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Attorney Docket No. 300007
8 February 2017

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Serial Number 15/185,207
Filing Date 17 June 2016
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IMPULSE PUMP

STATEMENT OF GOVERNMENT INTEREST

[0001] The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

CROSS REFERENCE TO OTHER PATENT APPLICATIONS

[0002] None.

BACKGROUND OF THE INVENTION

(1) Field of the Invention

[0003] The present invention relates to an impulse pump for generating a pulsed fluid jet.

(2) Description of the Prior Art

[0004] High velocity water jets are used in water jet cutting systems. Methods and systems exist to generate high pressures (often over 345 MegaPascals) needed for the high velocity water jets. A known system is to use a reciprocating piston pump to produce fluid flow at a fixed flow rate and pressure.

[0005] In operation, the output of the reciprocating pump is sent to a reservoir or attenuator capable of handling high pressure and is then discharged through a valve or orifice.

This type of system is designed to provide a steady jet of high

velocity water. However, the system is not adaptable for providing short duration pulses of water.

[0006] High-velocity (exceeding 300 meters per second) short-duration (less than 1 second) water jets can be used in underwater demolition by utilizing the effects of water-hammer and cavitation bubble collapse. Technical challenges related to generating the high-velocity short-duration water jets include: storage of mechanical energy; a rapid release of the stored energy; and conversion of the released energy to form a water jet. For example, in United States Patent No. 7,926,587, entitled "Explosive Water Jet with Precursor Bubble", a method is described for creating a pulsed water jet by using explosively released chemical energy.

[0007] Other systems exist to convert stored mechanical energy to an impulse started motion (an impact). In these systems, a mechanical spring is slowly compressed and then quickly and fully released to provide a sudden burst of energy to drive the impulse motion.

[0008] Other methods to store energy can be used to drive an impulse or impact device. Pneumatic and hydraulic systems can store energy that is released through a rapidly activated valve. Also, electrical energy can be converted to mechanical motion through electromagnetic forces such as electrical solenoids.

[0009] Desired characteristics of an improved energy storage and release systems are that the apparatus, device, or system has: a higher energy stored per unit mass of the overall system; a higher efficiency of energy conversion during energy release; and a rapid rate of energy release.

SUMMARY OF THE INVENTION

[0010] It is therefore an object of the present invention to provide an impulse pump that can quickly release water jet energy.

[0011] To attain the object described, the present invention assembles components suitable for: storage of energy in the form of rotational kinetic energy; a rapid release of the stored energy; conversion of the released rotational energy into linear motion; and a use of the linear motion to pressurize fluid with impulse energy.

[0012] The present invention uses a low power motor to store rotational kinetic energy in a flywheel. The stored energy is released using a planetary gear transmission that links the flywheel to a pusher shaft. The energy release is achieved when the planetary gear carrier is decelerated using a caliper brake. The planetary gear carrier deceleration forces rotational acceleration of the pusher shaft and deceleration of the

flywheel. Through a cam roller contact point between the pusher shaft and the cam raceway on the plunger; the rotational motion of the pusher shaft is converted to a linear and translational motion of a plunger device. The translational motion of the plunger rapidly empties a reservoir of the pump and creates a highly pressurized fluid path exiting a nozzle of the pump.

[0013] The pressurized fluid can drive a high-velocity short-duration water jet, with the qualities of a high energy storage-to-system weight ratio, efficient energy conversion, and a rapid energy release. Additionally, the present invention combines components known in the art, including an electric motor, a flywheel, a planetary gear clutch, hydraulic caliper brakes, a barrel type cam and follower, a piston pump, a reservoir, and a nozzle to assemble the inventive pump.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] A more complete understanding of the invention and many of the attendant advantages thereto will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in conjunction with the accompanying drawings wherein:

[0015] **FIG. 1** depicts an impulse pump built according to the teachings of the present invention with a portion of the housing removed to show internal components of the pump;

[0016] **FIG. 2** depicts a cross-section of the impulse pump of the present invention;

[0017] **FIG. 3** depicts an enlarged view taken from **FIG. 2** as sectioned area 3-3;

[0018] **FIG. 4** depicts an enlarged view taken from **FIG. 2** as sectioned area 4-4;

[0019] **FIG. 5** depicts an enlarged view taken from as sectioned area 5-5;

[0020] **FIG. 6** depicts a partial cross-section of the impulse pump with the cross-section showing as associated drive gear engaged with a flywheel rim gear with the view taken from reference lines 6-6 of **FIG. 2**;

[0021] **FIG. 7** depicts a partial cross-section of the impulse pump with the cross section showing an associated ring gear, planetary gears, planetary gear carrier, sun gear, and pusher shaft with the view taken from reference lines 7-7 of **FIG. 2**;

[0022] **FIG. 8** depicts a cross-section of the plunger placement in the head block of the impulse pump of the present invention;

[0023] **FIG. 9** depicts an isometric view of a pusher shaft of the present invention with the view also showing the shape of an associated cam race-way;

[0024] **FIG. 10** depicts an isometric view of a plunger of the present invention with the view showing the integral cam roller and spring of the pump;

[0025] **FIG. 11A - 11D** depict the plunger, spring, head block, nozzle, and pusher shaft of the present invention in four phases of an actuation cycle of the pump; and

[0026] **FIG. 12A - 12D** show the rotational speed of the flywheel and the rotational angle of the pusher shaft along with sequencing of a planetary gear carrier brake caliper and an idler disk brake caliper referenced to the four phases of an actuation cycle of the pump.

DETAILED DESCRIPTION OF THE INVENTION

[0027] Water jet pulses are useful in cutting and demolition applications. The instantaneous pump power requirements to create water jet pulses are high relative to a system imparting an equivalent average energy to a water stream at a uniform flow rate. To create a high energy water jet pulse; energy can be transferred into the system using a relatively low power drive which is stored in a rotation of a flywheel. Energy can be

rapidly released by converting the rotational motion of the flywheel into a linear motion of a piston or plunger.

[0028] A preferred embodiment of an inventive impulse pump **15** is shown in **FIG. 1**. In the figure, the pump **15** generally comprises a drive motor **17**, a planetary gear and flywheel gear box housing **20**, a cam assembly housing **70** attached to the gear box housing **20**, a plunger **72**, a head block **90**, and a nozzle **92**. Details of the gear box housing **20**, the cam assembly housing **70** and the head block **90** are depicted in **FIG. 2** through **FIG. 10**.

[0029] In operation, linear motion of the plunger **72** forces fluid through the nozzle **92** to form an impulse jet **100** into a liquid environment **200** or other suitable environment. The impulse jet formation is achieved by alternately drawing fluid into a reservoir **94** through the nozzle **92** from the liquid environment **200** and subsequently forcing the fluid from the reservoir through the nozzle into the liquid environment **200**.

[0030] The fluid is drawn into the reservoir **94** when rotating a pusher shaft **22** in a first angular direction to a second angular position in a rotation direction. An impulse pulse of fluid thru the nozzle **92** is created when the pusher shaft **22** is rotated in from the second angular position to the first angular position in the same rotational direction; thereby, completing a full rotation. Rotating the pusher shaft **22** results in the

movement of a cam race-way **74**. This movement changes the axial location of a contact point between a cam roller **76** and the cam race-way **74** relative to the nozzle **92**. Contact between the plunger **72** and the cam race-way **74** is maintained by a spring **78**.

[0031] An impulse jet **100** is formed by forcing liquid out of the reservoir **94** through the nozzle **92** by downward motion of the plunger **72**. The downward motion is forced by rotation of the pusher shaft **22** with the associated movement of the cam race-way **74**. Rotation of the pusher shaft **22** causes a cam follower arm **80** to be forced downward through the cam roller **76** as the contact roller follows the cam race-way **74**. A sleeve bearing **98** is placed between the plunger **72** and the head block **90** to minimize friction and to prevent flow of fluid from the reservoir **94** into the cam assembly housing **70** when drawing water into or expelling water from the reservoir.

[0032] In a further description of the arrangement of the impulse pump **15**; the drive motor **17** is mounted to a base plate **24**. The drive motor **17** drives a flywheel rim gear **26** through a drive shaft **28** and a drive gear **30** (See **FIG. 3**). Roller bearings **32** or their equivalent are positioned at moving areas throughout the pump **15** in order to reduce friction in those areas. The bearings are not all identified in the figure but

have generally the same shape and function as the identified bearing **32**.

[0033] In **FIG. 3**, the drive gear **30** engages with the flywheel drive gear **26** which is attached to a flywheel **34**. The drive gear **30** can be driven at predetermined rotational speeds required to store the desired energy in the flywheel **34**. The rotational speed may be near zero if the required energy is small or very high (up to the structural and vibrational limits of the system, e.g., multiple thousands of revolutions per minute) if the required energy is large.

[0034] In operation and prior to actuation of the impulse pump **15**, the pusher shaft **22** is held in a fully retracted position. The pusher shaft **22** is held in a fixed position by an idler disk caliper **48** (See **FIG. 4**). When the idler disk brake caliper **48** is activated through movement of a hydraulic piston **50**; frictional pads **52** are clamped against the surface of an idler rotor **54** and the idler rotor is held in place.

[0035] While the idler rotor **54** is held in place, a planetary gear carrier **42** must be allowed to rotate by depressurizing a hydraulic cylinder **56**. If both the idler rotor **54** and the pusher shaft **22** are simultaneously held in place, all internal components of the pump **15** will be forced to stop. A planetary gear carrier brake caliper **46** is released by depressurizing the

hydraulic cylinder **56** (See **FIG. 5**). The depressurization of the hydraulic cylinder **56** eliminates the contact forces between friction pads **60** and the planetary gear carrier **42** so that the planetary gear carrier is free to rotate.

[0036] **FIG. 7** depicts the flywheel **34** attached to a ring gear **36**. The ring gear **36** is a component in the gear box housing **20**. The ring gear **36** meshes with planetary gears **38** and the planetary gears mesh with a sun gear **40**. The sun gear **40** is attached to the pusher shaft **22**. The planetary gears **38** are attached to the planetary gear carrier **42** (not shown in **FIG. 7**) by planetary gear shafts **44**.

[0037] Referring again to **FIG. 2**, while the plunger **72** is fully retracted and the pusher shaft **22** is held stationary; the drive motor **17** can accelerate the flywheel **34** to a desired speed. In this way, energy is stored in the flywheel **34** in the form of rotational kinetic energy. Through kinematics of the planetary gear **38**, the planetary gear carrier **42** rotates at a fraction of the rotational speed of the flywheel **34**.

[0038] To convert the rotational energy of the flywheel **34** to a linear motion of the hydraulic piston **50**; the idler rotor **54** is released by depressurizing the idler brake caliper **48**. The planetary gear carrier **42** is subsequently decelerated by

actuating the brake caliper **46**. The planetary gear carrier brake caliper **46** is mounted to a positioning plate **58**.

[0039] The planetary gear carrier brake caliper **46** is activated through expansion of the hydraulic cylinder clamping frictional pads **60** against the surface of the planetary gear carrier **42** (See **FIG. 5**). In response to the clamping applied to the planetary gear carrier **42**; the flywheel **34** experiences a decelerating torque while the pusher shaft **22** experiences an accelerating torque.

[0040] As shown in **FIG. 8**, the plunger **72** has a square cross-section and is only free to move along a central pump axis **62** of the impulse pump **15**. The sleeve bearings **98** are affixed to the head block **90** to ease axial motion while the plunger **72** is under torsional loads.

[0041] The pusher shaft **22**, shown in detail in **FIG. 9**, includes the contoured cam race-way **74**. The cam race-way **74** is a surface machined onto an end of a large diameter portion of the pusher shaft **22** to form a barrel cam. Barrel cams are well known in the art as a means to convert rotational motion to linear motion. The cam function is realized when the pusher shaft **22** rotates and the elevation of the race-way contact point changes.

[0042] The elevation of the race-way contact point is defined as the distance along a line parallel to the pump axis **62** measured from a fixed point on a plane perpendicular to an axis of the pusher shaft **22** to the point at which the cam race-way **74** contacts the cam roller **76**. Over the course of one half revolution of the pusher shaft **22**; the elevation of the race-way contact point varies from a maximum distance from the nozzle **92** to a minimum distance.

[0043] The plunger **72**, shown in detail in **FIG. 10**, is attached to the cam roller **76** that contacts the cam race-way **74** at a fixed rotational location. The plunger **72** does not rotate relative to the head block **90**. As the pusher shaft **22** rotates and the elevation of the race-way contacts point varies from a maximum distance from the nozzle **92** to a minimum distance; the plunger **72** is forced downward and axially through contact of the cam roller **76** with the cam race-way **74** and a jet of fluid **100** is formed at the nozzle,

[0044] As the pusher shaft **22** rotates and the elevation of the race-way contact point varies from a minimum distance from the nozzle **92** to a maximum distance; the spring **78** forces upward motion of the plunger **72**. The upward force maintains contact between the cam roller **76** and the cam race-way **74**. The upward motion of the plunger **72** draws fluid into the reservoir **94** thru

the nozzle **92**. Thrust bearings **82** allow the pusher shaft **22** to rotate under axial loads (See **FIG. 11** for rotation of the pusher shaft).

[0045] Returning to **FIG. 2**, an angular position monitoring sensor **64** is included to assist in an actuation sequencing of the planetary gear carrier brake caliper **46** and the idler disk brake caliper **48**. The monitoring sensor **64** detects angularly positioned markings placed on the circumference of the idler rotor **54** to establish a rotational position of the rotor.

[0046] **FIG. 11A, FIG. 11B, FIG. 11C, and FIG. 11D** depict four positions of the pusher shaft **22** and the plunger **72** during a rotation of the pusher shaft. In position **11A**, the flywheel **34** is at full rotational speed (as indicated by direction arrow "A"); the plunger **72** is fully retracted; the reservoir **94** is full of liquid; and the plunger is held in position by the idler brake caliper **48** (the flywheel and idler brake caliper are not shown in this figure). The impulse jet **100** is initiated by releasing the idler brake caliper **48** and actuating the planetary gear carrier brake caliper **46** (the brake caliper is not shown in this figure). Through transfer of forces from the planetary gear carrier brake caliper **46** to the flywheel **34**; the flywheel is decelerated and the pusher shaft **22** is rotated (as indicated by direction arrow "A").

[0047] In position **11B**, the plunger **72** is forced downward through the cam roller **76** as the contact point with the cam race-way **74** moves downward. Liquid is forced from the reservoir **94** as the plunger **72** moves downward.

[0048] In position **11C**, the plunger **72** is at its lowest position. The planetary gear carrier brake caliper **46** is released and the idler brake caliper **48** is engaged to stop rotation of the pusher shaft **22**. The angular position monitoring sensor **64** monitors rotation of the pusher shaft **22** to time actuation and release of the calipers **46** and **48**.

[0049] Movement from position **11C** to position **11D** is achieved by releasing the idler disk brake caliper **48**. Fluid is drawn into the reservoir **94** by releasing the idler disk brake caliper **48** and partially engaging the planetary gear carrier brake caliper **46**. Engaging the planetary gear carrier brake caliper **46** causes the pusher shaft **22** to rotate. During the rotation, the contact points between the cam roller **76** and the cam race-way **74** translates upward parallel to the pump axis **62** while drawing fluid into the reservoir **94** through the nozzle **92**. Contact between the cam roller **76** and the cam race-way **74** is maintained through action of the spring **78**. The spring **78** provides the force necessary to move the plunger **72**.

[0050] The planetary gear carrier brake caliper **46** is released and the idler brake caliper **48** is engaged as the plunger **72** returns to a top position. The angular sensor **64** is monitored so that the motion of the plunger **72** is stopped at the correct position. The pulse jet sequence can then be repeated once the flywheel **34** has returned to a full pre-pulse rotational speed.

[0051] **FIGs. 12A - 12D** show the rotational speed of the flywheel and the rotational angle of the pusher shaft **22** along with the sequencing the planetary gear carrier brake caliper **46** and the idler disk caliper brake **48** referenced to the four phases of the actuation cycle of the pump **15**.

[0052] The primary advantages of the impulse pump **15** are twofold. First, the impulse pump **15** enables the rapid conversion of rotational kinetic energy stored in a flywheel **34** to a linear motion of the plunger **72** to form the short duration impulse jet **100**. The process of collecting energy from the low power drive motor **17** over a long period relative to the duration of the impulse jet **100** and rapidly converting that energy allows the overall size of the pump **15** to be small as compared to a device engineered with a drive motor capable of producing the instantaneous power requirements of the water jet production.

[0053] Second, the caliper brakes **46, 48** are sequenced to apply forces to components within the planetary gear system to rapidly decelerate and accelerate components within the impulse pump **15** in order to produce a rapid and forceful motion of the plunger **72**. The rapid motion of the plunger **72** creates the water (impulse) jet **100**. The rapid motion of the plunger **72** may be used for other applications other than the formation of a water jet. The impulse pump **15** with rapid motion of the plunger **72** may be used in punch presses or similar devices where short duration forceful motion of a linear actuator is needed.

[0054] What has thus been described is a device for creating a short duration and high velocity water jet **100**. The short duration and high velocity water jet **100** is created by the impulse pump **15** of the present invention by storing energy in a flywheel **34** that is rapidly converted to linear motion of a piston or plunger **72**. The linear motion of the plunger **72** forces water through a nozzle **92** to form the water jet **100**.

[0055] Central to the energy conversion process are the two caliper brakes **46, 48** that provide deceleration and restraining forces to components of the impulse pump **15**. The pusher shaft **22** is held in place as the flywheel **34** is accelerated. When the flywheel **34** is at full speed, the idler disk caliper brake **48** is released and the planetary gear carrier brake caliper **46** is

applied. A counter-torque is transferred to the pusher shaft **22** in reaction to the torque applied to the planetary gear carrier **42** by the planetary gear carrier brake caliper **46**.

[0056] This counter torque rotates the pusher shaft **22**, which in turn forces the plunger **72** downward and expels pressurized fluid **100** from the reservoir **94** thru the nozzle **92**. Work done on the system through application of the planetary gear carrier brake caliper **46** is proportional to the frictional force applied by the planetary gear carrier brake caliper times the speed of the pump components on which the disk brake acts.

[0057] The energy to perform that work is provided by the flywheel **34** and deceleration of the flywheel. Energy from the flywheel **34** is lost through the generation of heat during application of the system brake and transferred to other system components through a rotational acceleration of the pusher shaft **22**, linear acceleration of the plunger **72**, and work done on the fluid that forms the pressurized fluid jet **100**.

[0058] The drive motor **17** for the impulse pump **15** can be comparatively small because the instantaneous power requirements of the drive system are low. Because acceleration of the flywheel **34** can be slow; the drive motor **17** need only have power slightly in excess of that required to overcome system losses at a maximum flywheel rotational speed.

[0059] Many modifications and variations of the present invention may become apparent in light of the above teachings. A number of alternative devices could be constructed using the same general methods discussed herein to construct devices that would be optimized for a particular purpose. For example: the bearing types and configurations may be different than as shown; disk brake calipers could be replaced with drum, inductive, hydraulic, or band brakes; and the barrel cam and follower design could be replaced with a swashplate assembly.

[0060] I
In light of the above, it is therefore understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described.

IMPULSE PUMP

ABSTRACT OF THE DISCLOSURE

An impulse pump is provided with a low power motor to store rotational kinetic energy in a flywheel. The stored kinetic energy is released using a planetary gear transmission that links the flywheel to a pusher shaft. The kinetic energy is released when the planetary gear carrier is decelerated using a caliper brake. The planetary gear carrier deceleration forces rotational acceleration of the pusher shaft and deceleration of the flywheel. Through a cam roller contact point between the pusher shaft and the cam raceway on the plunger; the rotational motion of the pusher shaft is converted to linear and translational motion of the plunger. The translational motion of the plunger allows impulse jet energy to be rapidly released from a nozzle of the pump.

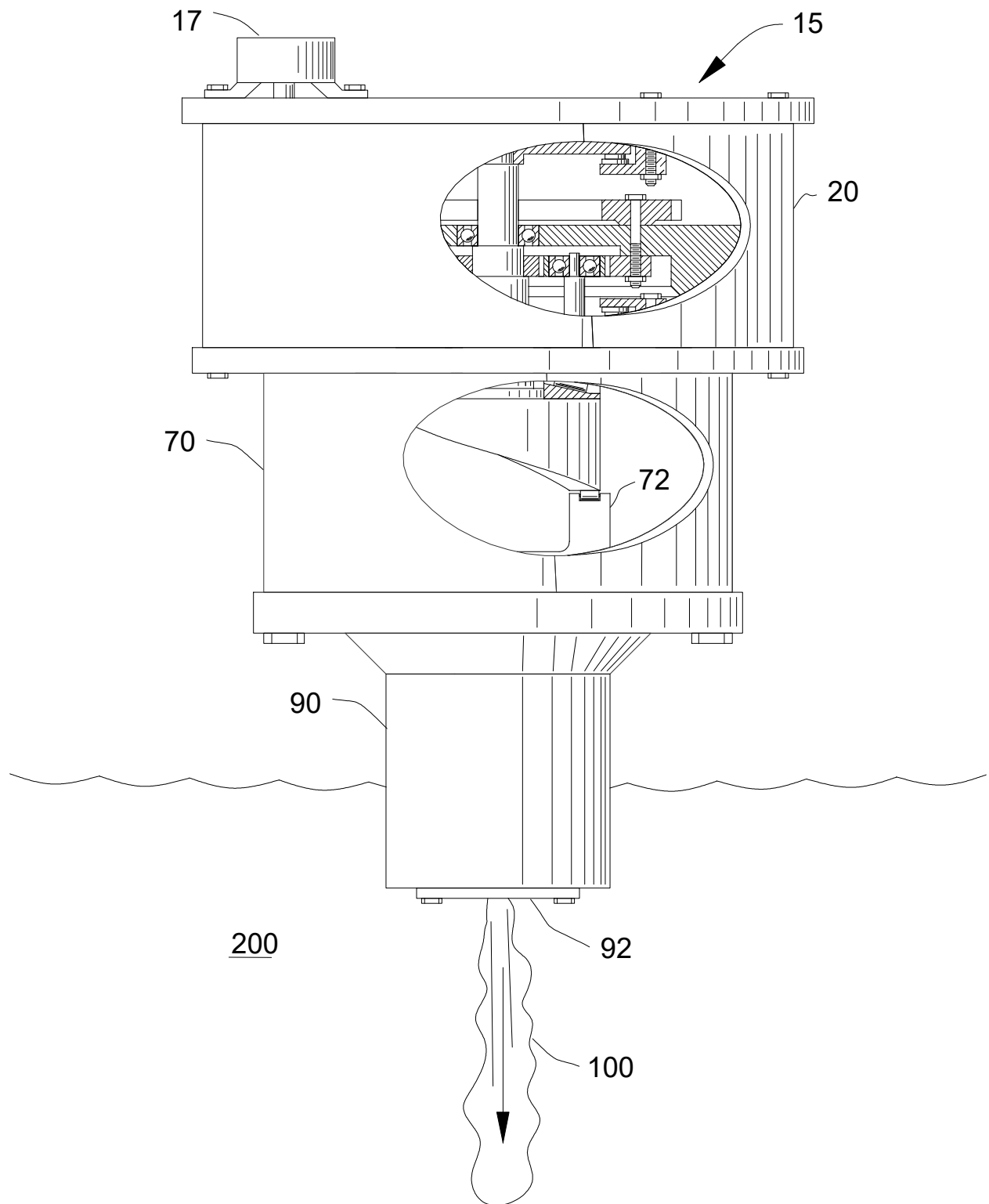


FIG. 1

FIG. 2

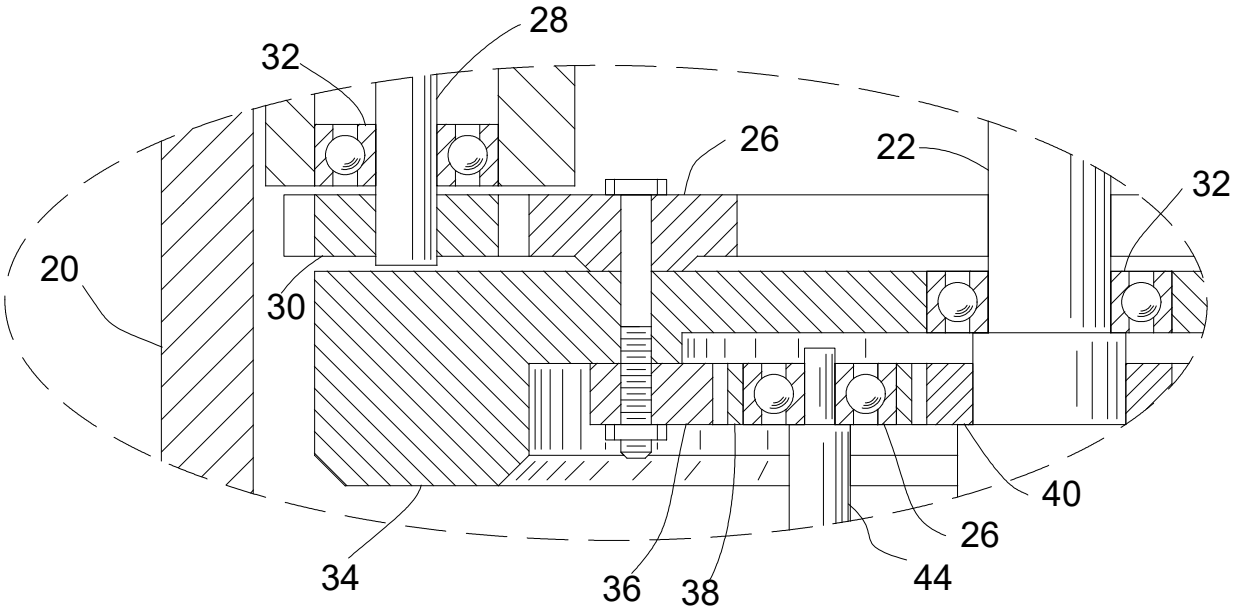


FIG. 3

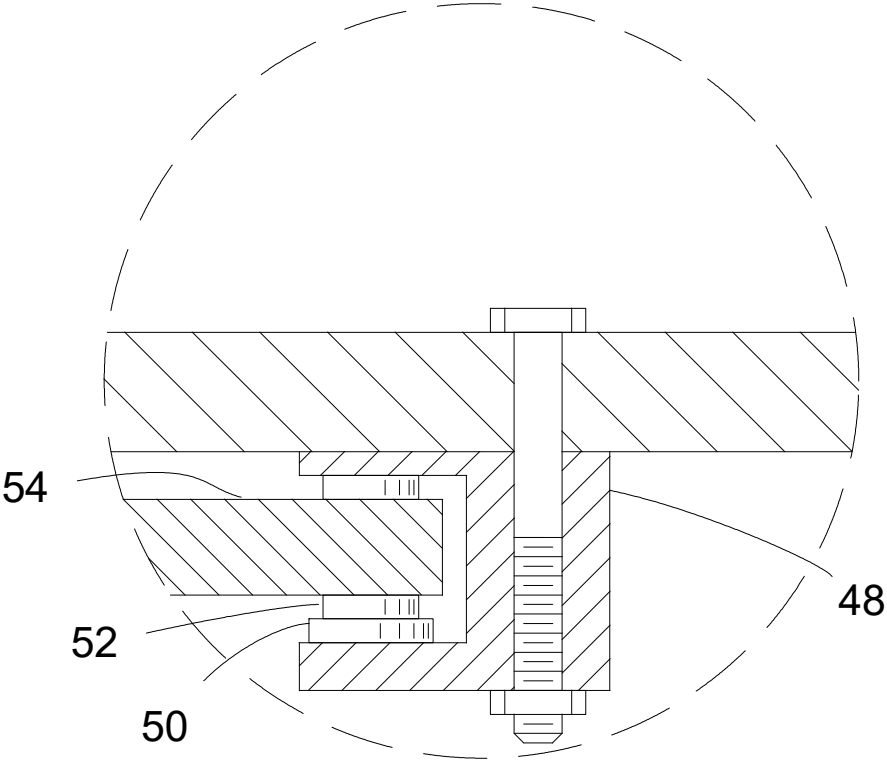


FIG. 4

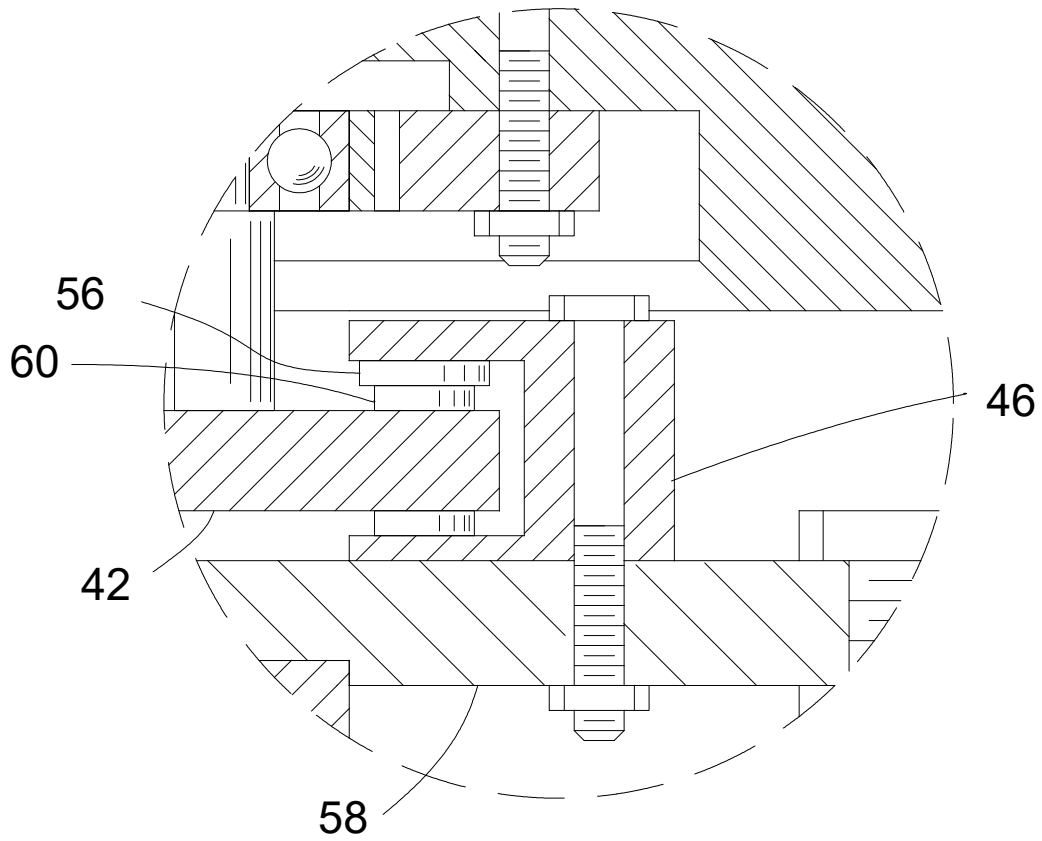


FIG. 5

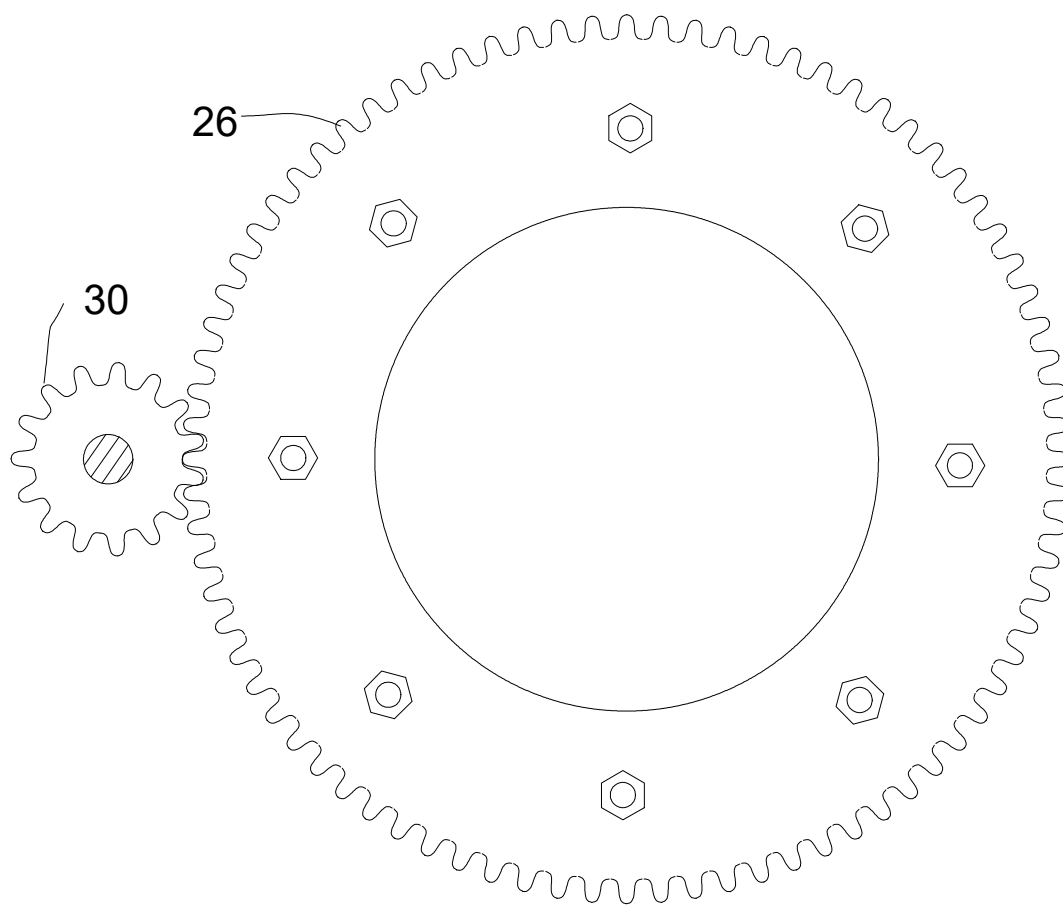


FIG. 6

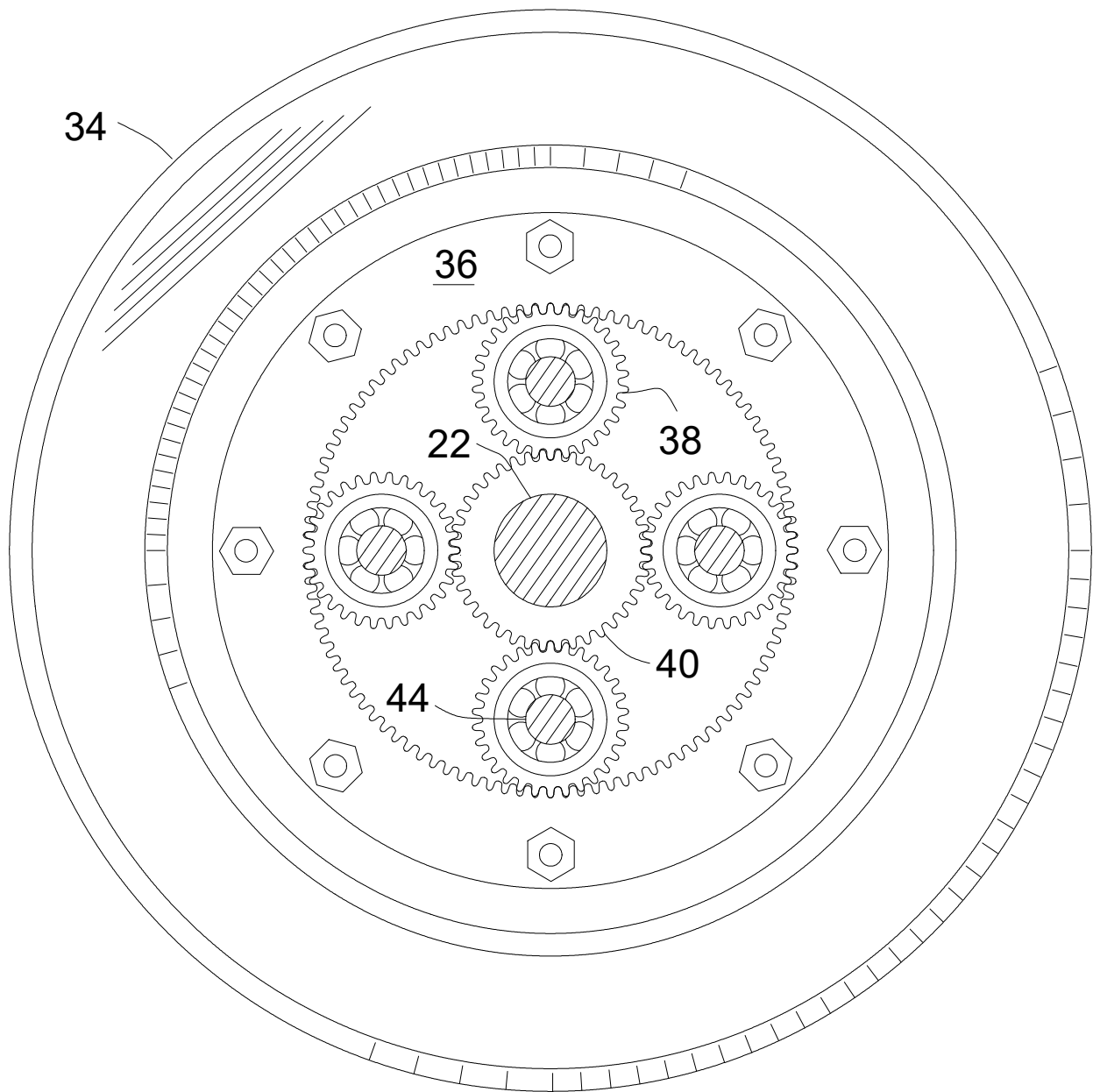


FIG. 7

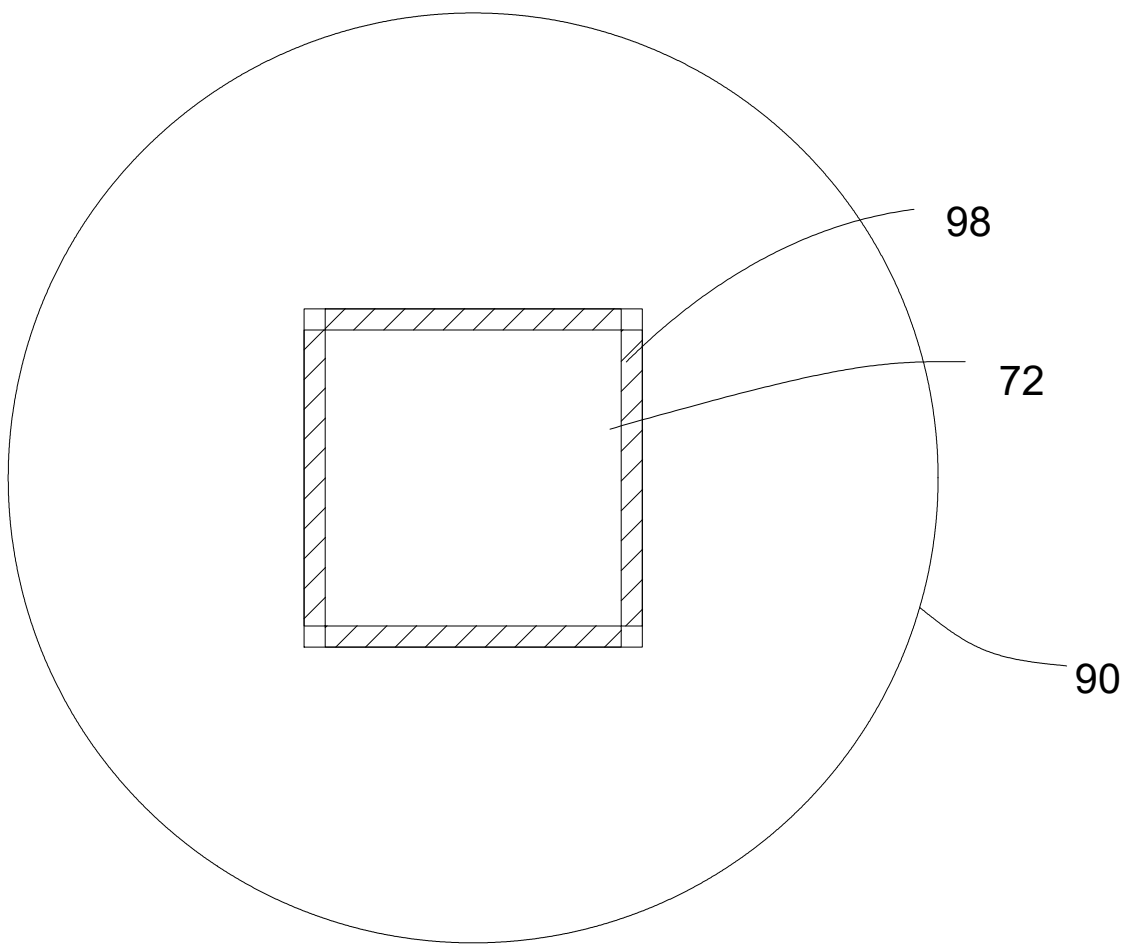


FIG. 8

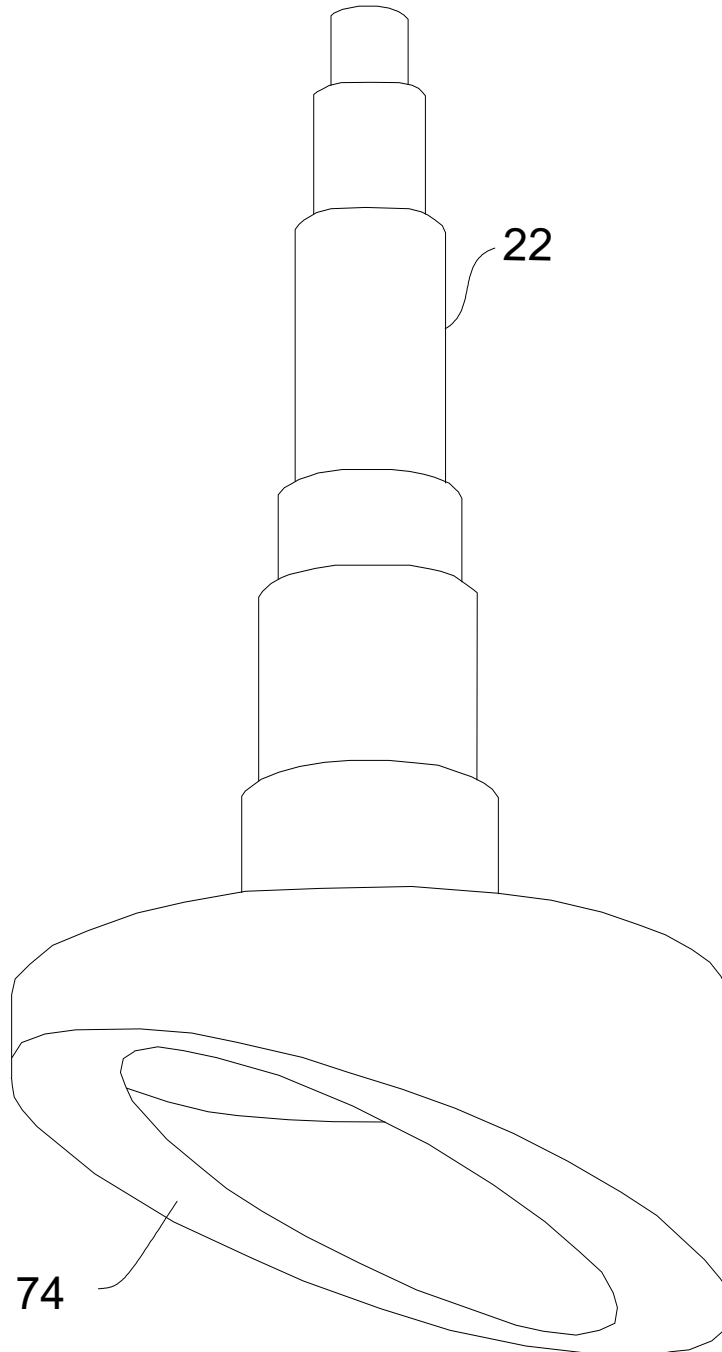


FIG. 9

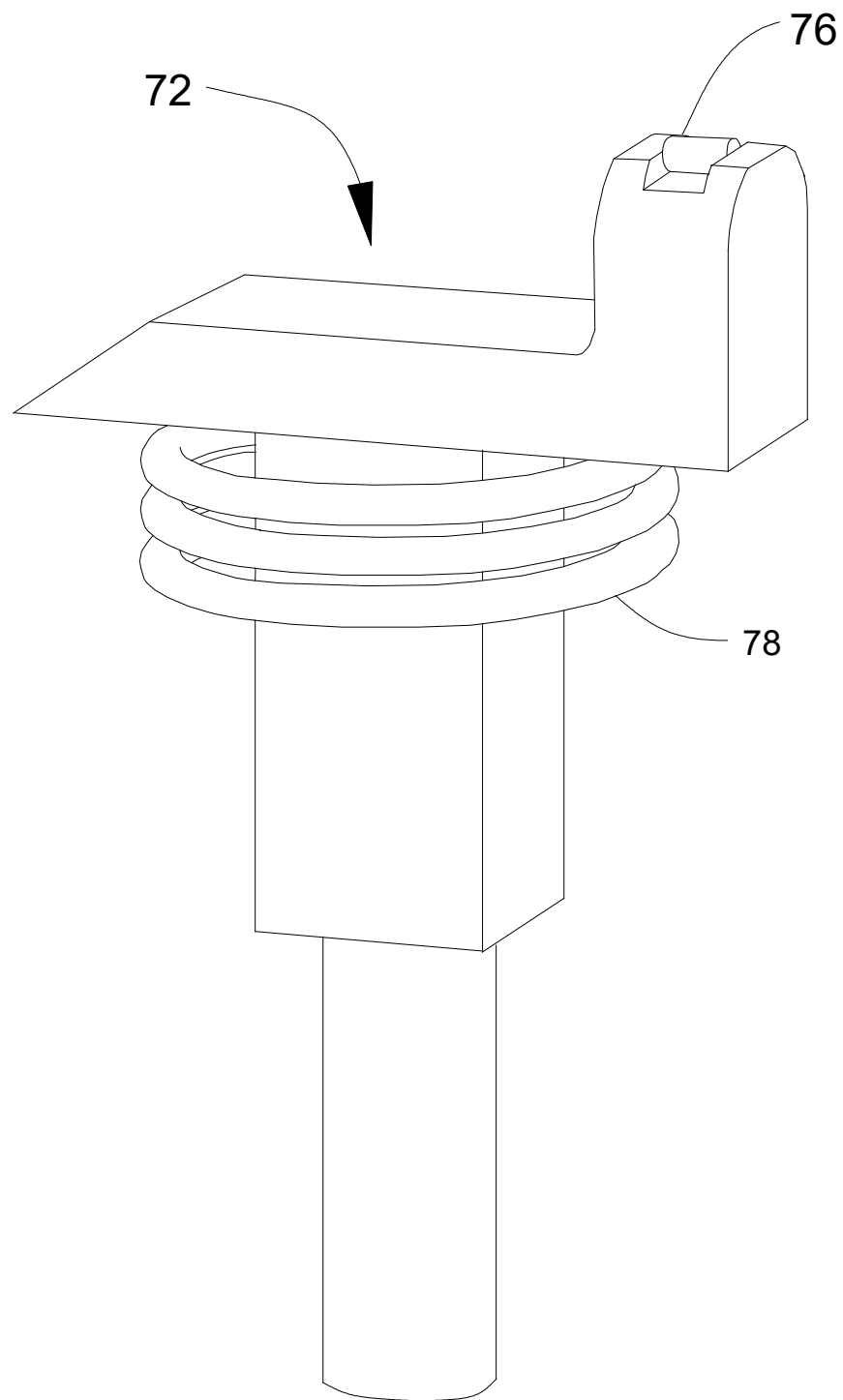


FIG. 10

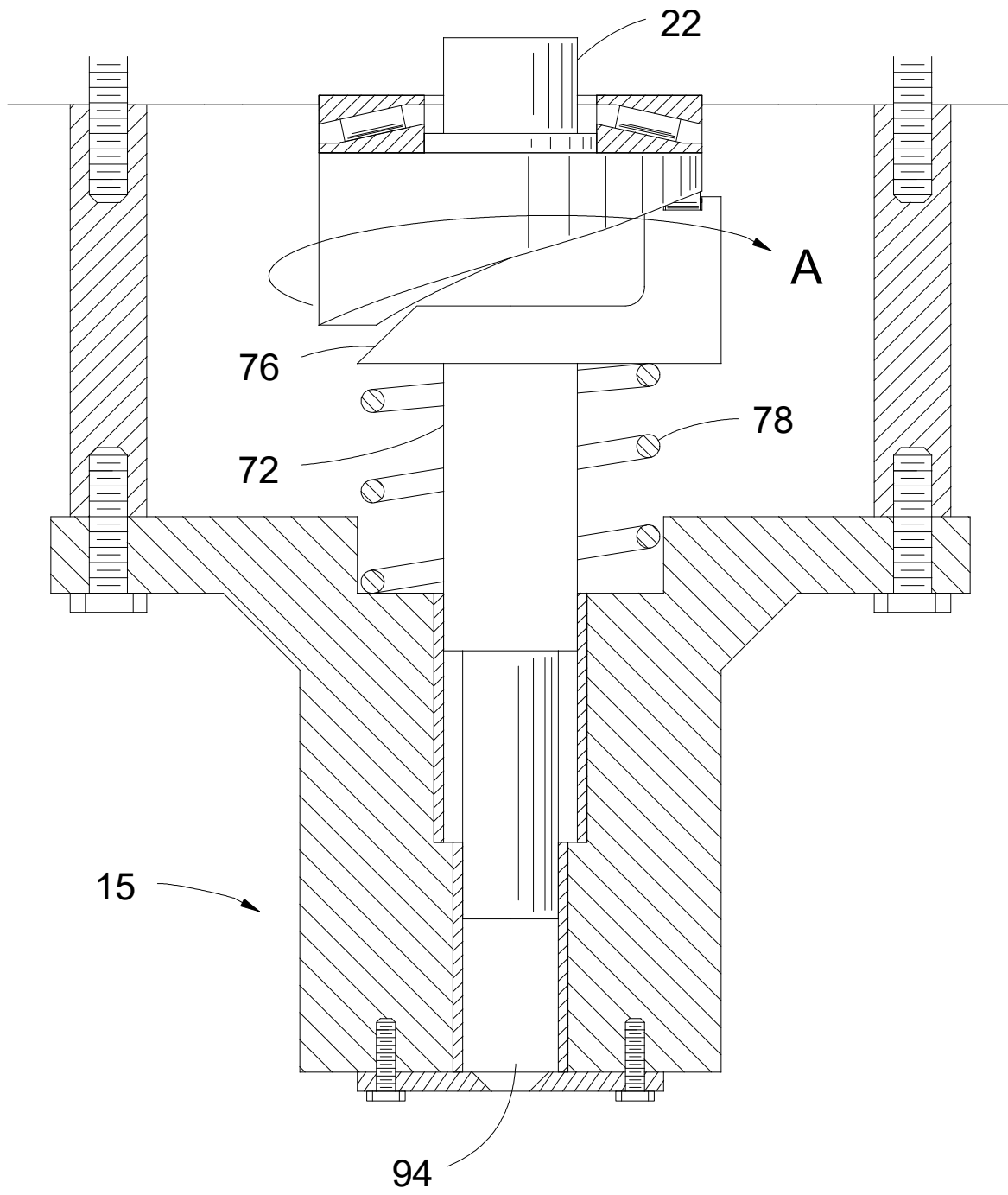


FIG. 11A

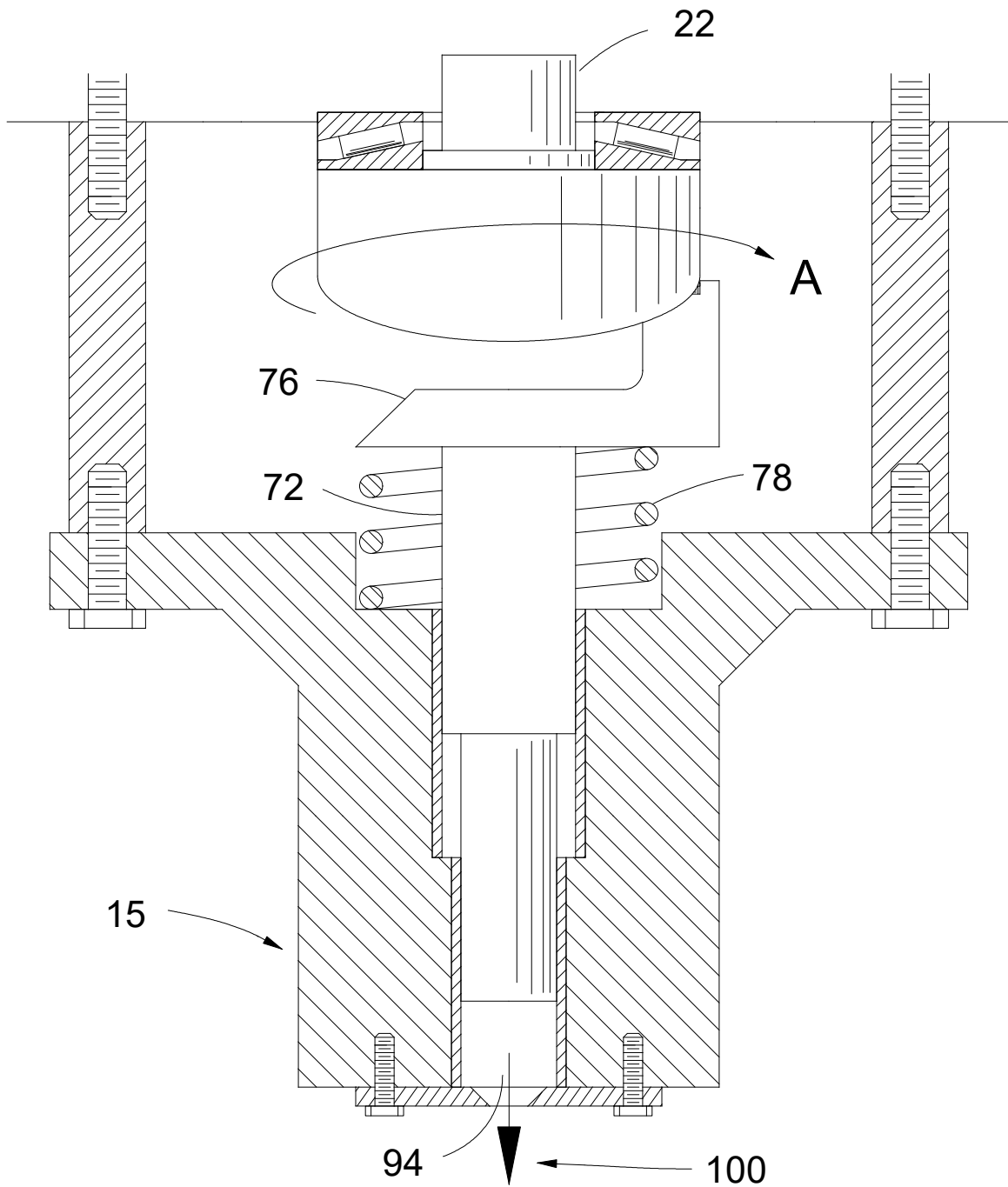


FIG. 11B

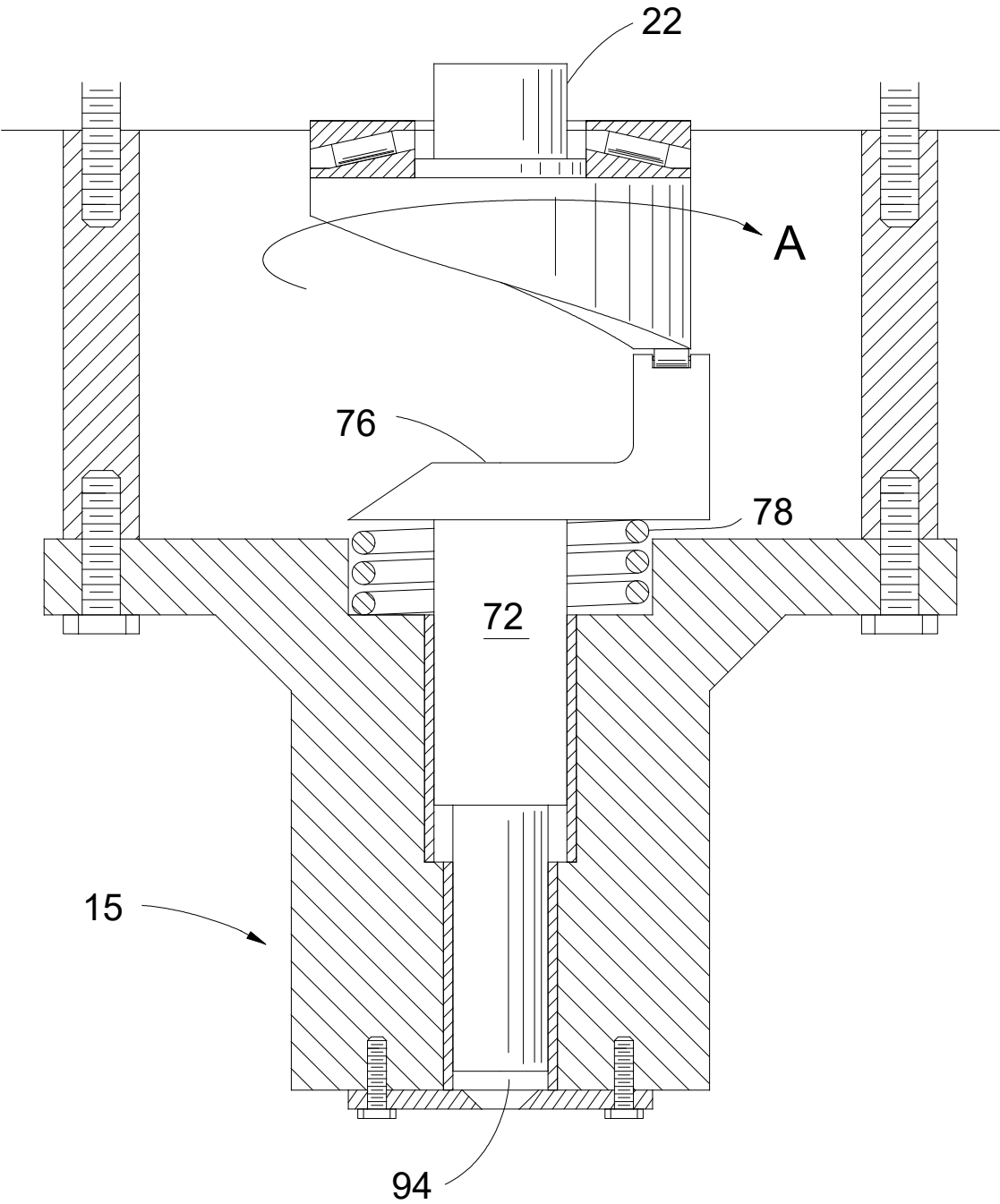


FIG. 11C

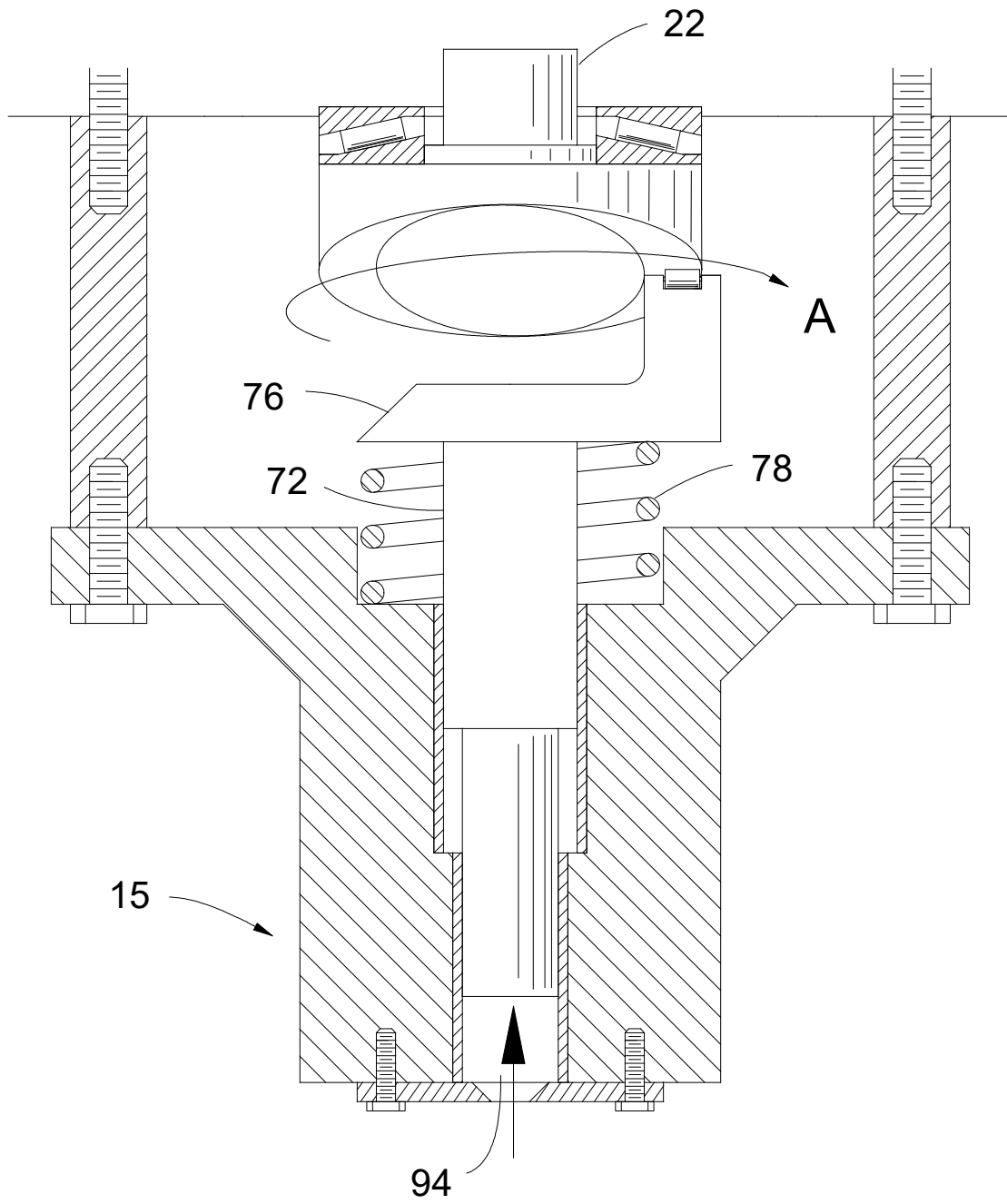


FIG. 11D

15 / 15

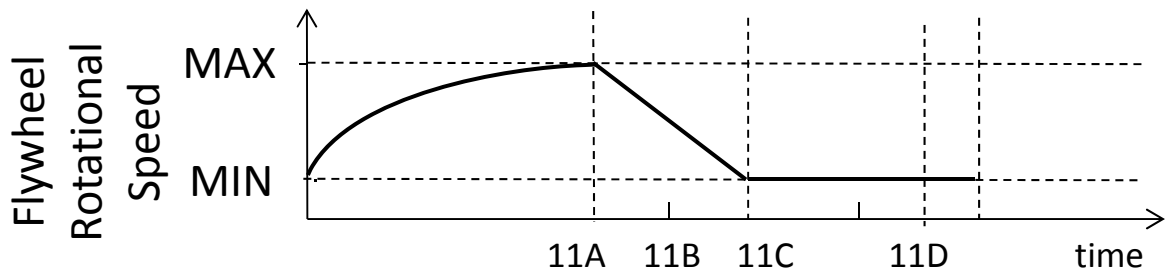


FIG. 12A

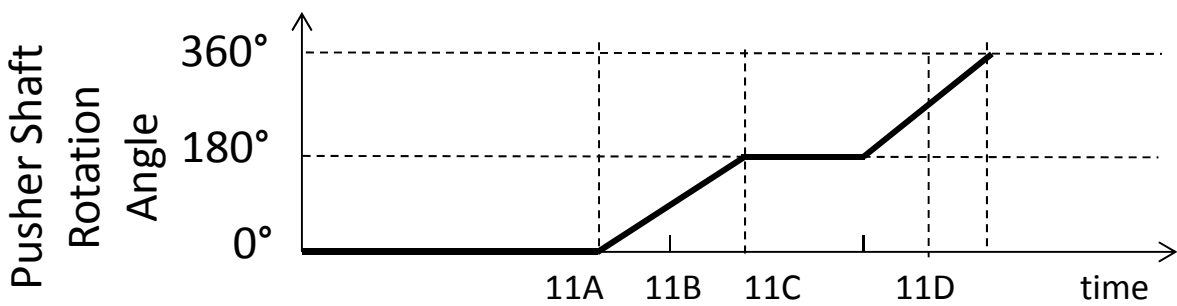


FIG. 12B

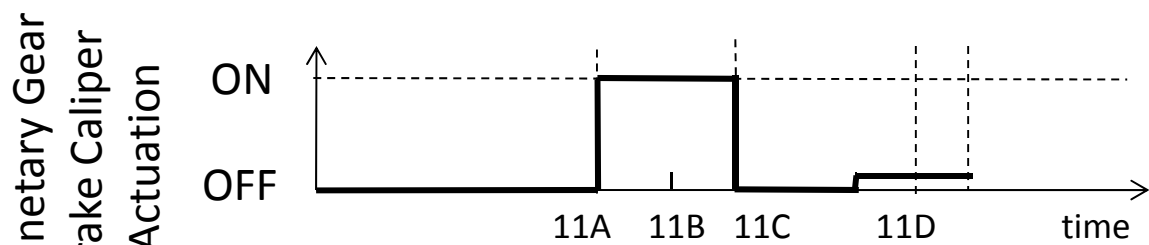


FIG. 12C

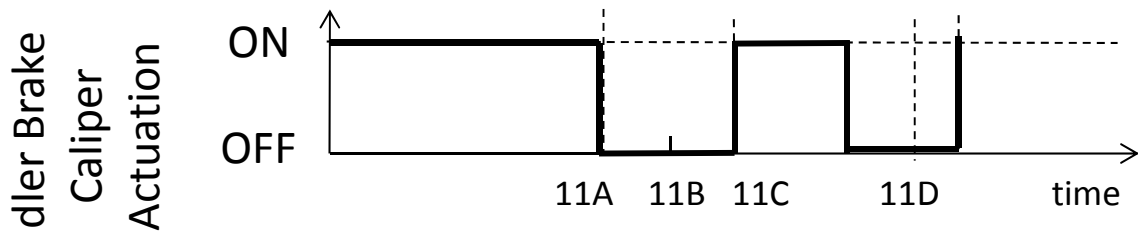


FIG. 12D