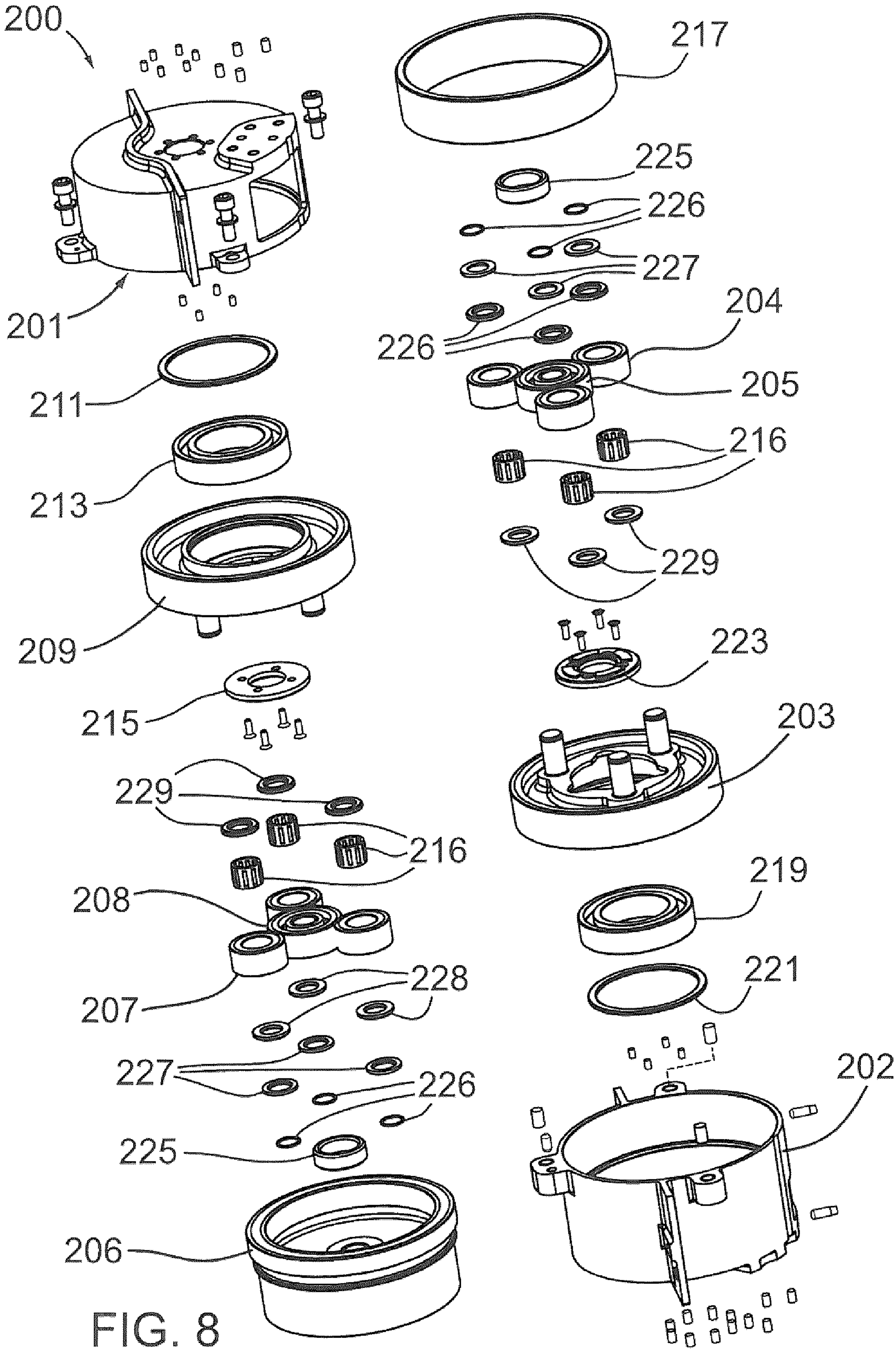
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FIG. 8

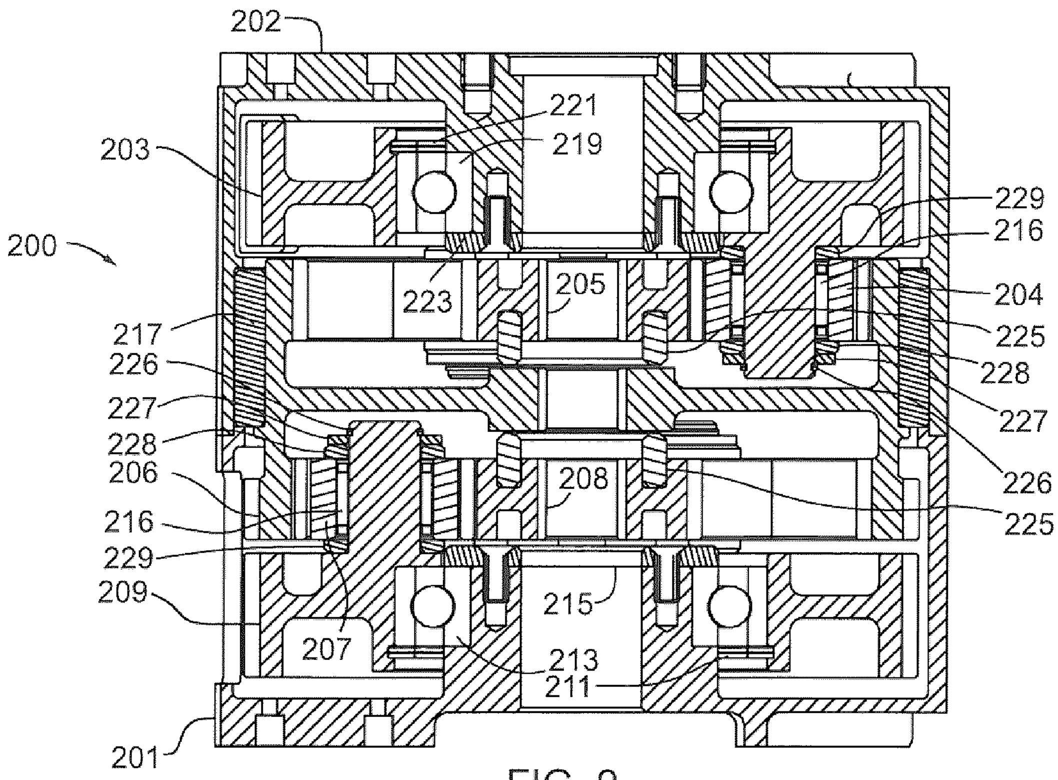

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FIG. 9

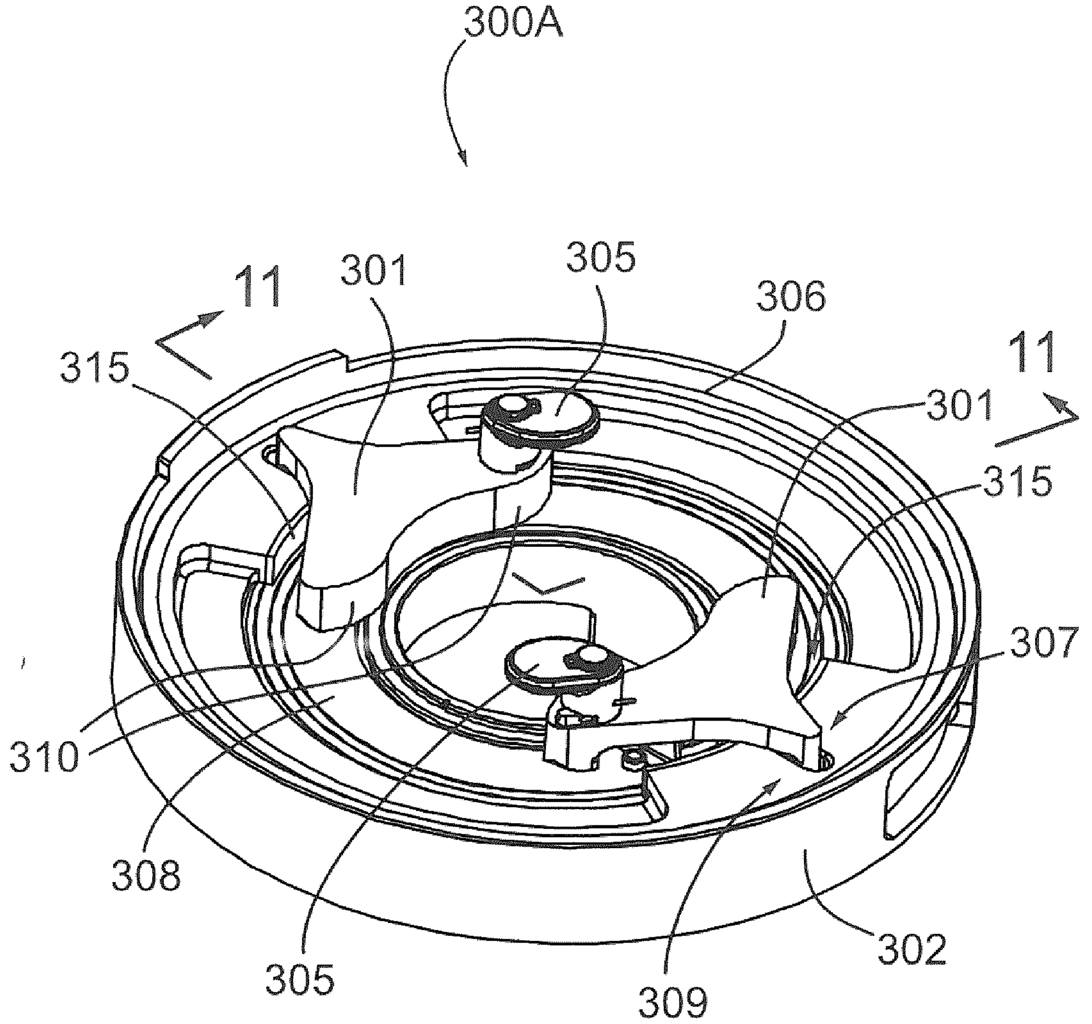

FIG. 10

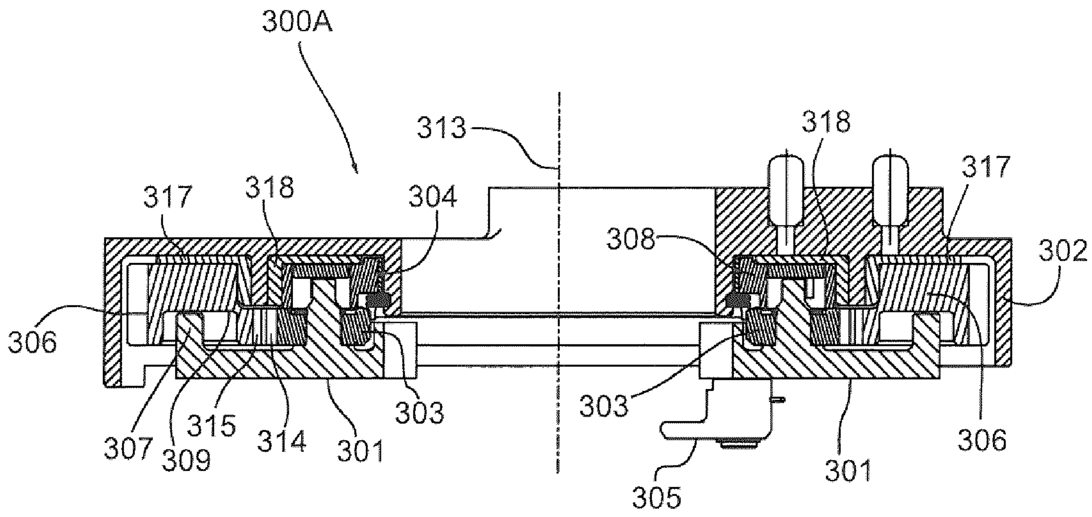
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FIG. 11

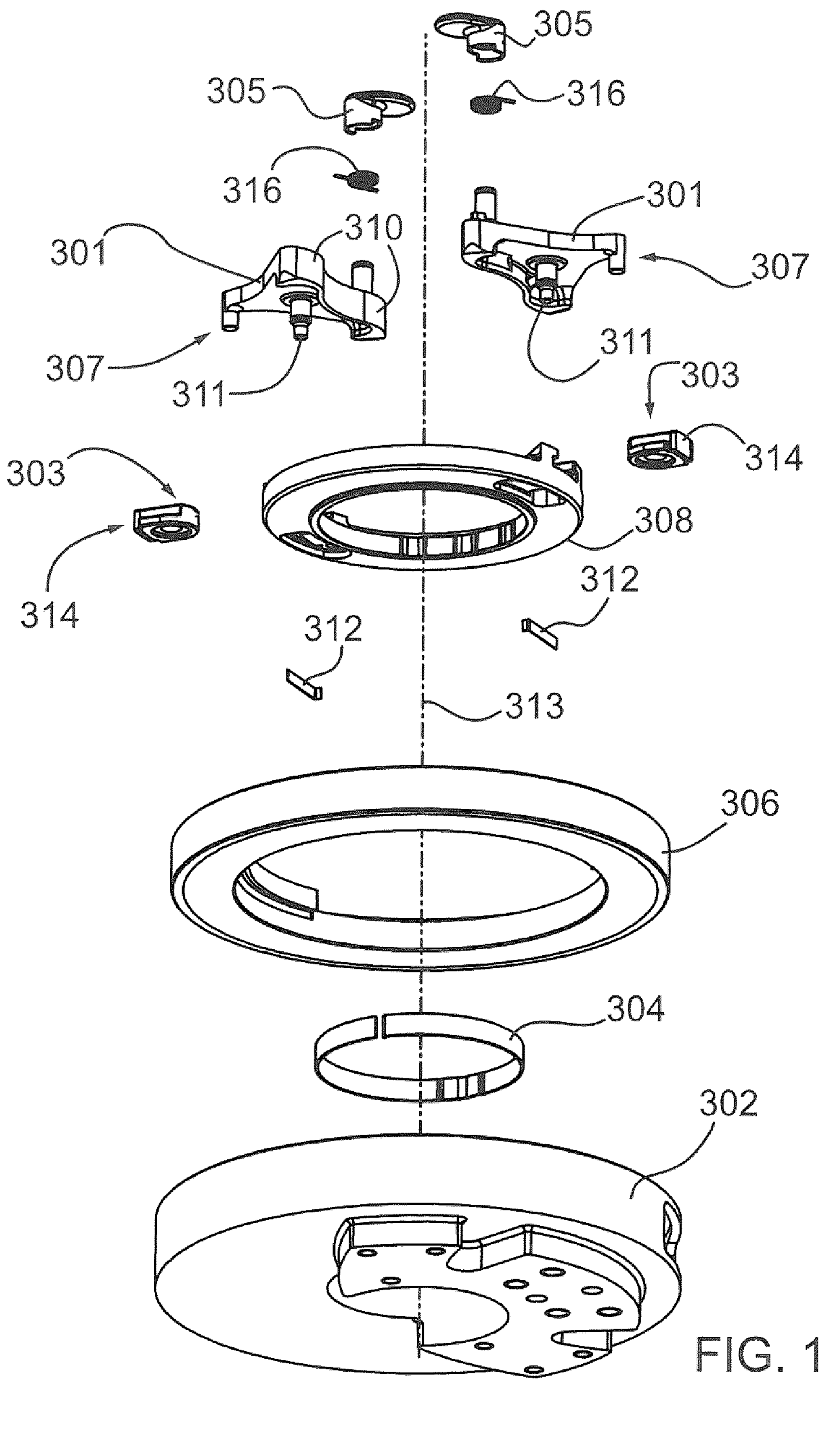
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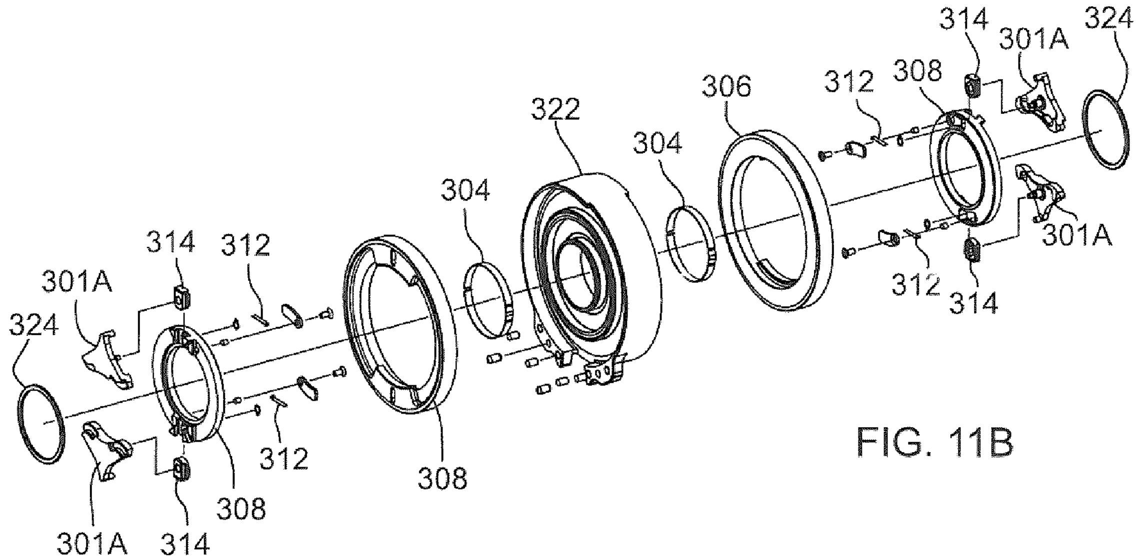
FIG. 11A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301A
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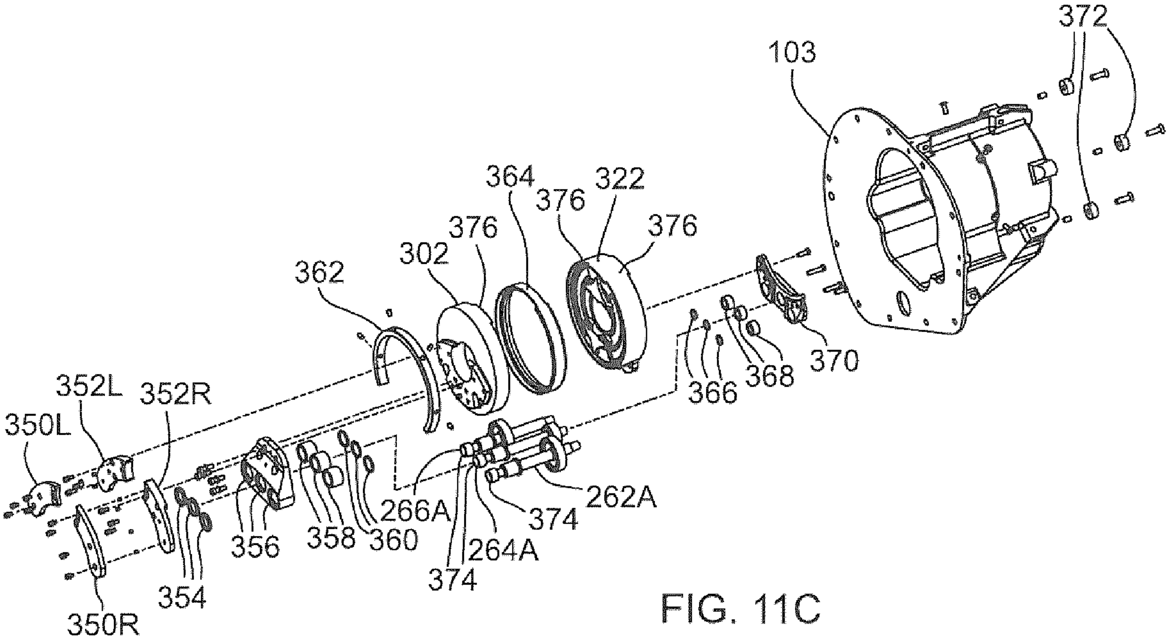
FIG. 11B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302
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352L
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264A
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354
350R

FIG. 11C

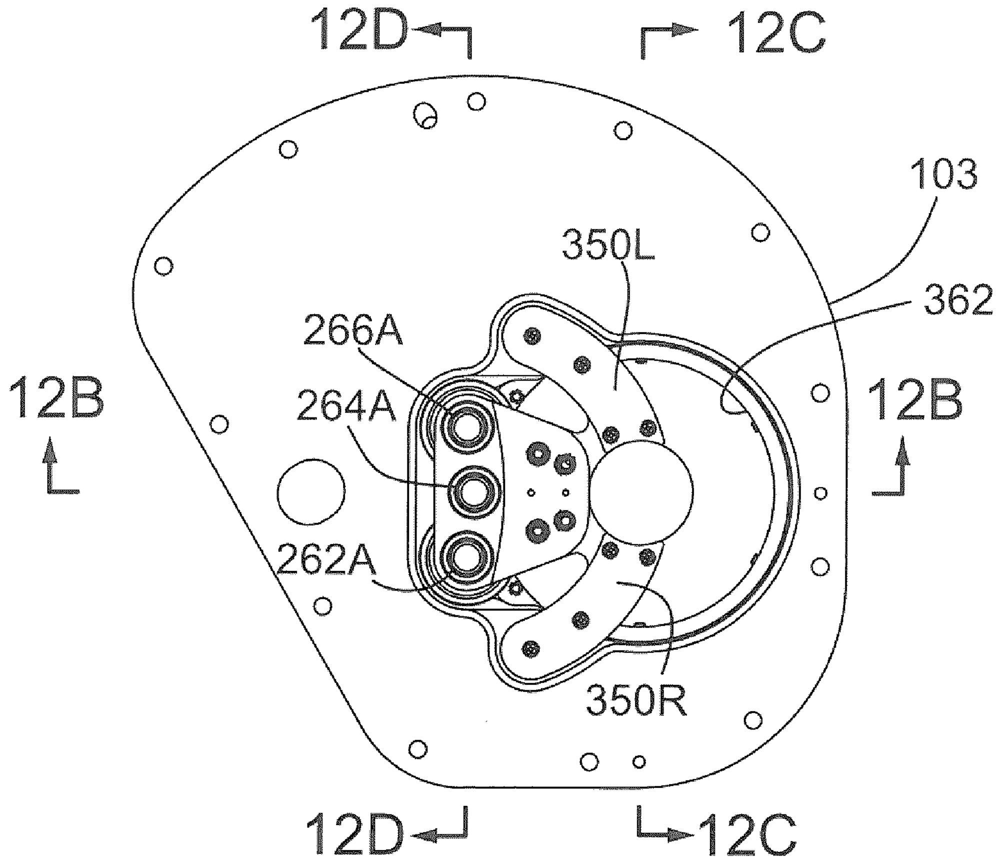


FIG. 12A

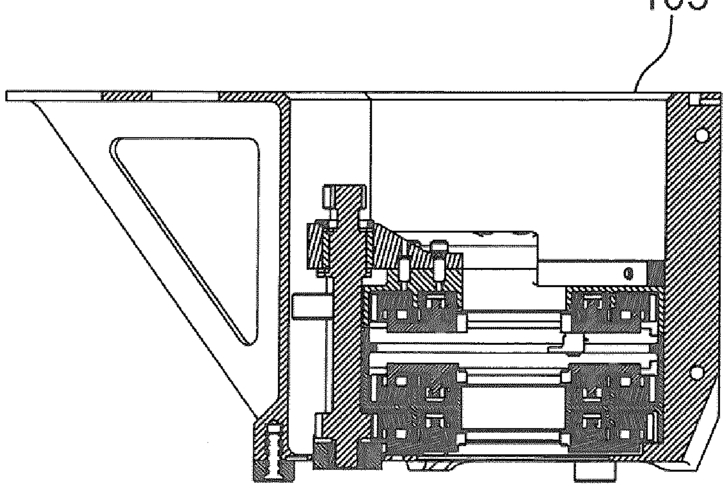


FIG. 12B

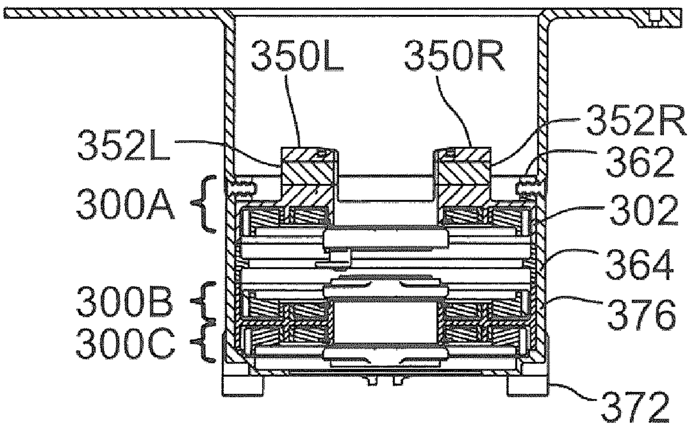


FIG. 12C

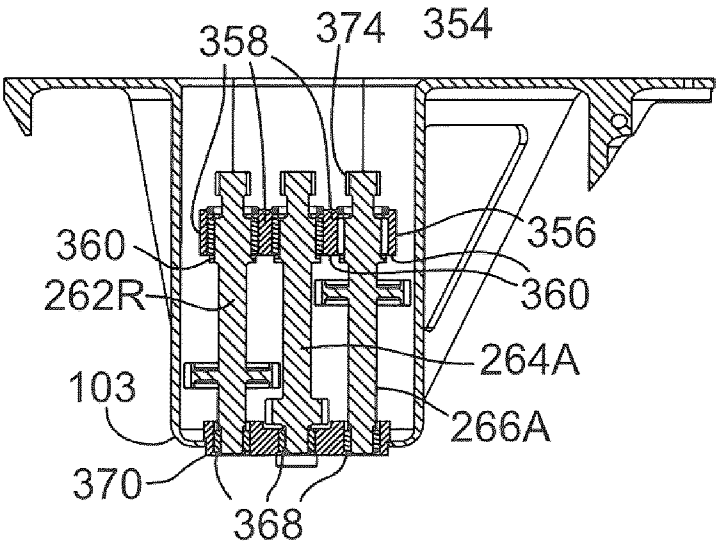


FIG. 12D

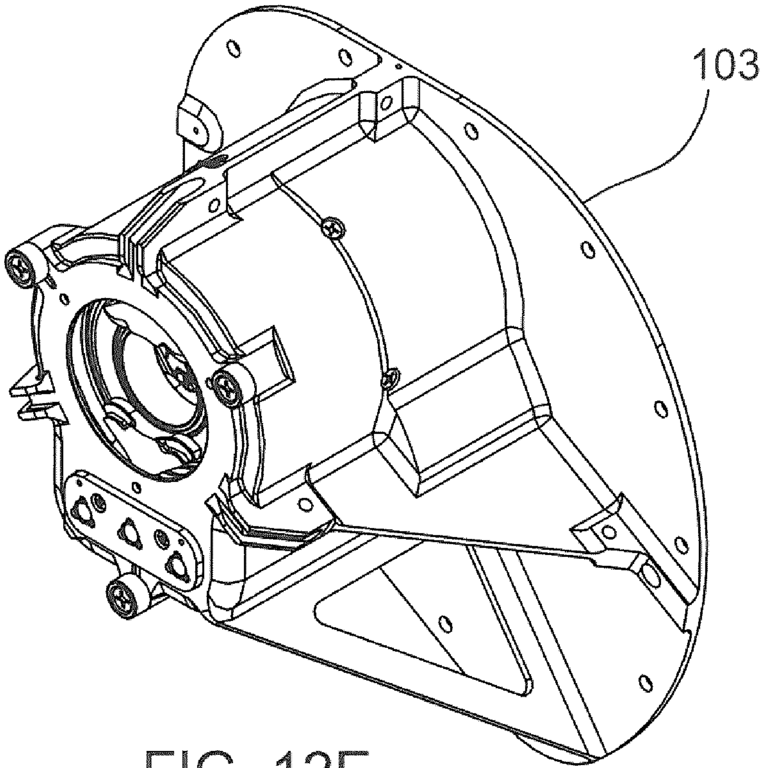


FIG. 12E

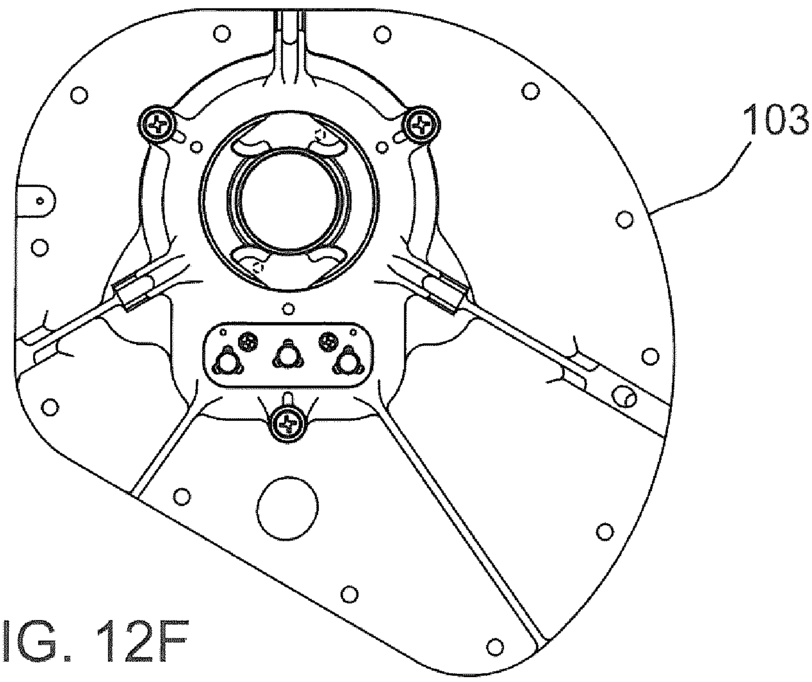
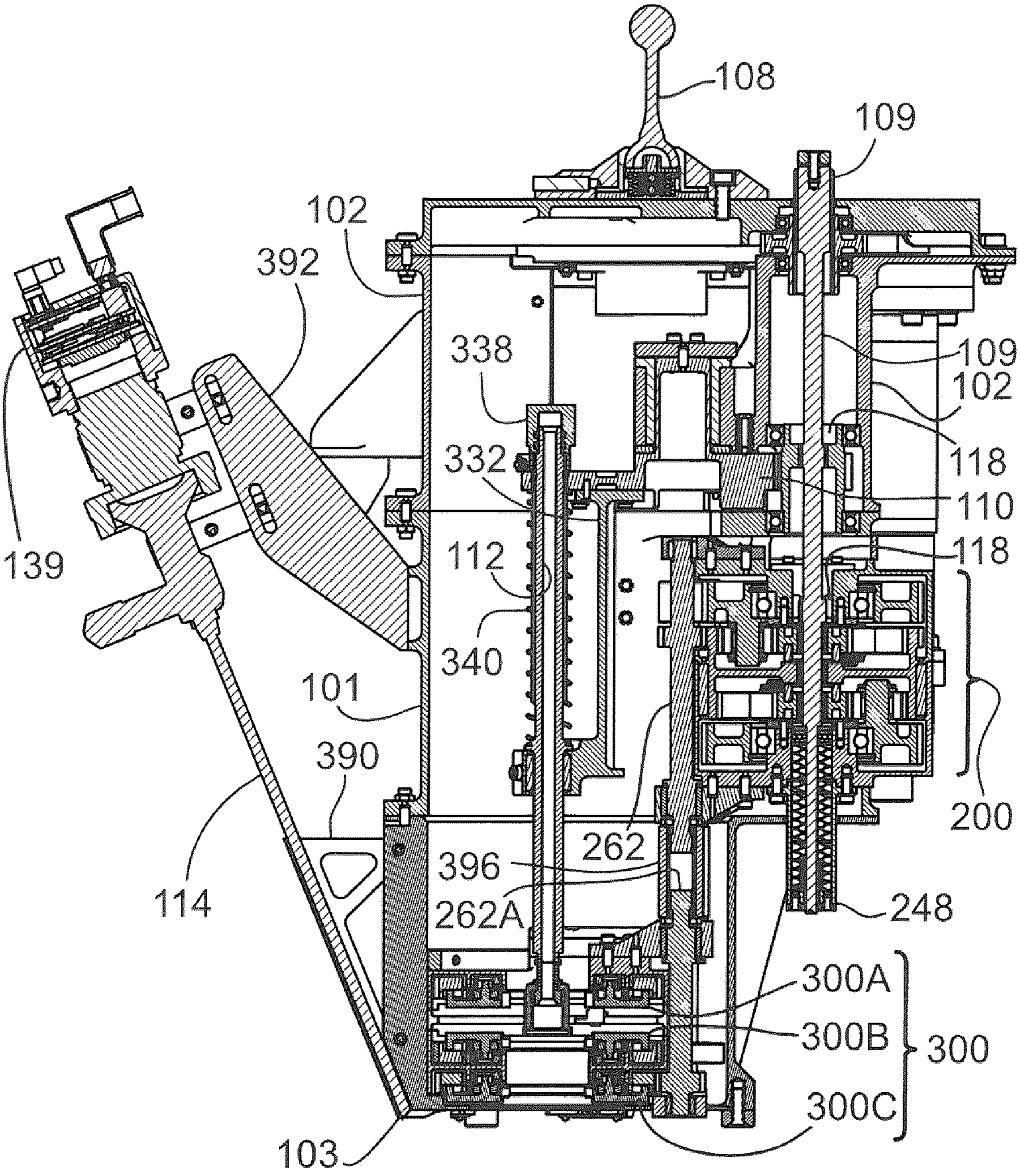


FIG. 12F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262A
300A
300B
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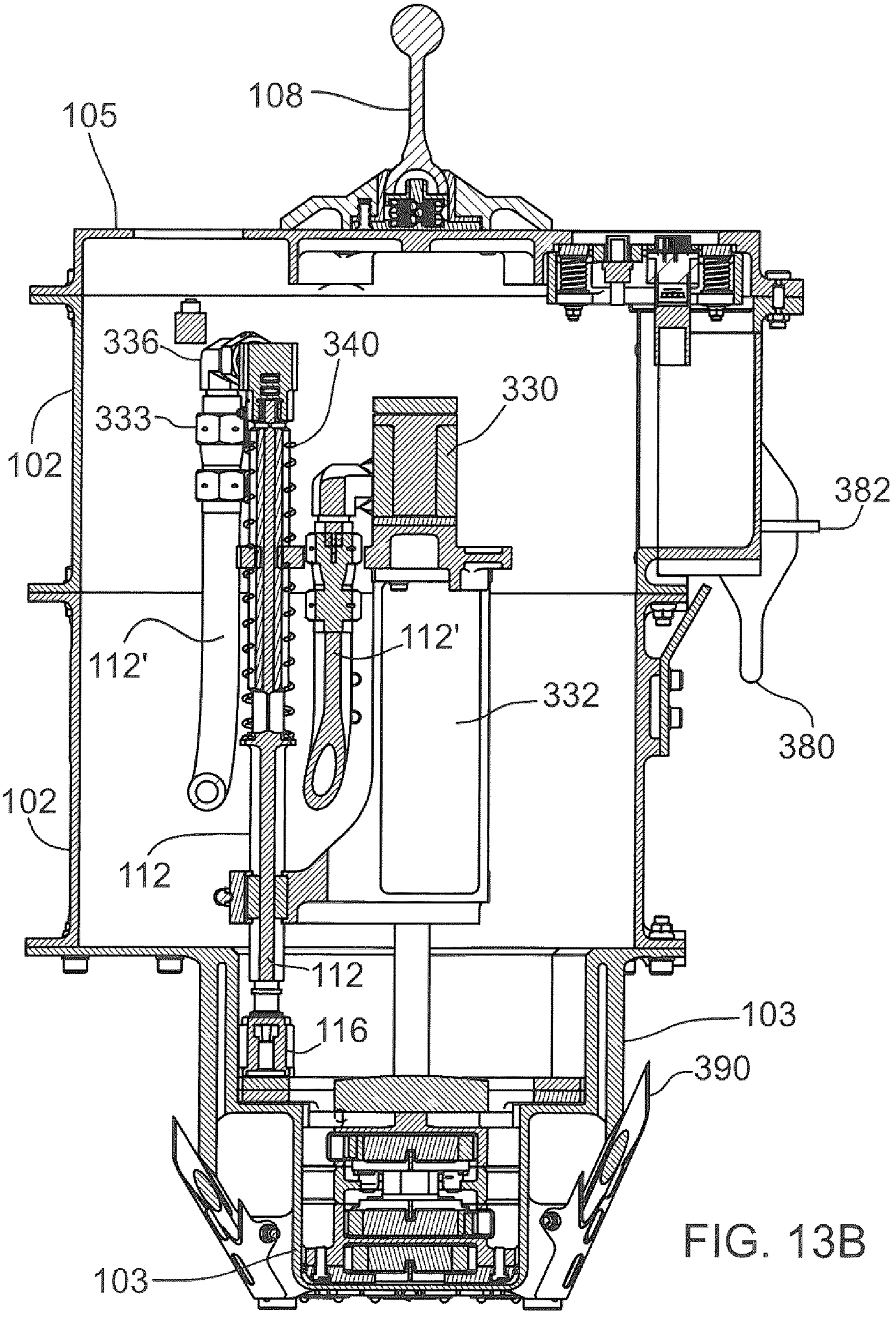
300C
103

FIG. 13A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103

FIG. 13B

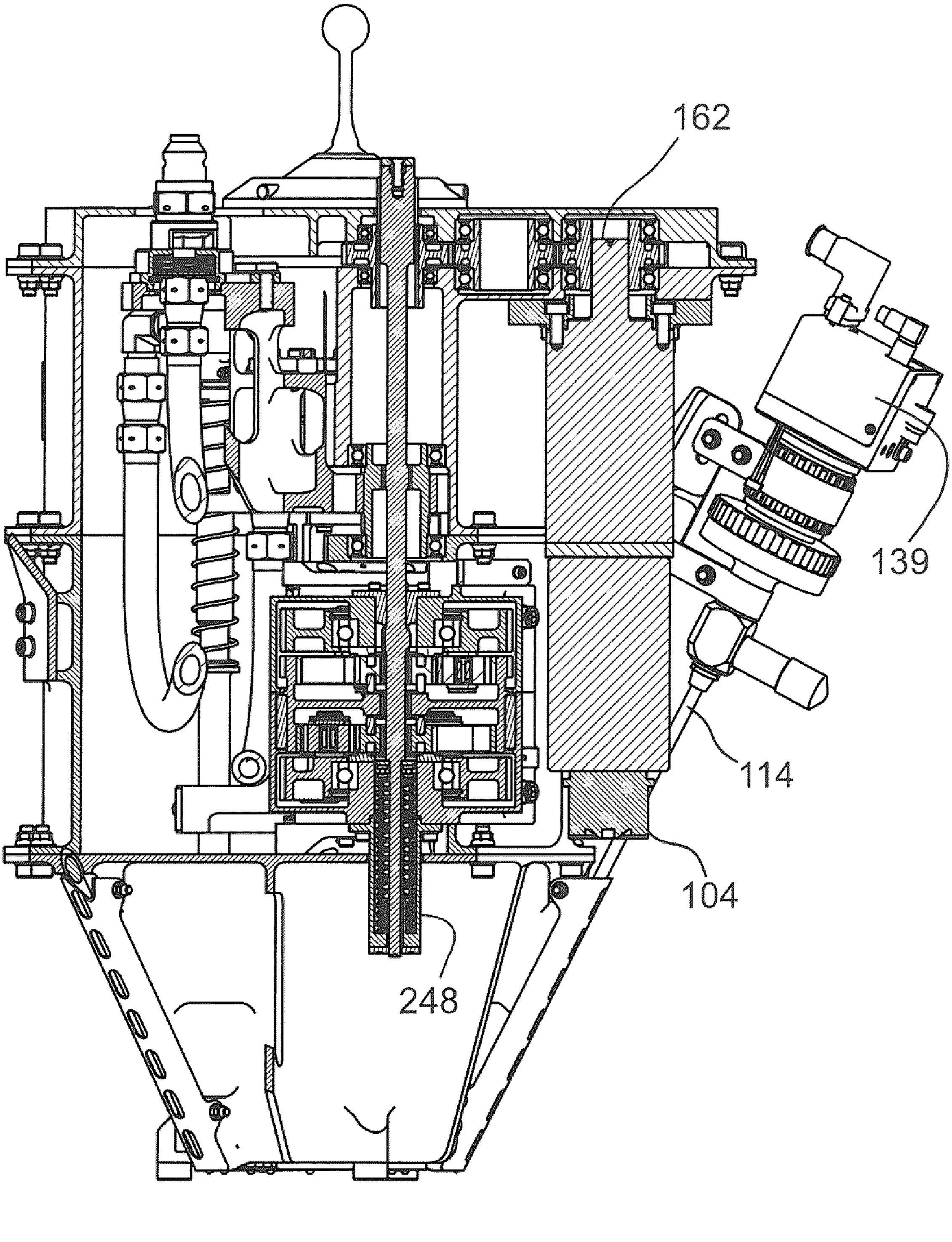

FIG. 13C

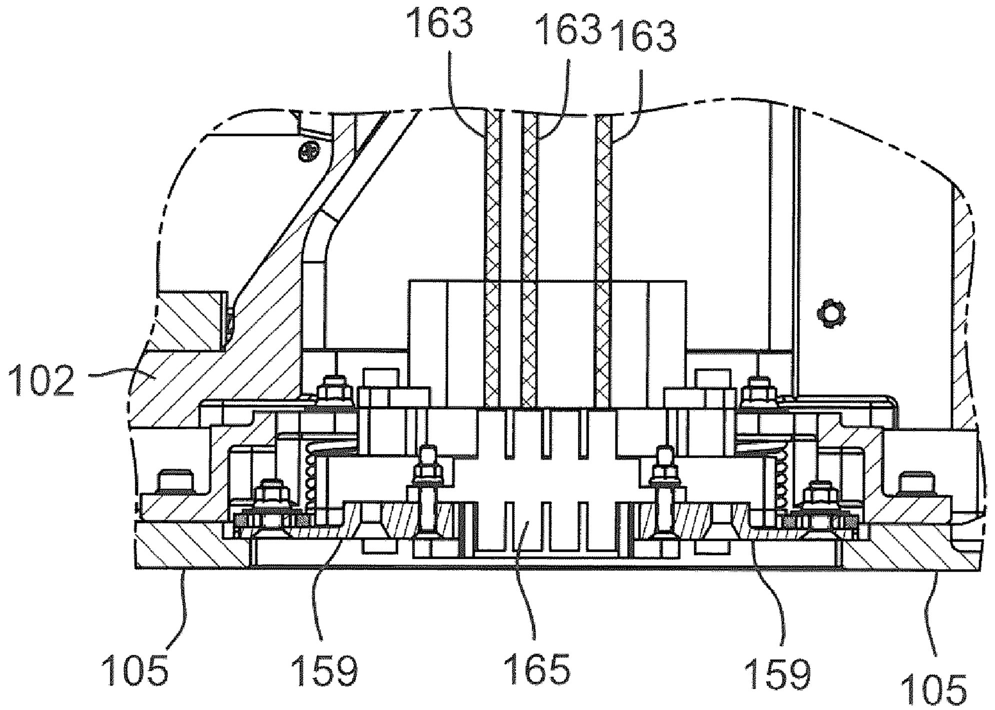
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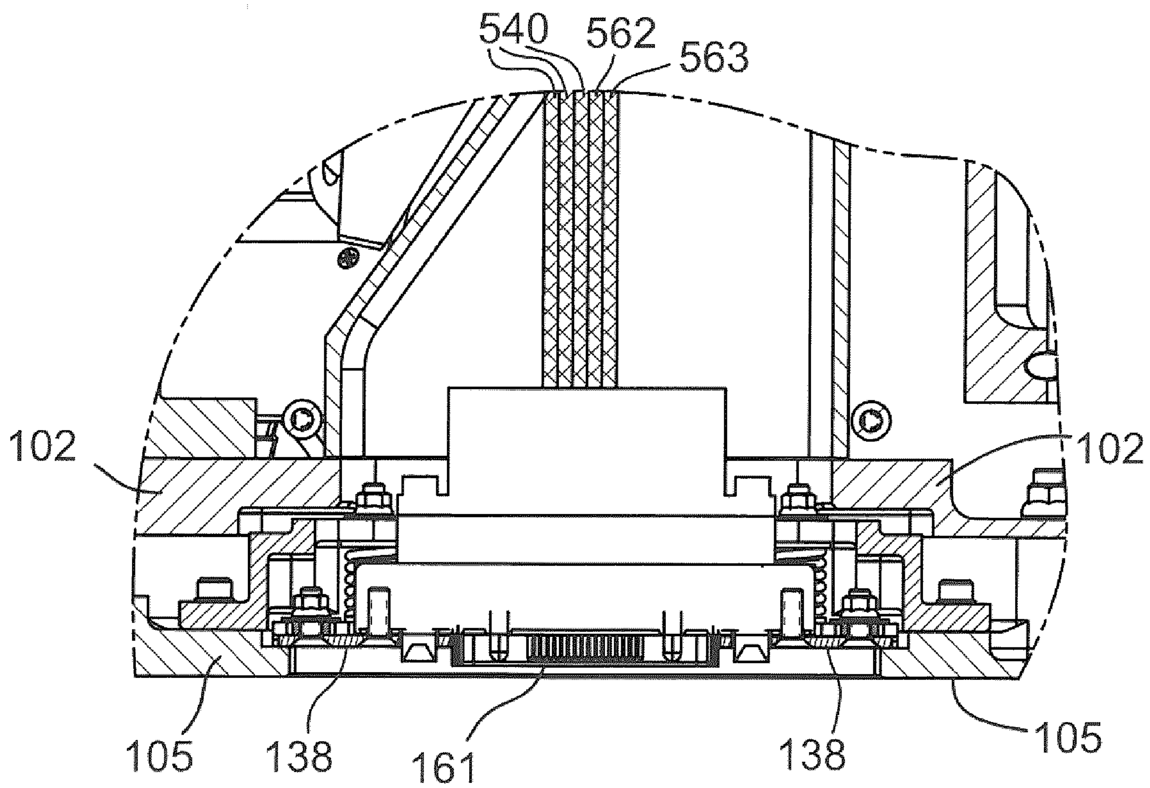
FIG. 14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138
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FIG. 15

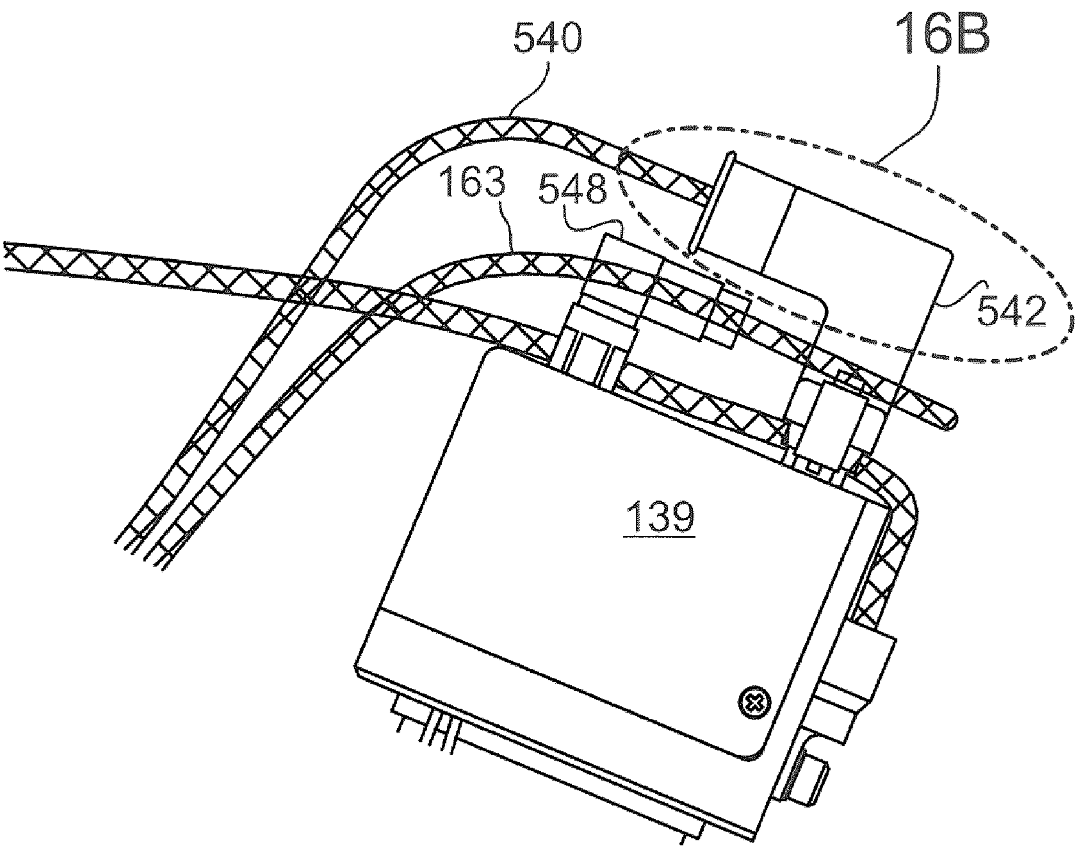

FIG. 16A

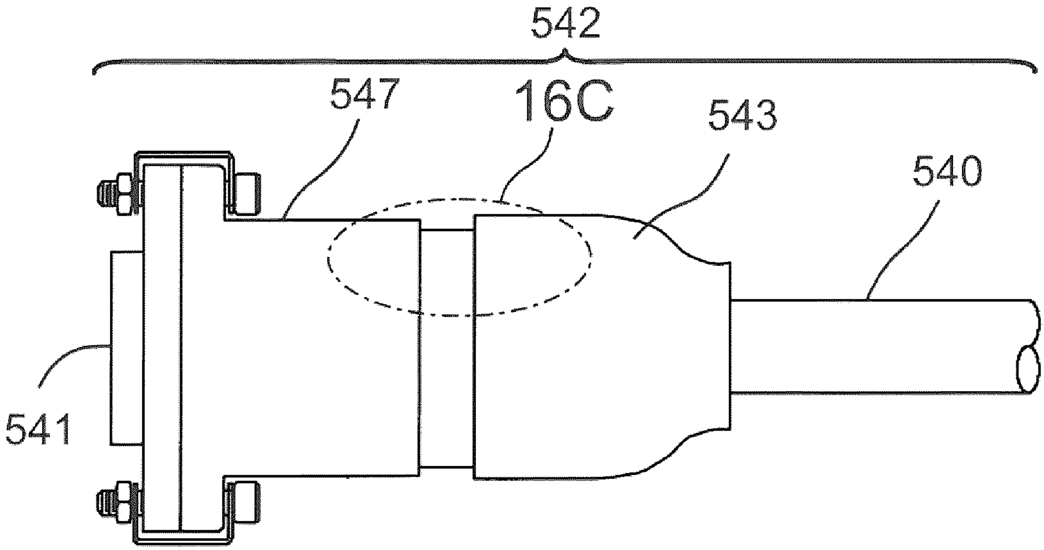

FIG. 16B

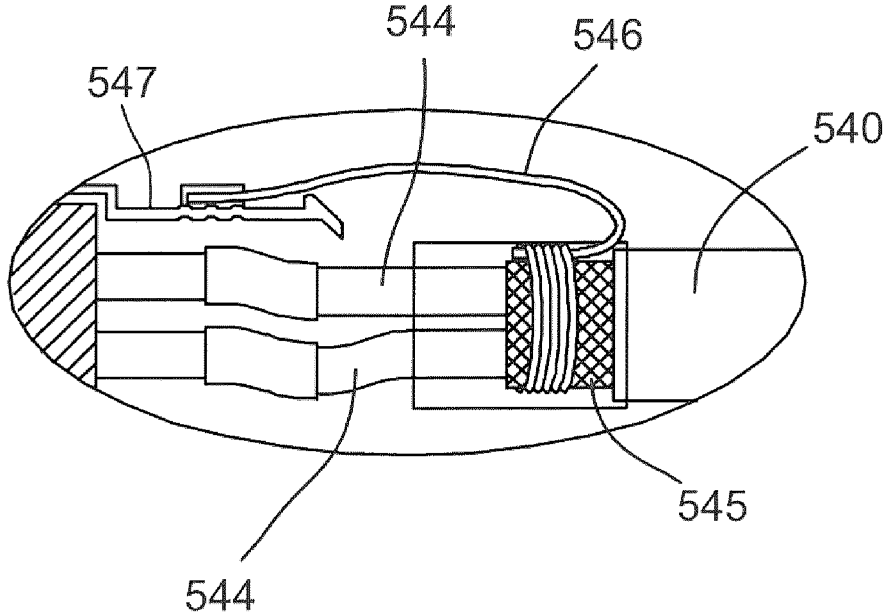

FIG. 16C

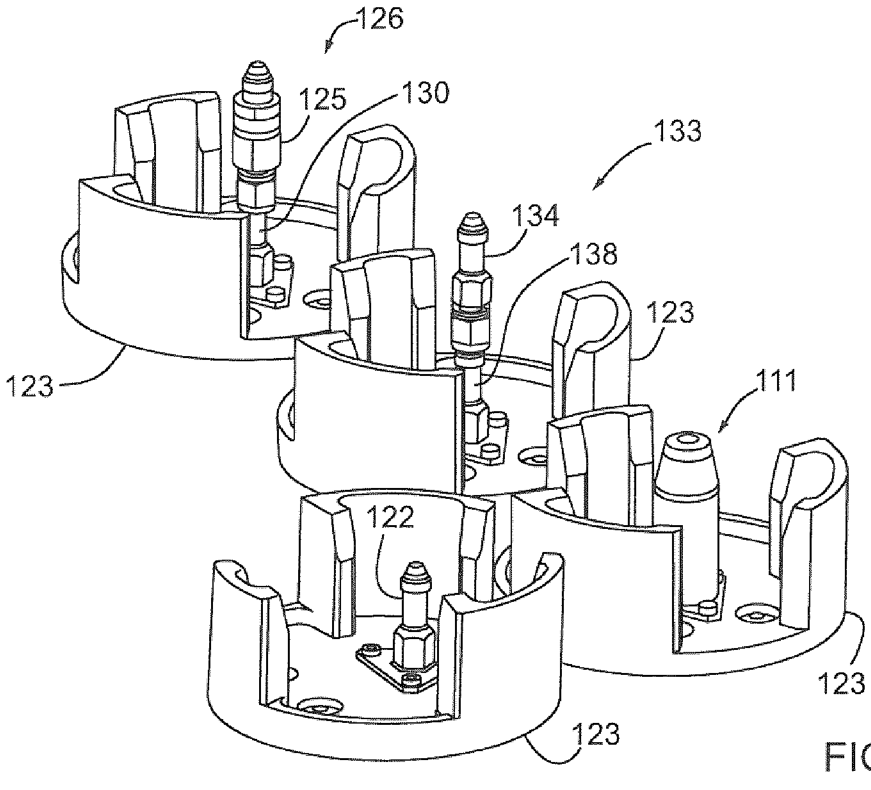

FIG. 17

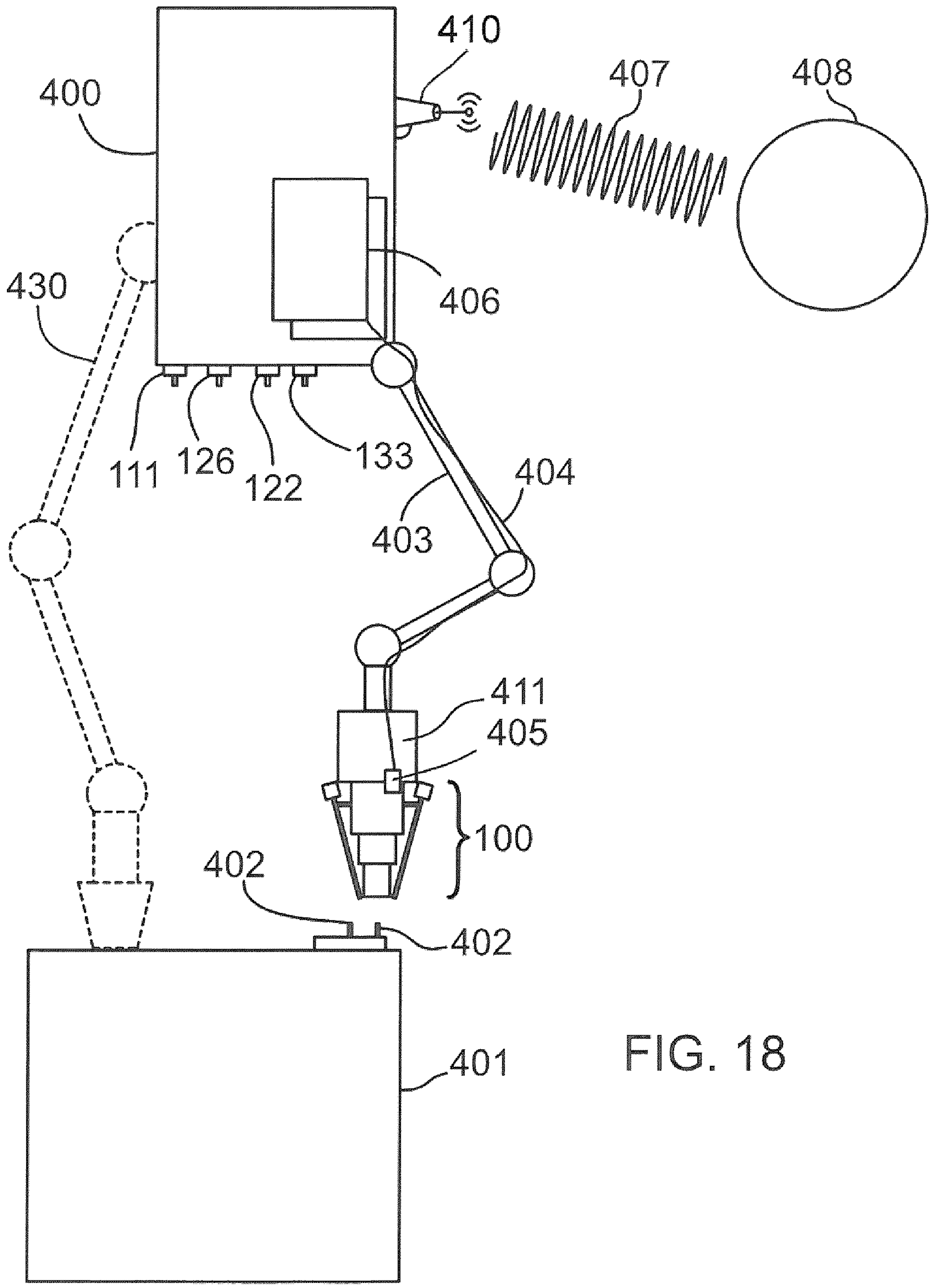

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FIG. 18

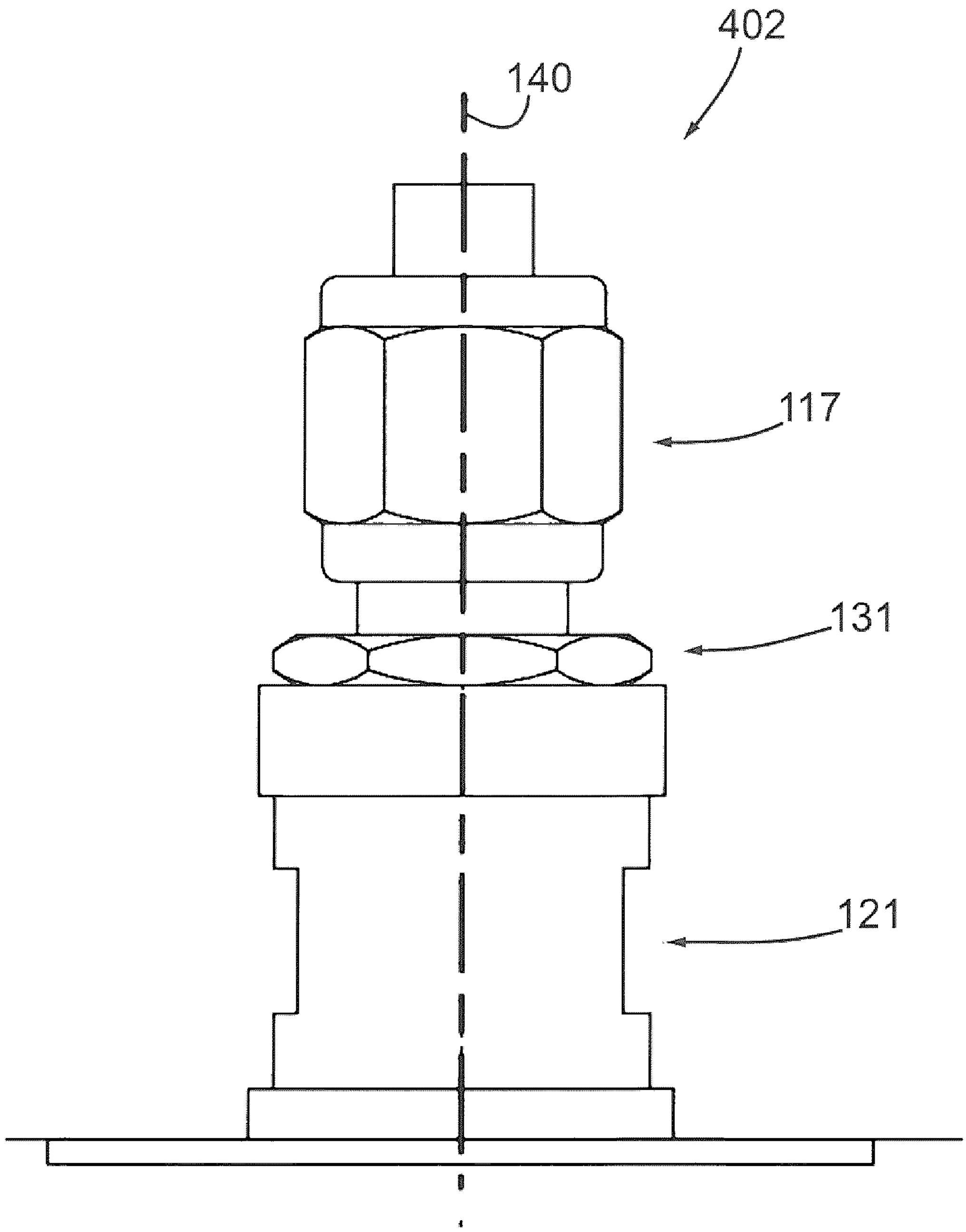

FIG. 19

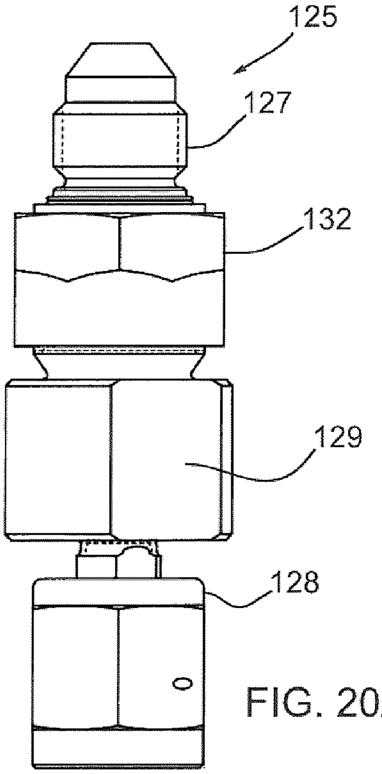

FIG. 20A

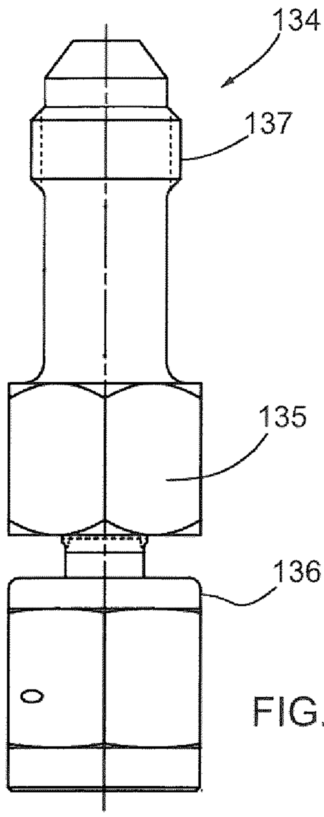

FIG. 20B

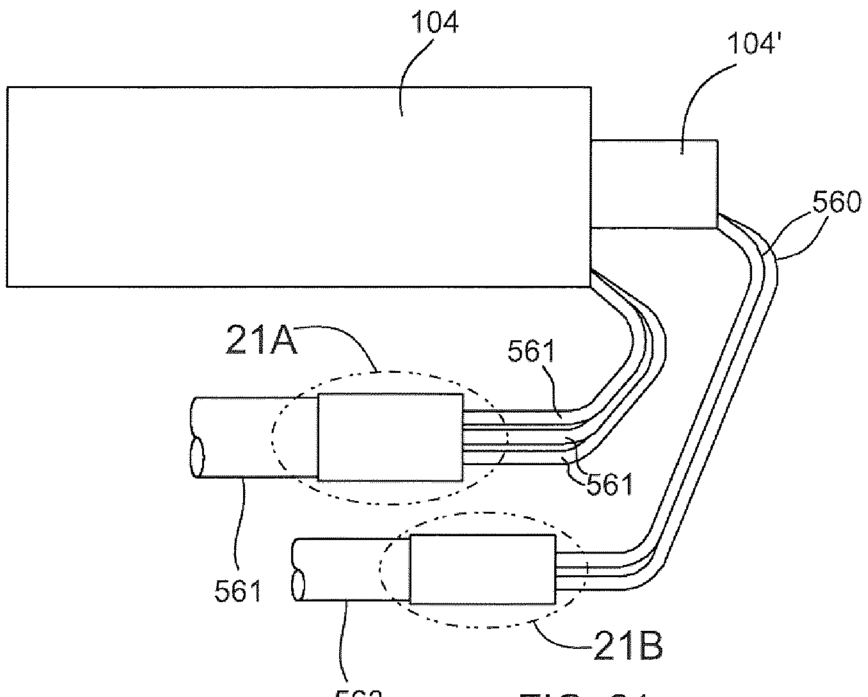

FIG. 21

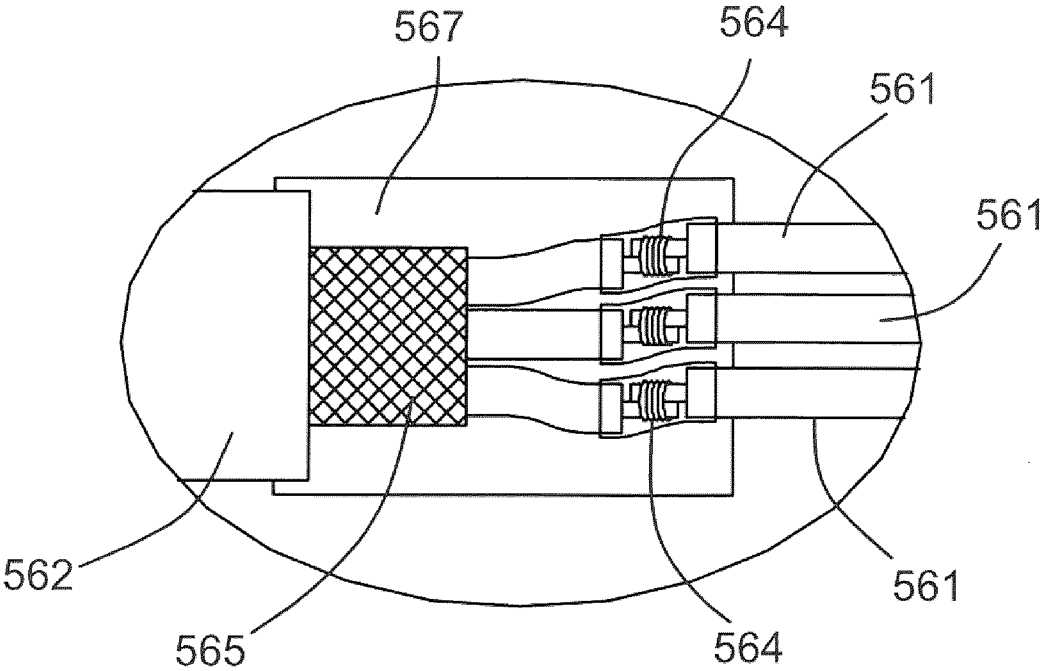

FIG. 21A

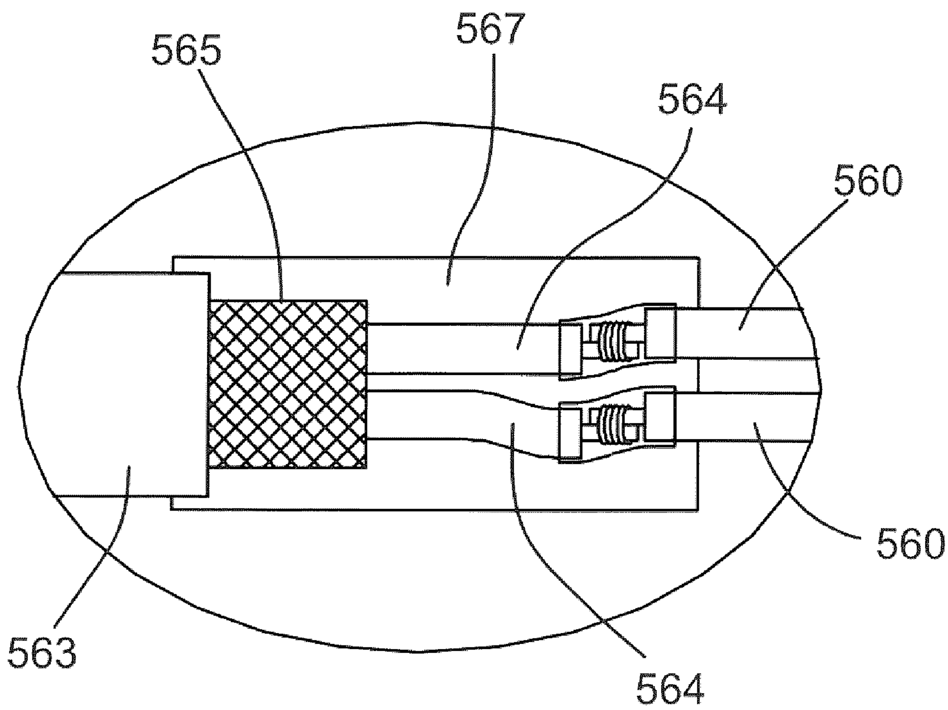

FIG. 21B

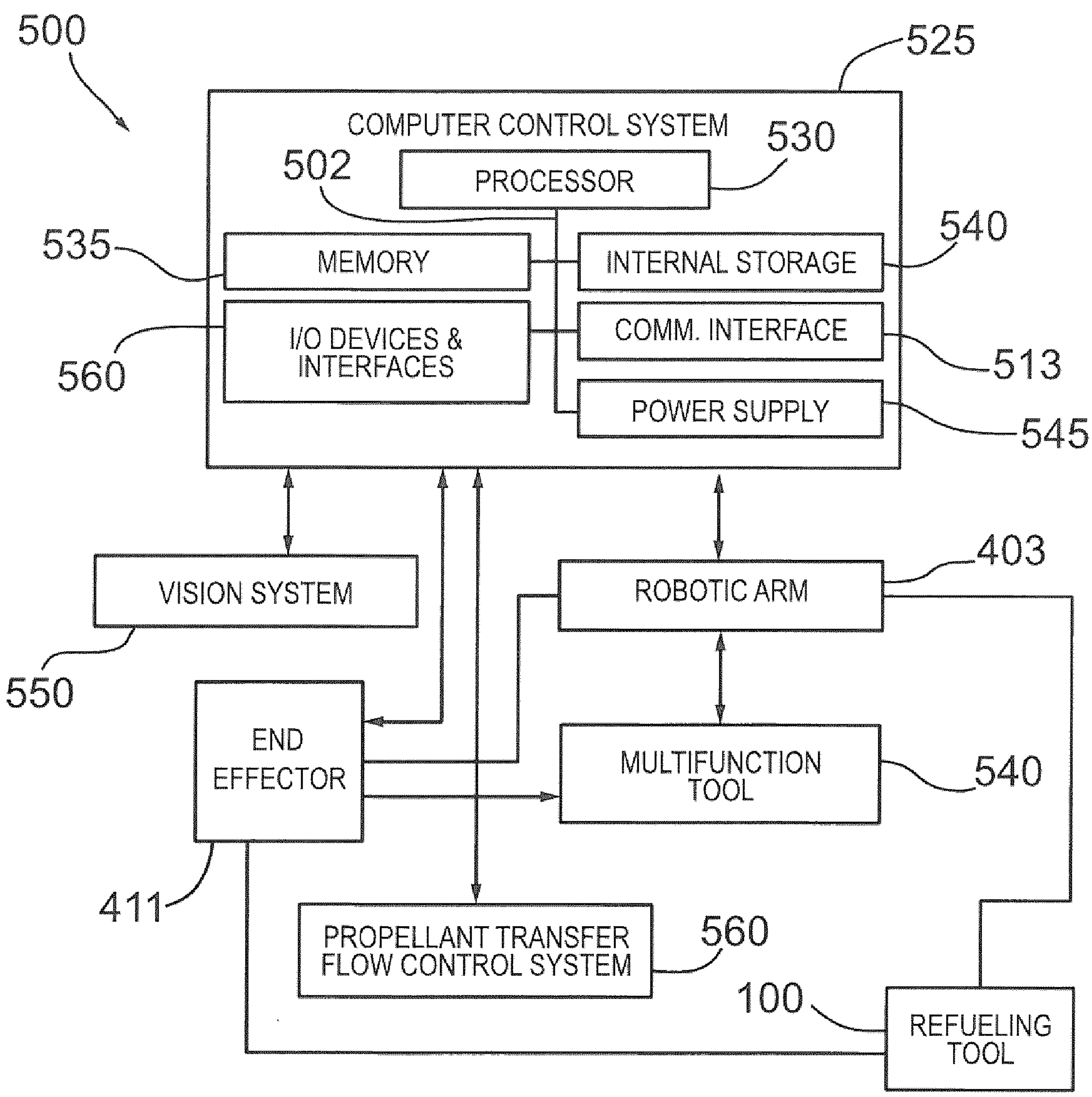
500
525
COMPUTER CONTROL SYSTEM
530
502
PROCESSOR
535
MEMORY
INTERNAL STORAGE
540
560
I/O DEVICES & INTERFACES
COMM. INTERFACE
513
POWER SUPPLY
545
VISION SYSTEM
550
ROBOTIC ARM
403
END EFFECTOR
MULTIFUNCTION TOOL
540
411
PROPELLANT TRANSFER FLOW CONTROL SYSTEM
560
100
REFUELING TOOL

FIG. 22

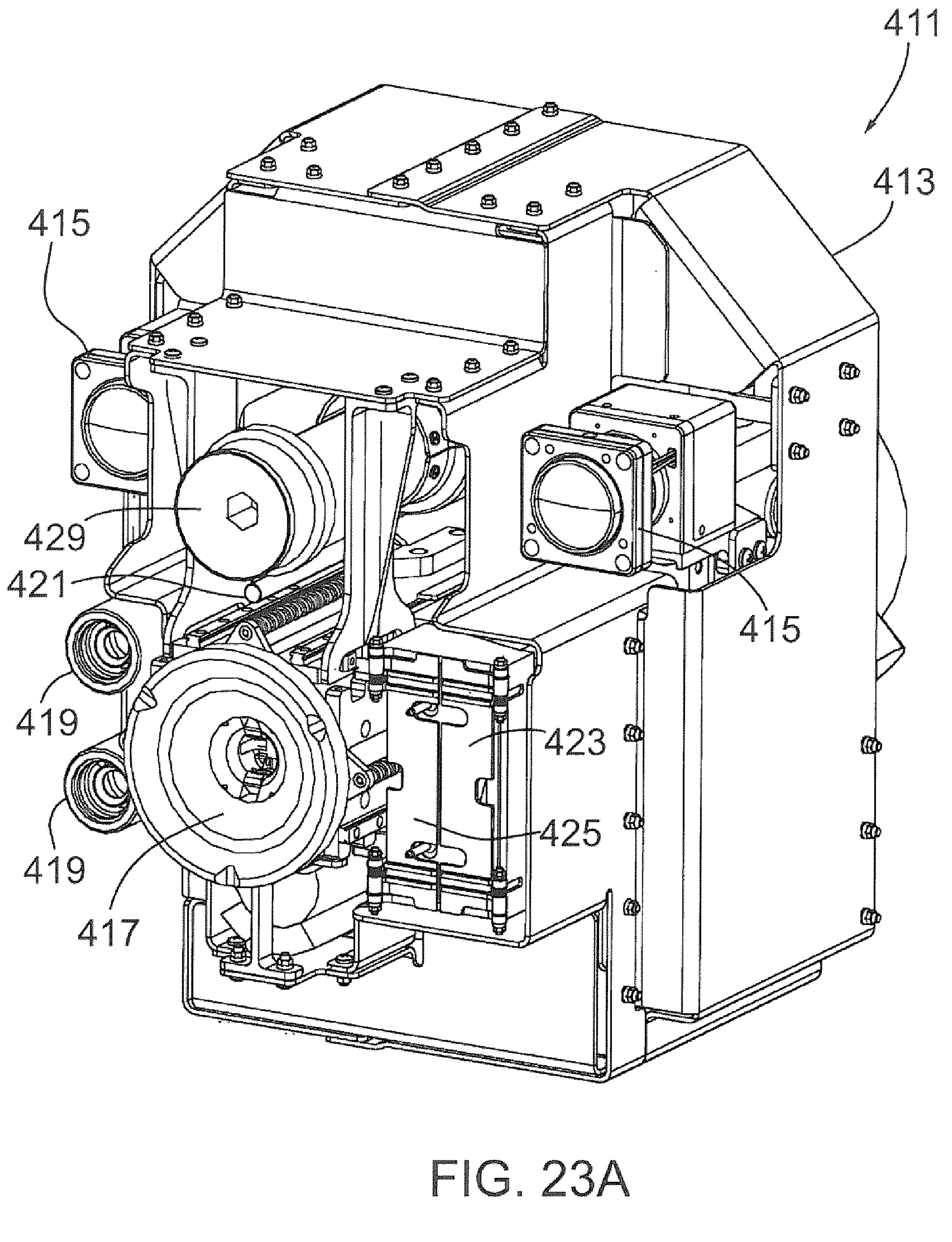

FIG. 23A

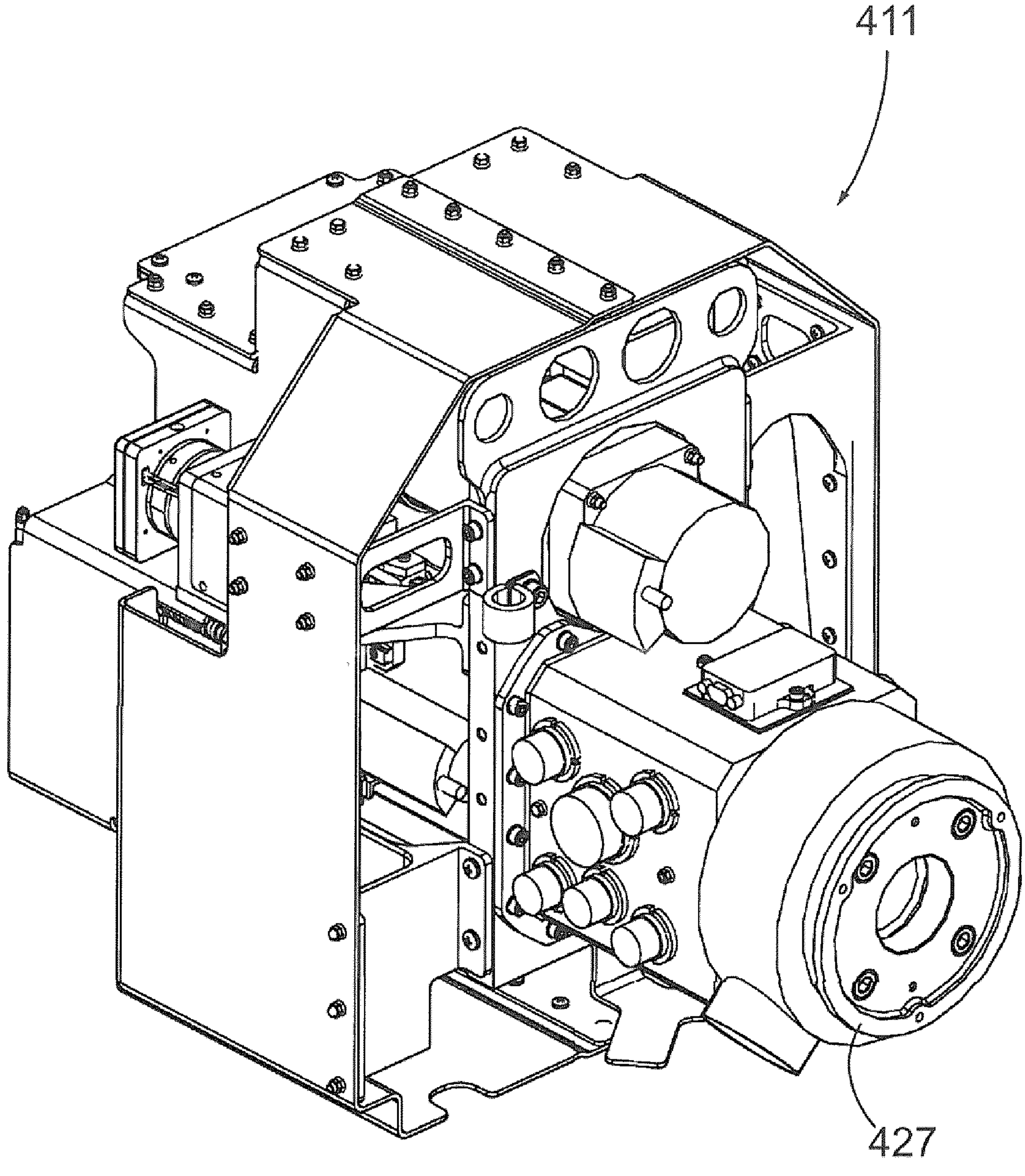

FIG. 23B

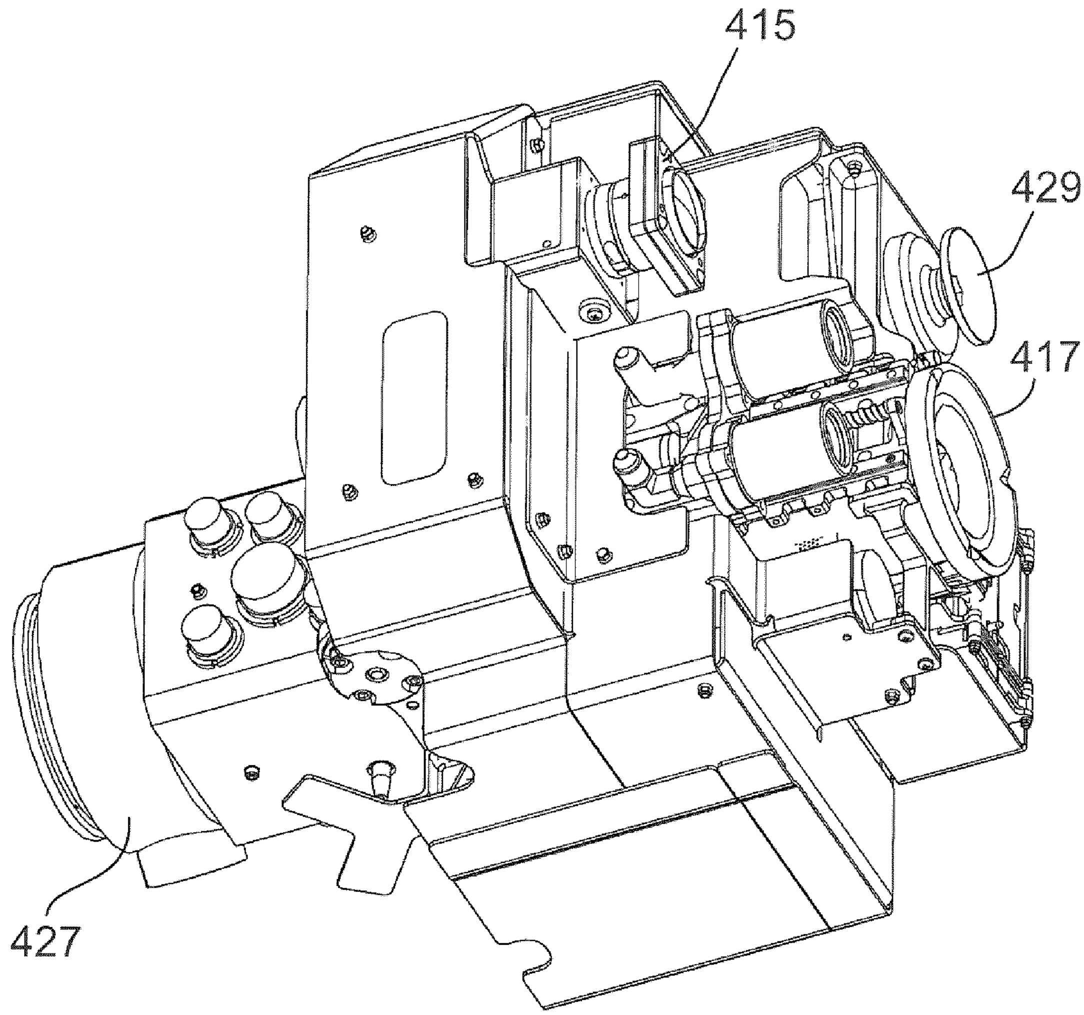

FIG. 23C

INTERNATIONAL SEARCH REPORT	International application No. PCT/CA2012/050876

A. CLASSIFICATION OF SUBJECT MATTER
IPC: ***B64G 4/00*** (2006.01) , ***B64D 39/00*** (2006.01) , ***B64G 1/10*** (2006.01) , ***B64G 1/64*** (2006.01)
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC (2006.01): B64G 4/00, B64D 39/00, B64G 1/10, B64G 1/64

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
CPD, EPODOC, TotalPatent, Google
satellite, refuel, wrench, torque, effector

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CA2680364 (CRYMBLE, D et al.) 18 September 2008 (18-09-2008) *figures la, 3: description*	22, 29-32
A	CA2473981 (.TONES, H et al.) 14 January 2006 (14-01-2006) * the whole document *	1-34
A	US4609169 (SCHWEICKERT, T et al.) 2 September 1986 (2-09-1986) * the whole document*	1-34
A	US5511748 (SCOTT, D) 30 April 1996 (30-04-1996) * the whole document*	1-34
A	US20070125910 (CEPOLLINA, F et al.) 7 June 2007 (7-06-2007) * the whole document*	1-34
A	DE102008061978A1 (GRIJBER, R) 1 July 2010 (1-07-2010) * figures, abstract	1-34

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance ; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance ; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 April 2013 (18-04-2013)	24 April 2013 (24-04-2013)

Name and mailing address of the ISA/CA	Authorized officer
Canadian Intellectual Property Office Place du Portage I, C114 - 1st Floor, Box PCT 50 Victoria Street Gatineau, Quebec K1A 0C9 Facsimile No.: 001-819-953-2476	Darren Hubley (819) 994-7655

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO2008066512A2 (CHRISTY, C) 5 June 2008 (5-06-2008) * the whole document*	1-34
A	WO2007117373A1 (BEHRENS, J et al.) 18 October 2007 (18-09-2007) * the whole document*	1-34

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of the first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons :

1. [ ] Claim Nos. :
   because they relate to subject matter not required to be searched by this Authority, namely :

2. [ ] Claim Nos. :
   because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically :

3. [ ] Claim Nos. :
   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows :

Group A - Claims 1 and 33 are directed to a tool featuring a wrench assembly having first and second adjustable wrench mechanisms.

Group B - Claim 22 is directed to a system for transferring fluid to a satellite comprising a positioner, end effector and a tool having a housing, a fixture, a fluid selection and coupling mechanism, a wrench mechanism, and an actuator, a sensor system, and a controller.

The subject matter of the independent claims fails to include a common special technical feature, and therefore is not directed to a single inventive concept.

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [X] As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claim Nos. :

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim Nos. :

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

[ ] The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

[ ] No protest accompanied the payment of additional search fees.

Patent document Cited in Search report	Publication Date	Patent Family Member(s)	Publication Date
CA2680364 Al	18-09-2008	US2012325972 Al	27-12-2012
		US2012080563 Al	05-04-2012
		US8196870 B2	12-06-2012
		US20121 12009 Al	10-05-2012
		US818191 l Bl	22-05-2012
		RU2009135297 A	20-04-201 l
		JP2010520832 A	17-06-2010
		EP2 134606 Al	23-12-2009
		EP2 134606 A4	02-03-201 l
		WO2008109993 Al	18-09-2008
CA2473981 Al	14-01-2006	- -	
US4609169 A	02-09-1986	- -	
US551 1748 A	30-04-1996	US5806802 A	15-09-1998
		WC-9731822 A2	04-09-1997
		US5803407 A	08-09-1998
		W0951461 1 Al	01-06-1995
		JPH08505828 A	25-06-1996
		JP3934153B B2	20-06-2007
		EP0684920 Al	06-12-1995
		EP0684920 A4	21-08-1996
		DE69425730T T2	19-04-2001
US2007125910 Al	07-06-2007	US200801 1904 Al	17-01-2008
		US75 13460 B2	07-04-2009
		US2007138344 Al	21-06-2007
		US7438264 B2	21-10-2008
		US2007164164 Al	19-07-2007
		US75 13459 B2	07-04-2009
		US7293743 B2	13-1 1-2007
		US7240879 Bl	10-07-2007
DE102008061978 Al	01-07-2010	- -	
WO2008066512 A2	05-06-2008	EP2086836 A2	12-08-2009
		WO2008066512 A3	25-09-2008
		JP2010510922 A	08-04-2010
		JP5124589B B2	23-01-2013
		EP2530018 Al	05-12-2012
WO20071 17373 Al	18-10-2007	US2007228220 Al	04-10-2007
		US201 1031352 Al	10-02-201 1
		US8006938 B2	30-08-201 l
		JP2009532253 A	10-09-2009
		JP5138671B B2	06-02-2013
		EP2001743 Al	17-12-2008
		EP2001743 Bl	22-09-2010
		AT482143T T	15-10-2010
		US7823837 B2	02-1 1-2010