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(54) **ADJUSTABLE-DISPLACEMENT GEAR PUMP**

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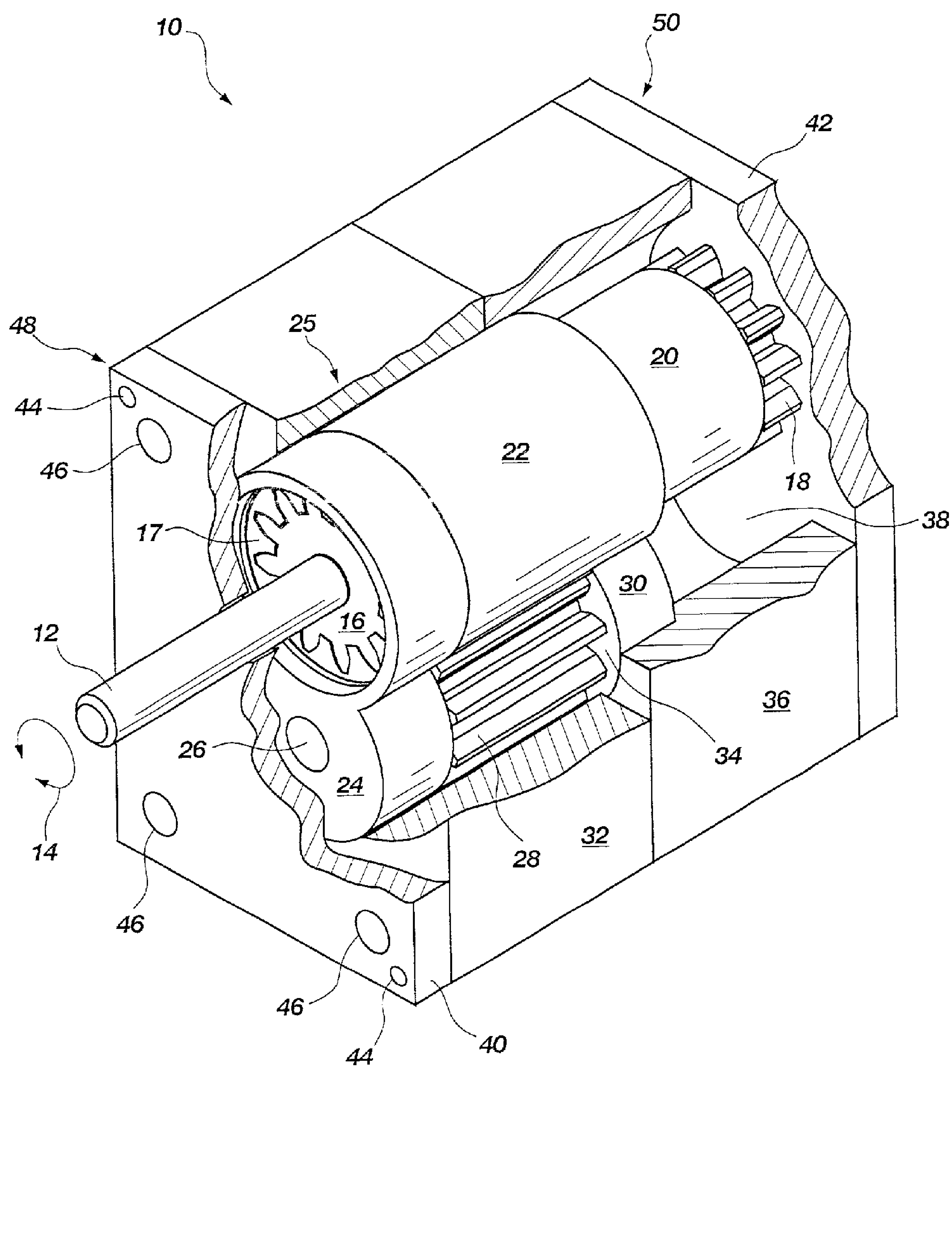
(57) **ABSTRACT**

A positive displacement fluid pump capable of an output flow rate can be varied from a maximum to zero at a given pump rotation speed. The pump is a variable-fluid-displacement-volume, gear pump having complement elements associated with pumping gears to provide end seals for a variable-length pumping chamber. A timing arrangement maintains both pumping gears always in synchronization, whether engaged or fully disengaged (zero pump output). And a follower provides effective sealing with a movable face of an axially-translating pumping gear.



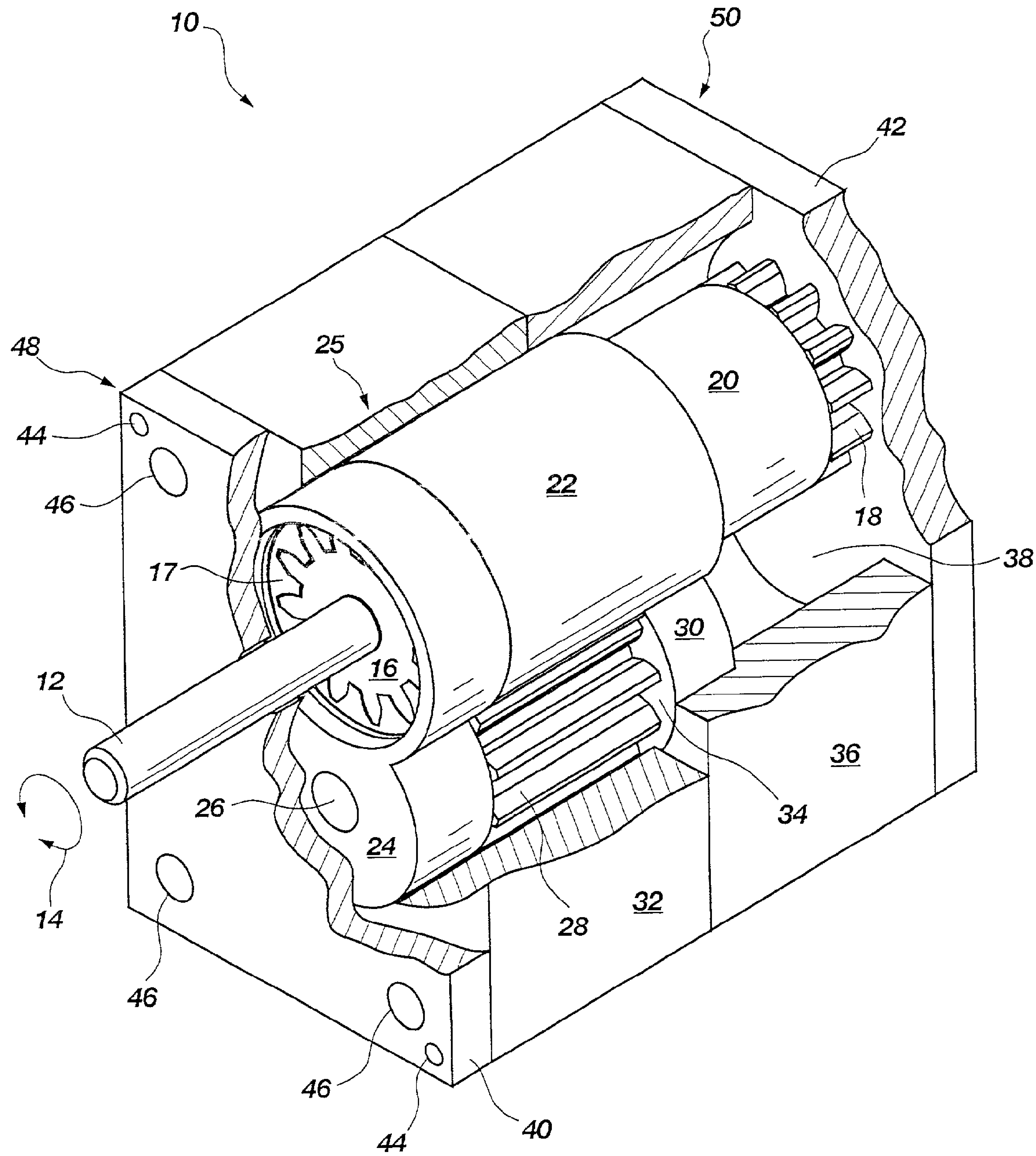

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Fig. 1

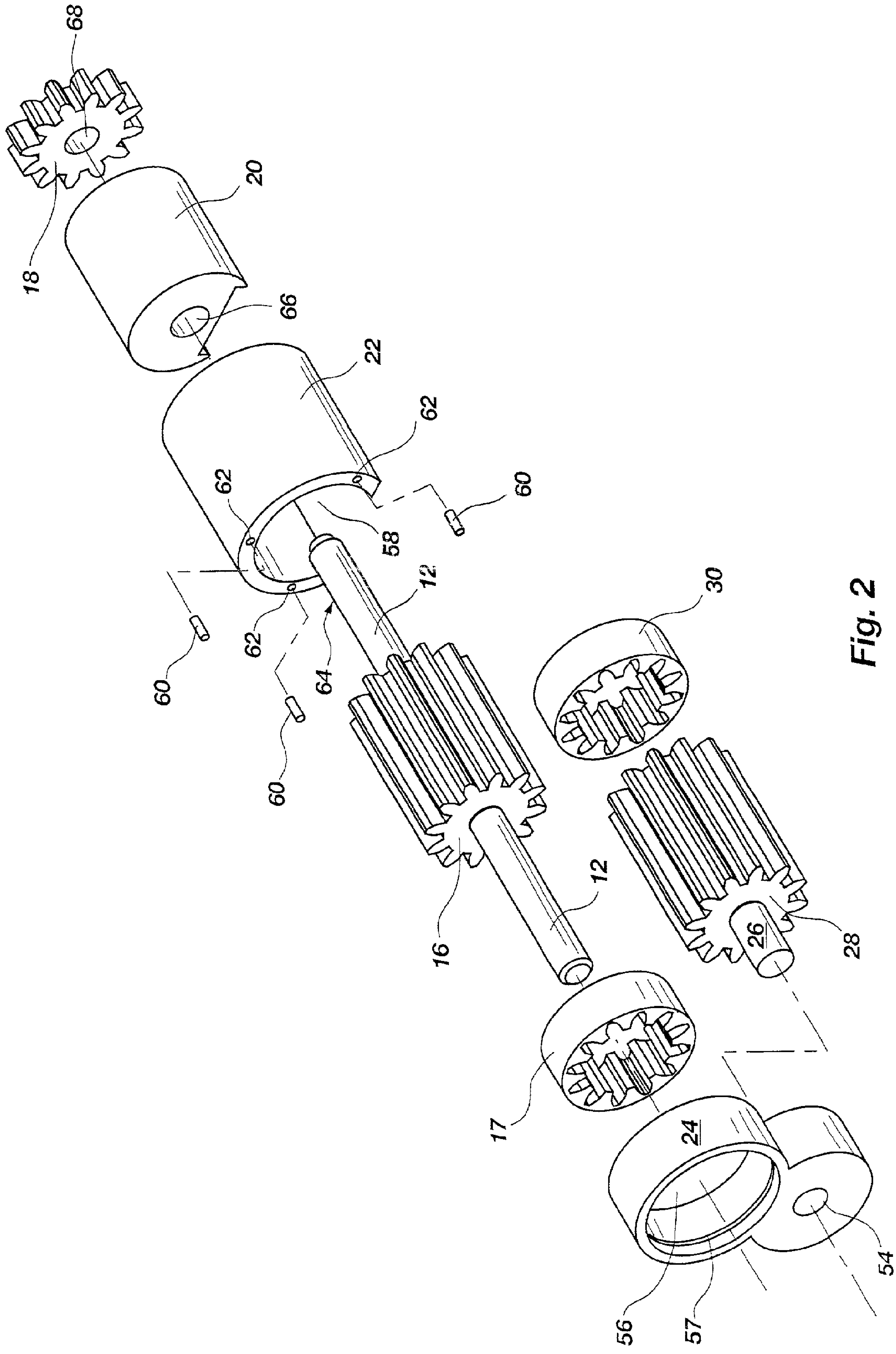
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Fig. 2

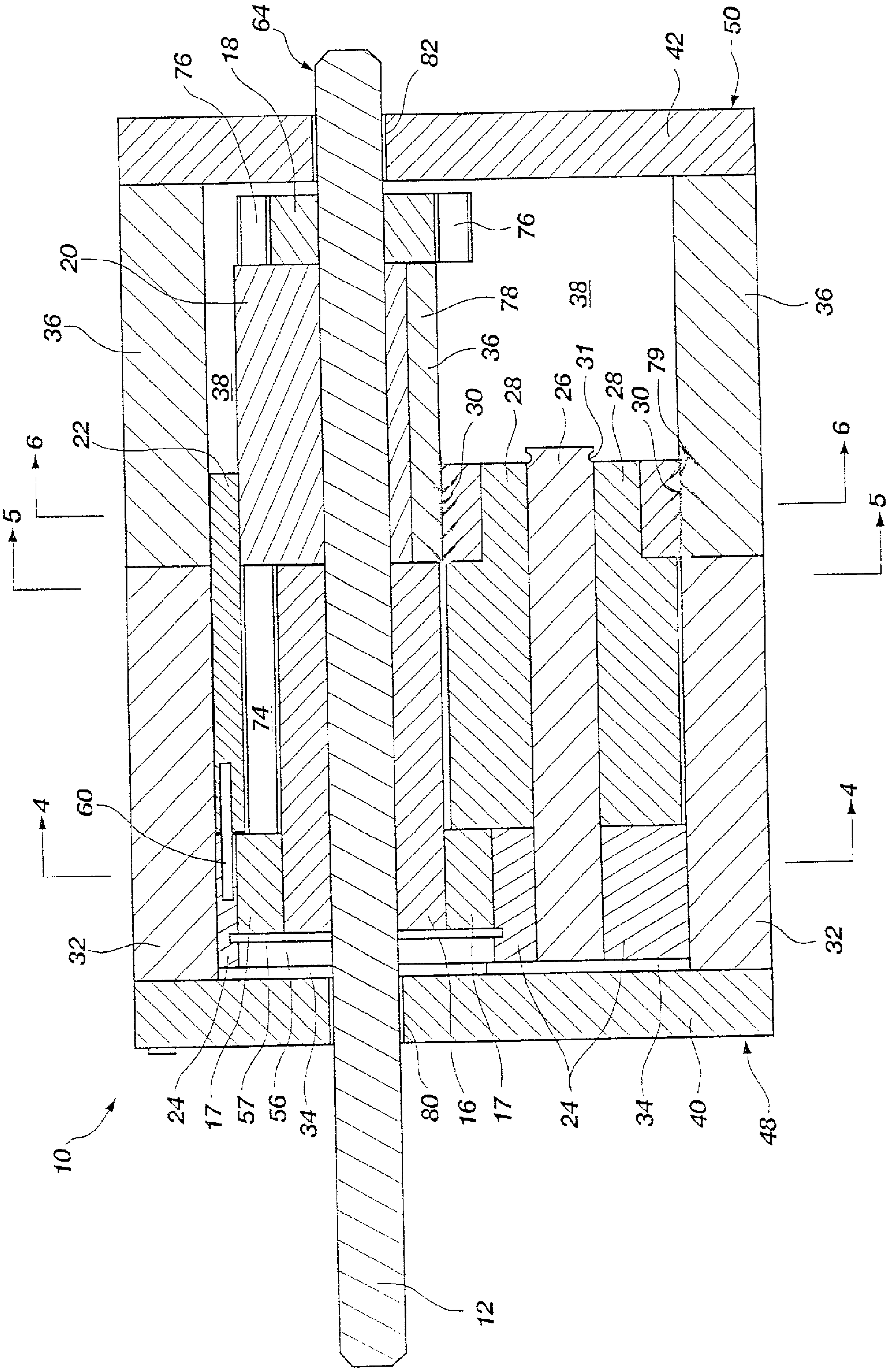
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Fig. 3

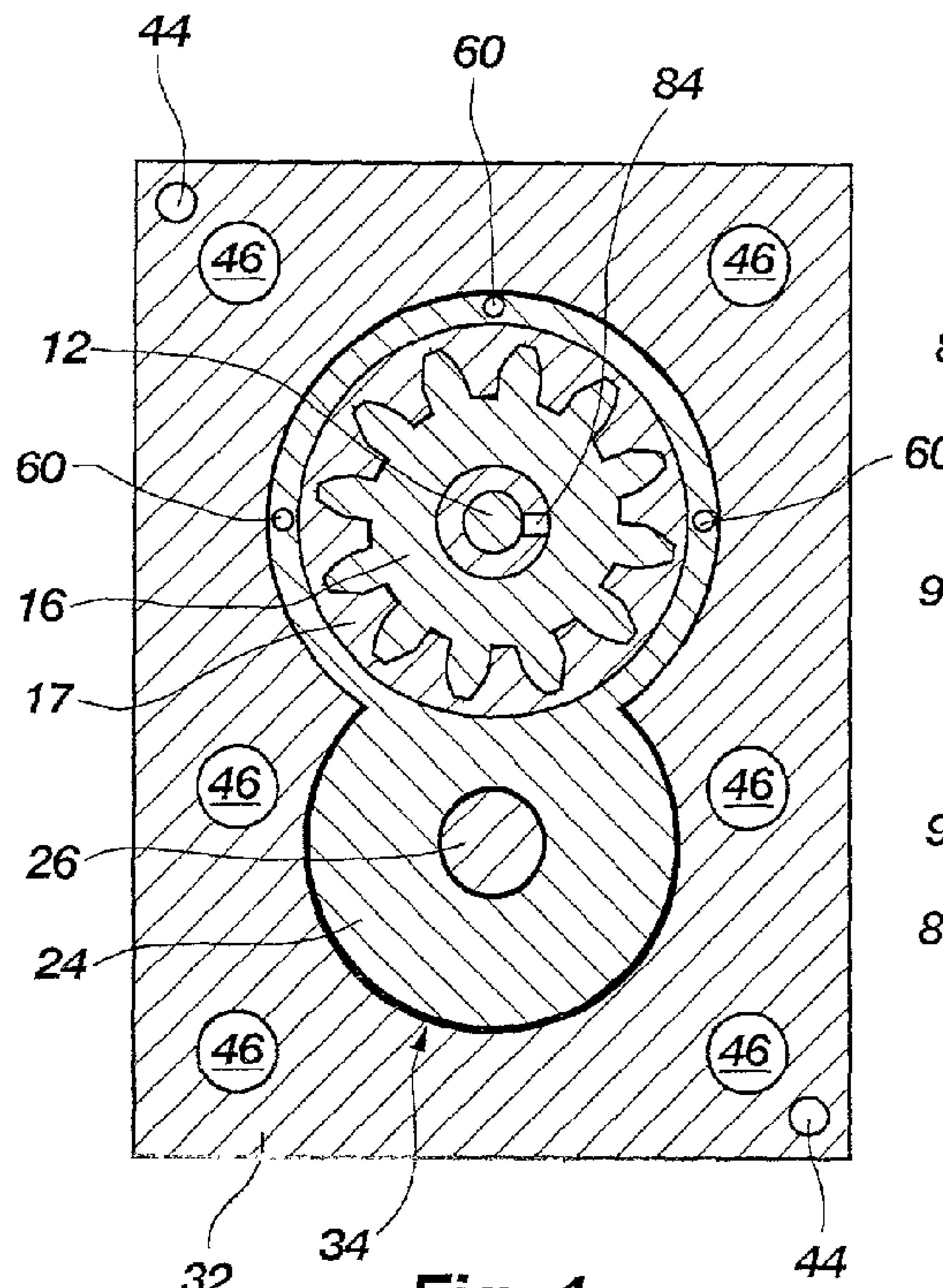

Fig. 4

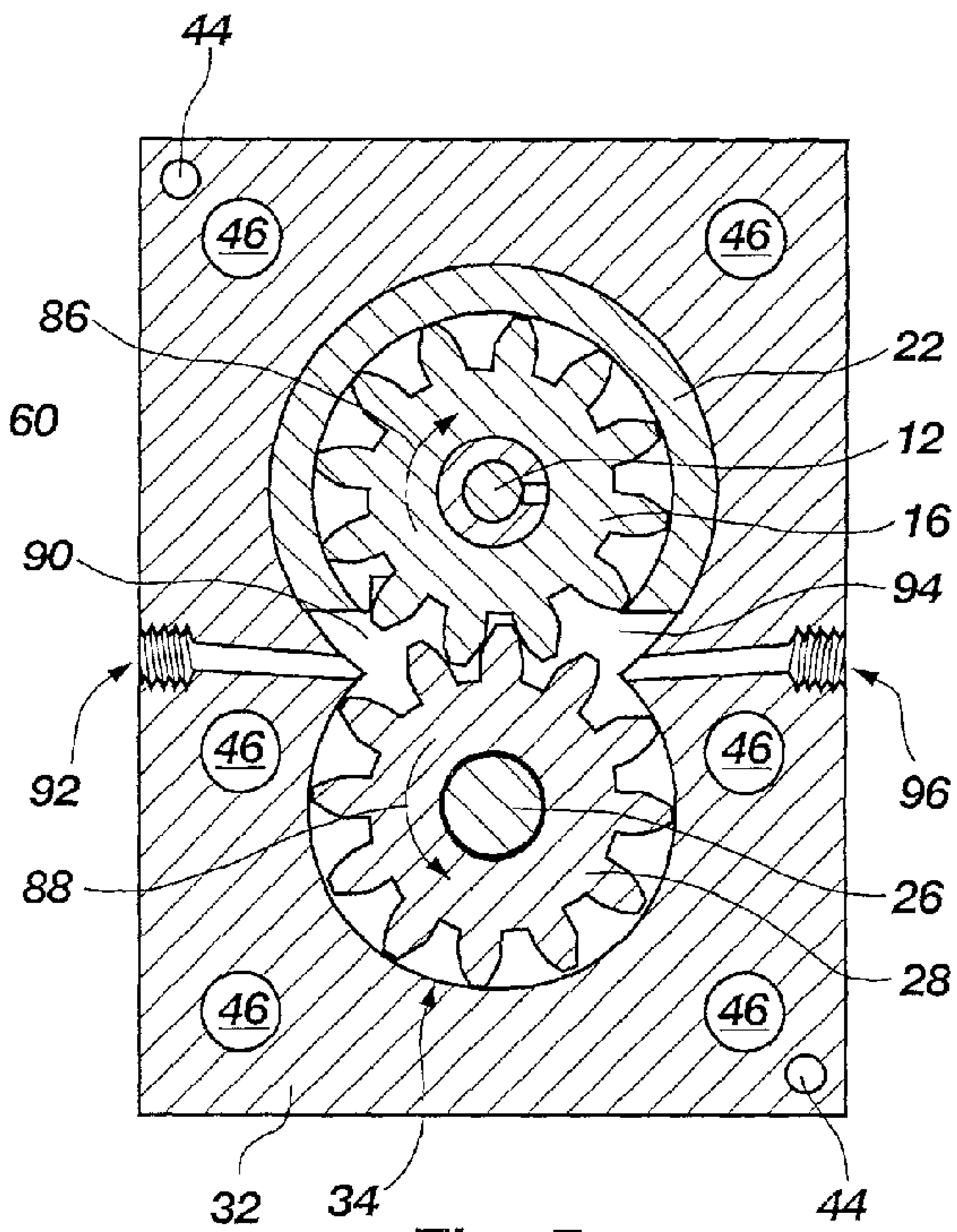

Fig. 5

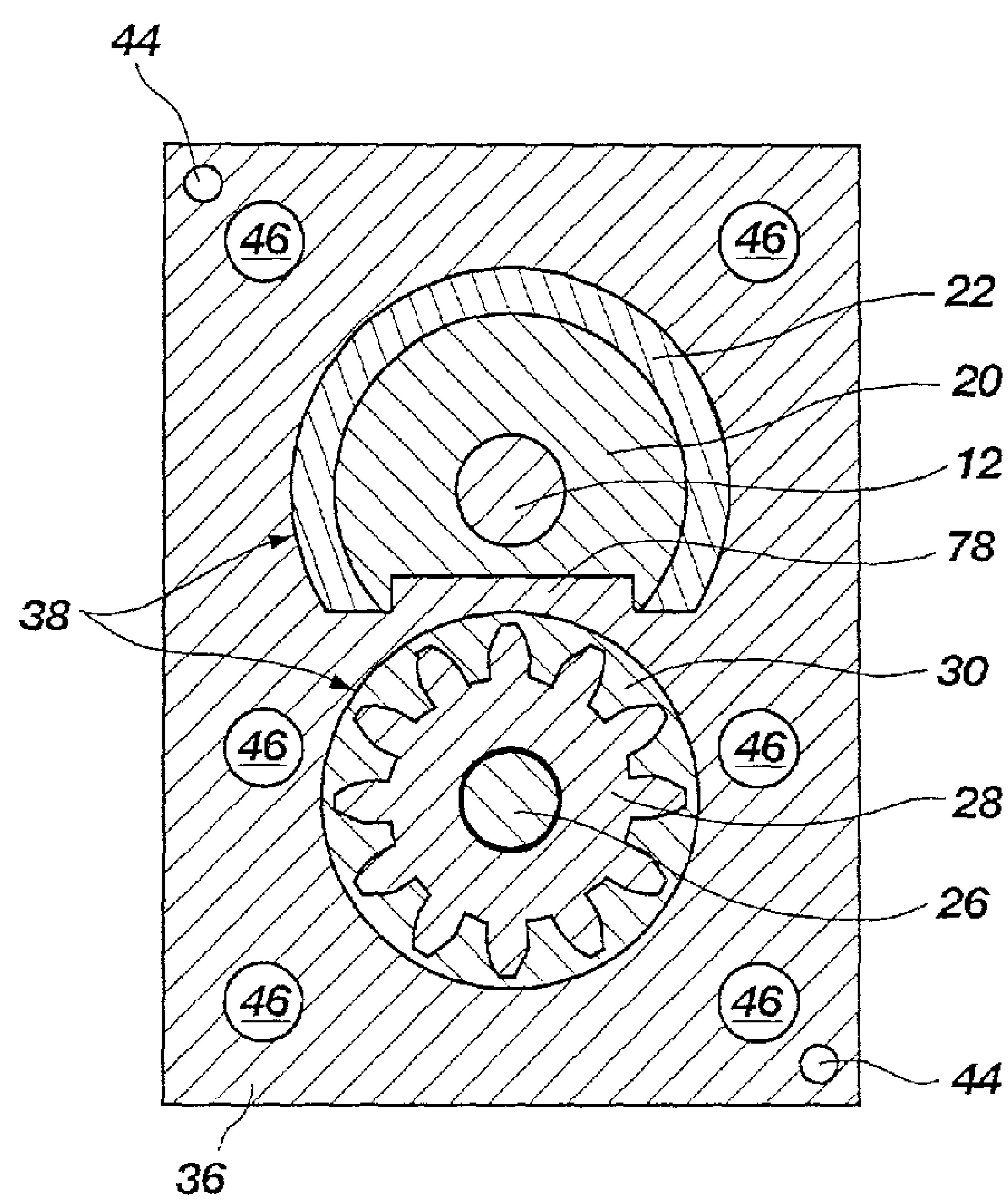

Fig. 6

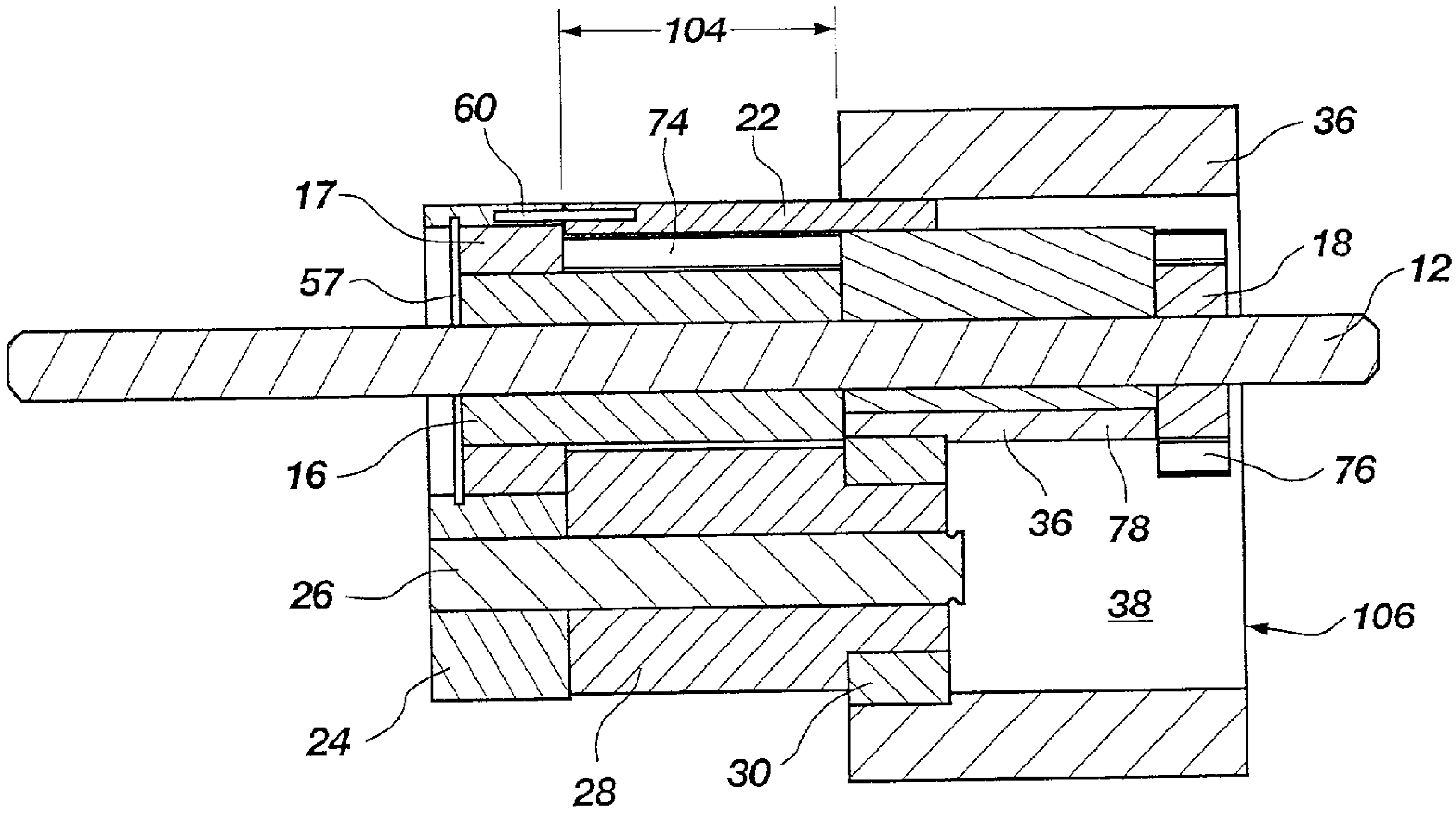
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Fig. 7

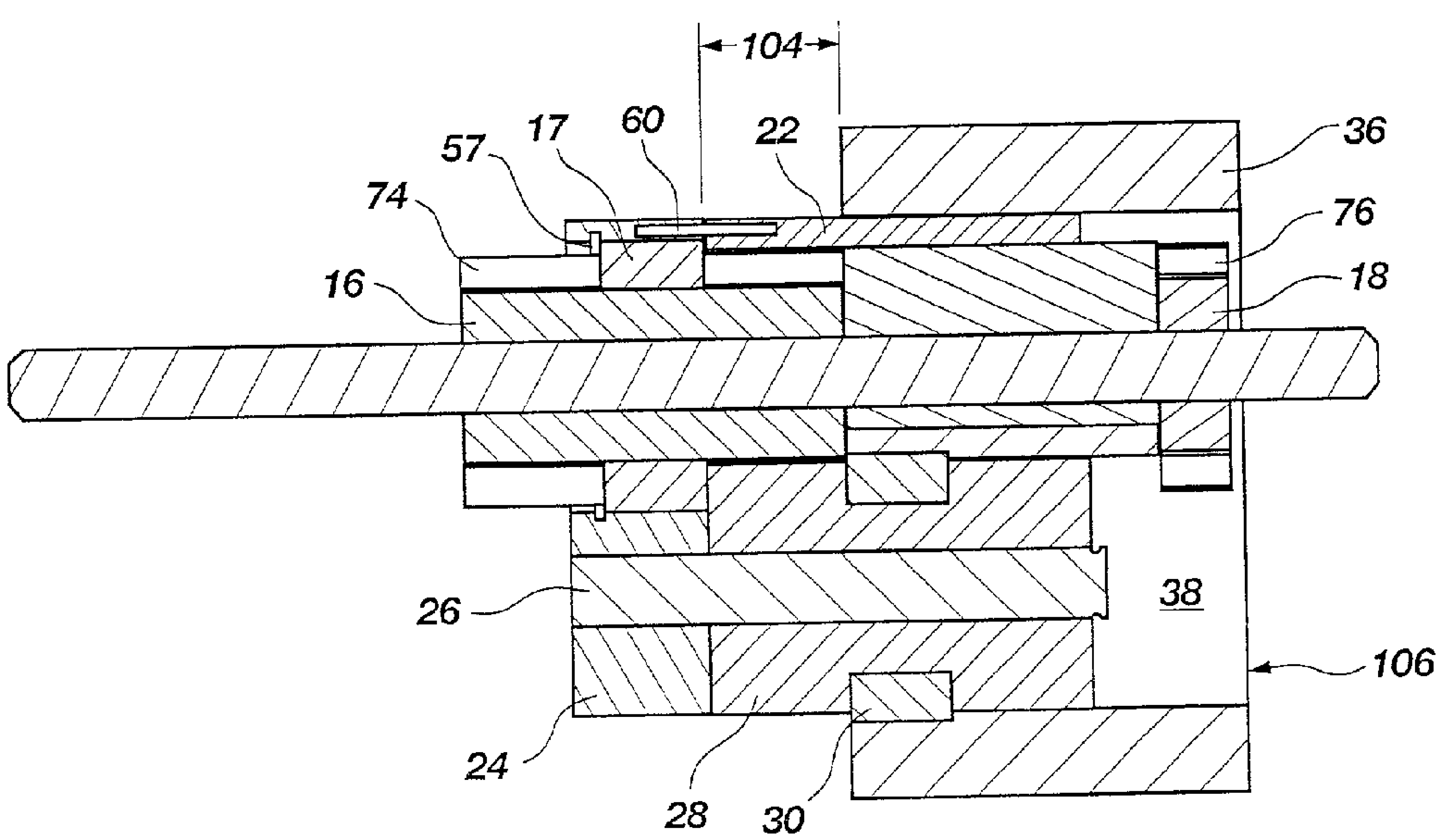
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Fig. 8

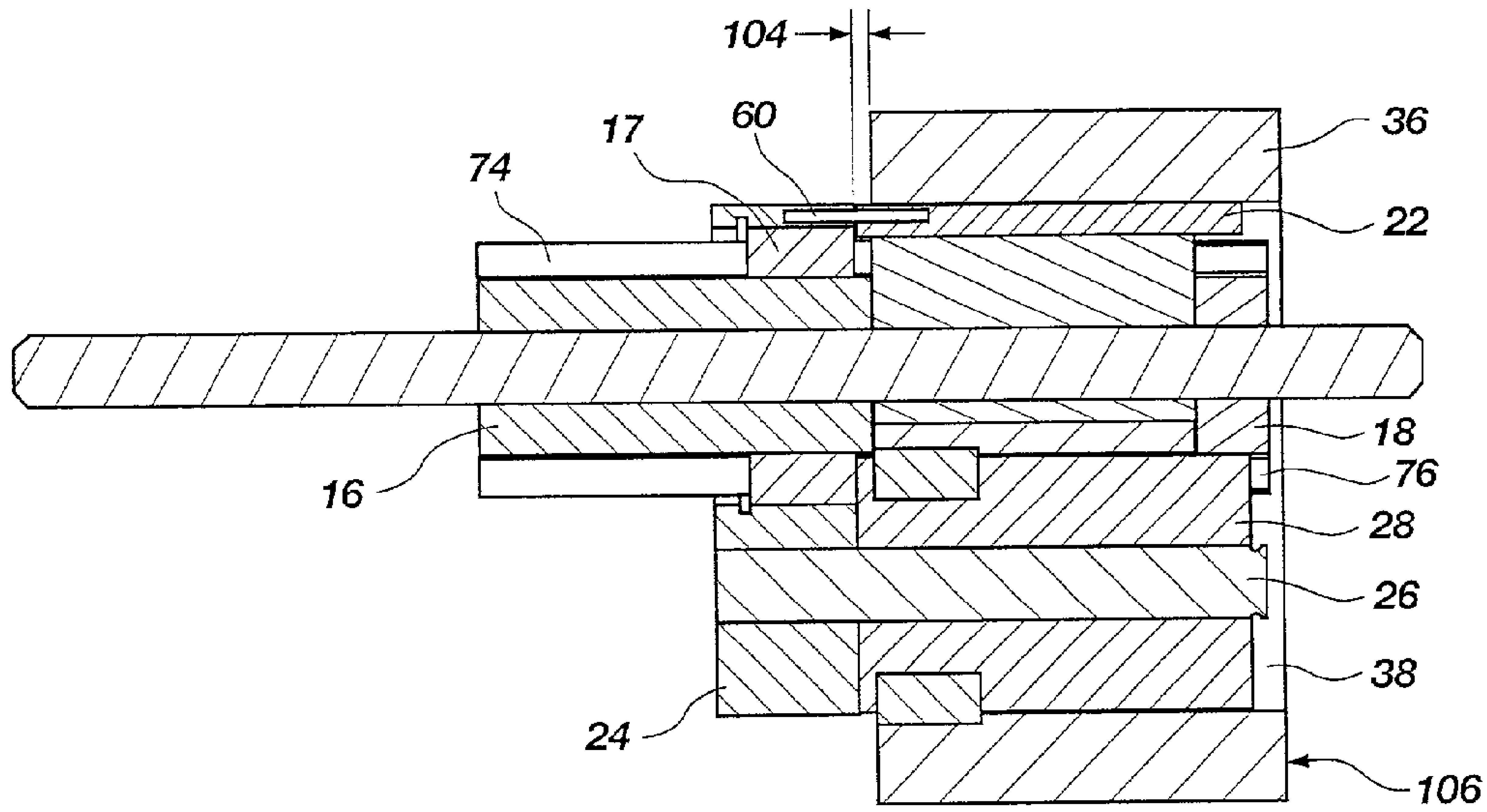
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Fig. 9

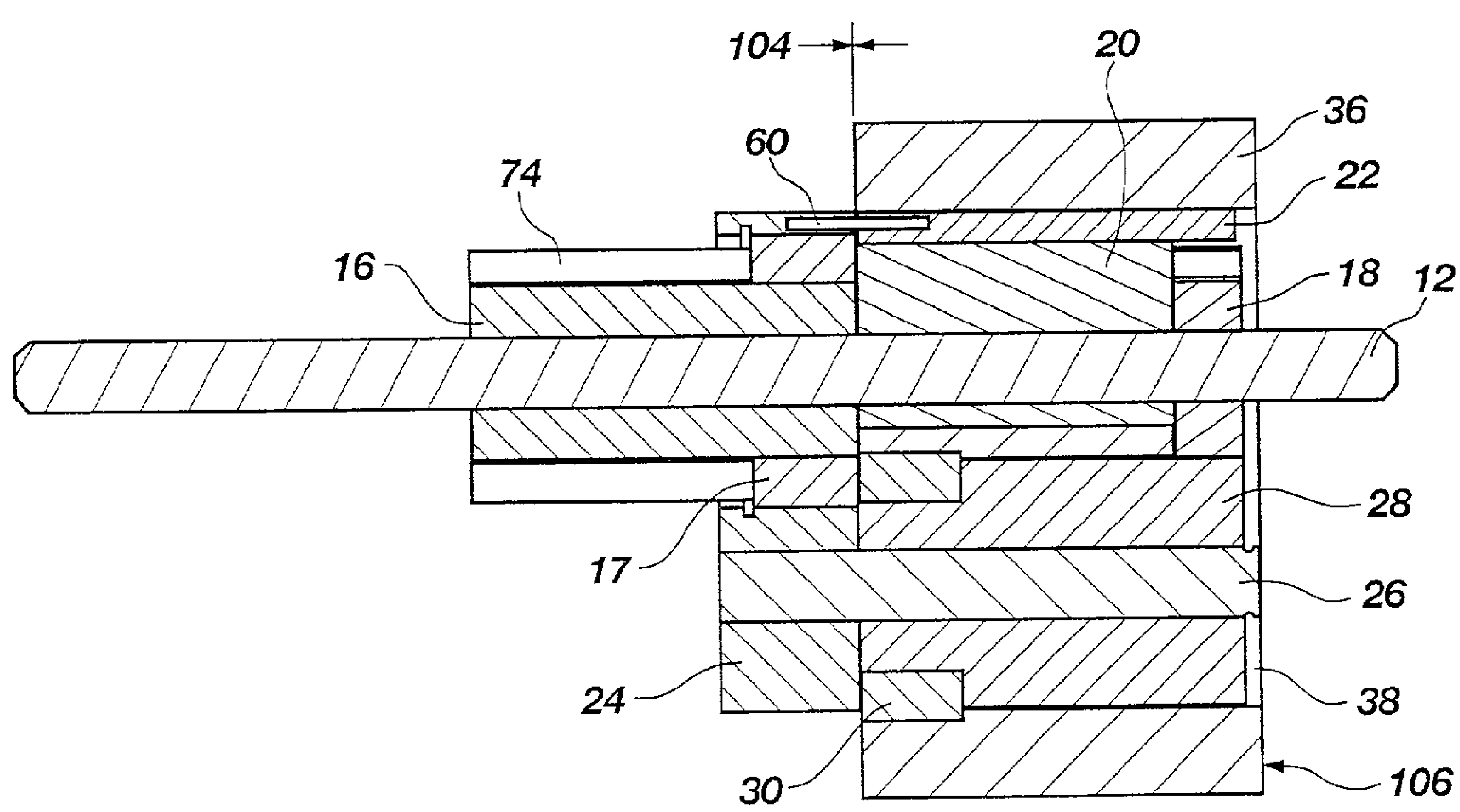
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Fig. 10

ADJUSTABLE-DISPLACEMENT GEAR PUMP

RELATED APPLICATIONS

[0001] This application claims priority to application Ser. No. 60/168,362, filed Dec. 1, 1999, and directed to an ADJUSTABLE-DISPLACEMENT GEAR PUMP.

BACKGROUND

[0002] 1. The Field of the Invention

[0003] This invention relates to hydraulic and other fluid pumps capable of a variable fluid throughput rate with respect to a given input rotational velocity. More particularly, the invention relates to novel systems and methods for controlling the volumetric displacement of gear pumps.

[0004] 2. The Background Art

[0005] Hydraulic pumps have been a key component of all hydraulic actuation systems for many years. Often, a hydraulic pump may be matched with one or more hydraulic motors. The hydraulic pump transfers energy to a working fluid. The hydraulic motor removes energy from the working fluid.

[0006] Currently, diaphragm, as well as vane, pumps are known in the art. Solid impeller pumps are used in circumstances that may not require positive displacement. For positive displacement, three common types of hydraulic pumps are used.

[0007] Vane pumps sweep fluid ahead of a vane mounted on a hub eccentrically positioned within a chamber. Vanes are urged toward an outer surface. Meanwhile, the vanes against the outer surface, are continually closing and opening chambers cyclically. The vane's extension toward the outer surface changes with the eccentricity of the hub with respect to the outer chamber, sweeping fluid in and out of ports positioned in the outer surface, or otherwise accessing the space between the hub and the outer surface.

[0008] Diaphragm pumps and piston pumps operate with one moving wall to draw a selected volume into a chamber. Then, using valves to control input and output ports, the moving wall (piston or diaphragm) of such pumps drives the working fluid into an output line. New developments in piston hydraulic pumps have made piston pumps extremely popular, as evident by the quantity in operation. In one piston pump type, a crank shaft is replaced by a driven shaft and a crank plate or "swash plate" that drives substantially orthogonally extending connecting rods for each piston. Such an apparatus has conventionally been associated with the manufacturer Sundstrand.

[0009] Finally, gear pumps are known in the art. Typically, spur gears sweep the space between teeth thereon through a cavity containing each gear. The cavity typically provides an axially oriented seal at the perimeter of the gear teeth. With the two gears mated together at a central contact position, hydraulic fluid may be sealed against completing a full circle with either gear.

[0010] For example, an input side of gears may move past an input port having access to the gears separating from contact with one another. At the input port location, the gear teeth are moving out of engagement and into their respective, circular, surrounding cavities. Oil (a typical working fluid) is swept with each tooth, filling the space between that tooth and its predecessor tooth moving along a rotary path.

[0011] As the gears each make a full rotation, the gears once again mesh, forcing oil out from between the teeth. Meanwhile, each contact line between the teeth forms a seal prohibiting, or greatly restricting, passage of working fluid back through from the outlet side to the inlet side of the contact region of the gears.

[0012] In the process of operation, a gear pump of a conventional design does not permit any variation in the pump displacement for each revolution of a pump. In more recent times, offsetting pump gears from one another in an axial direction has been postulated as a method of varying pump displacement and throughput. However, sealing the pumping region remains a continuing problem.

[0013] For example, conventional gear pumps maintain sealing between an end of a gear and a wall of a containment chamber. Clearances are typically very close, sufficient to maintain a virtually complete liquid seal. Upon relative axial movement of gears, the mating gears each may have an open cavity at one end thereof. This cavity must be filled or the pump has communication from a high pressure side to a low pressure side of each gear.

[0014] What is needed is a gear pump providing axial displacement of pump gears with respect to one another, with a close follower maintaining an end seal for each gear. A close follower may be a fixed wall for a gear that does not move axially. However, in the case of the gear that moves axially, the follower must follow closely enough to an end face of a moving gear to provide a liquid seal.

[0015] Meanwhile, each gear needs a complement to provide an end seal for a pump cavity having a variable length. That is, to the extent that a region of pump gear engagement is reduced, a liquid seal needs to be provided in the axial direction of each gear to close off the engaged (fluid driving) portion of the gears from the non-engaged portion of the gears.

[0016] A complement is needed to fill in the space between teeth in the disengaged regions of the gears. A variable displacement gear pump having close followers that always remain positioned sealingly proximate the end of a moving gear face, and having a complement on each gear to fill in the voids between teeth in order to present pseudo-walls defining a length of the active cavity (engaged or pumping region of a gear) is needed. Such a configuration has not been found in the prior art. A great advance in the art would provide an ability to vary displacement of a gear pump through a full range from zero (idling, no pumping occurring) at operational rotational speeds, to 100 percent of a maximum capacity when the gears are engaged to their maximum extent.

[0017] In the art, Applicant has not found any operable design for a gear pump capable of variable displacement, varying between no output flow and a full output flow, at a given pump rotational rate. Moreover, such a performance characteristic has not been found for any control mechanism for a gear pump.

[0018] An additional desired characteristic in a variable displacement pump would provide for a reduced amount of energy being applied to the working fluid during conditions when the pump is configured for reduced output. Producing a reduced overall pump output by redirecting pump output, such as in a load bypass or recirculating circuit, still undesirably applies energy from the pump to the working fluid. The working fluid is continually undergoing work in such a recycling pump arrangement, and thereby suffers from premature wear. This work creates unnecessary heat and draws unnecessary energy from the source of the rotational power. It would be an advance in the art to provide a pump capable of: (1) a variable output; (2) a reduced stress on the working fluid; and (3) more energy efficient during pump operation under low flow, or no flow, conditions.

[0019] Moreover, it would be an advance in the art to provide such a functionality in a gear pump by providing a timing gear that maintains synchronization between the two pumping gears, even when the pumping gears are not engaged. Thus, it would be an advance in the art to provide a variable displacement gear pump having complements associated with gears to provide end seals, a timing arrangement for maintaining both gears always in synchronization, whether engaged or fully disengaged (zero pump output), and a follower that remains close enough to a movable face of an axially-translating gear of a gear pump to provide effective sealing of the working fluid from passing therebetween.

BRIEF SUMMARY OF THE INVENTION

[0020] In accordance with the invention as embodied and broadly described herein, an apparatus and method are disclosed in suitable detail to enable one of ordinary skill in the art to make and use the invention. In certain embodiments, an apparatus and method in accordance with the present invention may include a case or pump housing, a pair of mated, rotating, mutually engaging gears. Both gears having a complement that substantially seals a variable length end portion of the gear from an engaged portion of the gear.

[0021] The gear pump may have followers, including solid members through which supporting axles of each respective gear may pass, as appropriate. A follower typically maintains a substantially complete, operational, fluid seal between a portion of itself and an end face of a pump gear. A follower that always maintains an effective seal between a portion of itself and a corresponding gear end face may be characterized as a close follower.

[0022] The apparatus may include a timing gear located remotely from an axially fixed gear. The timing gear maintains synchronization between the axially translating gear and the axially fixed gear. Such synchronization allows the axially translating gear to engage selectively with the axially fixed gear.

[0023] An exemplary adjustable displacement gear pump is capable of a variable fluid output between a maximum flow rate and zero flow at a constant drive shaft speed. One embodiment provides complement elements associated with a pair of pumping gears, the complement elements being portions of end seals for a pumping chamber having a variable length between a maximum length and zero length. The chamber length may be characterized as a distance between a proximal pumping chamber end seal and a distal pumping chamber end seal.

[0024] Also present is a timing arrangement for maintaining both pumping gears always in synchronization, whether the pumping gears are engaged or fully disengaged. A stationary close follower provides effective sealing with a fixed face of an axially fixed gear. A movable close follower provides effective sealing with a movable face of an axially translating pumping gear. A means to vary the pumping chamber length from a maximum length to a zero length provides a way to control pump output.

[0025] A pump may further include a metering valve arrangement between structure of a follower and structure associated with fluid input and output ports. The metering valve would operate to further control pump output during conditions of reduced pump chamber length.

[0026] One presently preferred timing arrangement uses a timing gear having a similar cross-section to a first of the pumping gears. The timing gear may typically be oriented in axial alignment, maintained in meshing agreement with, and spaced apart axially from the first pumping gear. The meshing agreement allows a second of the pumping gears, while meshed with the first pump gear, to be axially translated to mesh with the timing gear. Whenever the second gear is axially translated out of mesh with the first gear, the timing gear maintains synchronization of the gears such that the second gear may be axially translated back into mesh with the first gear. A timing arrangement may even be located exterior to a pump housing. Any convenient way to maintain synchronization between pumping gears may be adequate for the practice of certain embodiments of this invention.

[0027] The first chamber end seal typically includes a distal end of a first complement and structure associated with a movable close follower. The movable, close follower substantially seals with a proximal end of a first pumping gear. The first complement is typically carried by structure associated with the movable close follower for axial translation in substantially sealed sliding engagement with an exterior surface of a second pumping gear.

[0028] The second chamber end seal includes a stationary close follower. A close follower may be one of various structures, such as a proximal end of a sleeve center, a portion of a proximal end of a housing bridge structure, and a portion of a proximal end of a second complement. The second complement is typically fixed in place axially in rotatable engagement with structure of a pump housing and in slidable concentric engagement with the first gear. The second complement functions to allow axial translation of the first gear while substantially maintaining a fluid seal therebetween.

[0029] One embodiment of a pump, according to the present invention, may typically include means to vary the pump chamber length from a maximum length to zero length. One way to accomplish changes in chamber length may include applying differential hydraulic pressure between proximal and distal ends of a piston structure to control axial displacement of the first pumping gear. Suitable piston structures may generally include a follower assembly carrying the first gear.

BRIEF DESCRIPTION OF THE DRAWINGS

[0030] The foregoing and other features of the present invention will become more fully apparent from the following description and appended claims, taken in conjunction with the accompanying drawings. Understanding that these drawings depict only a typical embodiment of the invention and are, therefore, not to be considered limiting of its scope, the invention will be described with additional specificity and detail through use of the accompanying drawings in which:

[0031] **FIG. 1** is a perspective view in elevation, partially in section, of an apparatus in accordance with the invention;

[0032] **FIG. 2** is an exploded, perspective assembly view of the internal operating elements of the apparatus of **FIG. 1**;

[0033] **FIG. 3** is a side, elevation, cross-sectional view taken through a midplane of the apparatus of **FIG. 1**;

[0034] **FIG. 4** is a front, cross-sectional, elevation view taken through the plane **4-4** indicated in **FIG. 3** and looking in the direction of the arrows;

[0035] **FIG. 5** is a front, cross-sectional, elevation view taken through the plane **5-5** indicated in **FIG. 3** and looking in the direction of the arrows;

[0036] **FIG. 6** is a front, cross-sectional, elevation view taken through the plane **6-6** indicated in **FIG. 3** and looking in the direction of the arrows;

[0037] **FIG. 7** is side, elevation, cross-sectional view of the internal operating elements of the apparatus of **FIG. 3**, where the operating elements are arranged in an approximately full flow configuration;

[0038] **FIG. 8** is side, elevation, cross-sectional view of the internal operating elements of the apparatus of **FIG. 3**, where the operating elements are arranged in an approximately half-capacity flow configuration;

[0039] **FIG. 9** is side, elevation, cross-sectional view of the internal operating elements of the apparatus of **FIG. 3**, where the operating elements are arranged in a greatly reduced flow configuration;

[0040] **FIG. 10** is side, elevation, cross-sectional view of the internal operating elements of the apparatus of **FIG. 3**, where the operating elements are arranged in a zero flow configuration.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0041] It will be readily understood that the components of the present invention, as generally described and illustrated in the Figures herein, could be arranged and designed in a wide variety of different configurations. Thus, the following more detailed description of embodiments of the system and method of the present invention, as represented in **FIGS. 1 through 10**, is not intended to limit the scope of the invention. The scope of the invention is as broad as claimed herein. The illustrations are merely representative of certain presently preferred embodiments of the invention. The invention will be best understood by reference to the drawings, wherein like parts are designated by like numerals throughout.

[0042] Those of ordinary skill in the art will, of course, appreciate that various modifications to the details of the Figures may easily be made without departing from the essential characteristics of the invention. Thus, the following description of the Figures is intended only by way of example, and simply illustrates certain presently preferred embodiments consistent with the invention as claimed.

[0043] Referring to **FIG. 1, a** pump assembly, generally indicated at **10**, is illustrated. The pump **10** typically includes a drive shaft **12**, which may be rotated in either direction, as indicated by circumferential double-headed arrow **14**. In the pump **10**, reversing the direction of rotation of the drive shaft **12** merely reverses the direction of fluid flow through the pump **10**. That is, intake and output ports (not shown) of the pump **10** are determined by the direction of rotation of the drive shaft **12**.

[0044] As illustrated in **FIG. 1**, the drive shaft **12** carries a pump gear **16** in driving relation at an axially fixed position along the drive shaft **12**. A complement **17** fits the toothed surface of gear **16** in a substantially sealed, slidable, relation. Taken together, the complement **17** and gear **16** form a substantially solid circular cross-section. Spaced apart axially from the gear **16**, and also carried in driving relation by the drive shaft **12**, is a timing gear **18**. Gears **16** and **18** may have identical cross-sections and are mounted in meshing alignment on the drive shaft **12**.

[0045] A sleeve center **20** receives the drive shaft **12** in a sealed and load-bearing relationship, and also serves as a spacer between the gears **16** and **18**. The sleeve center **20** has a maximum radial dimension in agreement with a maximum radial dimension of the gears **16** and **18**. Alternatively, the sleeve center may be a solid extension of a receiver housing **36**. A sleeve **22** is constructed to circumscribe and slide over the sleeve center **20**. The inside bore surface of the sleeve **22** provides a wiping, sealing surface for teeth carried by the gear **16**. A follower **24** and the sleeve **22** together form a follower assembly **25**.

[0046] The follower **24** provides a structural base from which to cantilever an idler axle **26**. The axle **26** is typically fixed in position within the follower **24** by a press-fit, although other mounting methods are also conceivable. An idler gear **28** is carried in a rotatable bearing relationship by the axle **26**. A portion of the distal face of the follower **24** forms a seal with the proximal end of the idler gear **28**. Therefore, the follower **24** is a close follower to the idler gear **28**.

[0047] Gears **16** and **28** have meshing tooth profiles, and may typically be identical in cross-section. Gears **16** and **28** need not be identical, although such a configuration simplifies manufacturing by reducing the pump parts count, and reducing costs.

[0048] A gear complement **30** receives the idler gear **28** in an axially sliding relation, and provides a substantial seal on the idler gear **28** surface against fluid flow in an axial direction. A slot **31 (FIG. 3)** may be provided on the distal end of axle **26**. The slot **31** functions to hold a split ring (not shown), and maintain the gear **28** in position on the axle **26**. Other retaining structure, such as keys, sleeves, pins, splines, and so forth, may also be conceivable.

[0049] Continuing to refer to **FIG. 1, a** sender housing **32** may be essentially a solid block having an internal sender cavity **34**. In the illustrated embodiment, the cavity **34** extends completely through the housing **32**. It may be formed by two parallel, intersecting bores. The resulting cavity **34** has a cross-section that approximates a numeral **8**, or is peanut shaped. The follower assembly **25** is received in the cavity **34** in an axially sliding, substantially sealed relationship.

[**0050**] The receiver housing **36** is similar to the sender housing **32** in that it also may be formed by two intersecting bores to form a receiver cavity **38**. However, additional dividing structures including the sleeve center **20** and others not shown in **FIG. 1** are also present in the receiver cavity **38**. The receiver cavity **38** receives the sleeve **22** in an axially sliding, substantially sealed relationship. As the follower assembly **25** is moved, from the illustrated position toward the receiver housing **36**, the gear **28** correspondingly moves into the receiver cavity **38**. The receiver cavity **38** may be constructed to provide a portion designed to receive the gear **28** in an axially slidable, bearing relation.

[**0051**] For convenience, the pump **10** and its elements will be described with reference to orientations defined by a proximal end **48** and a distal end **50** of the pump **10**. The sender housing **32** is axially sealed on the proximal end **48** of the pump **10** by a cap plate **40**. The distal end of the sender housing **32** seals against a proximal end of the receiver housing **36**. The distal end of the receiver housing **36** is axially sealed by a cap plate **42**.

[**0052**] A set of alignment holes **44**, passing completely through both cap plates **40** and **42** and housings **32** and **36**, in the illustrated embodiment, are provided to assist in assembly of the pump **10**. Another set of holes **46**, also passing completely through both cap plates **40** and **42** and housings **32** and **36**, receive tension bolts (not shown). The tension bolts carry the axial load required to maintain a fluid seal between all of the pump housings (**32** & **36**) and cap plates (**40** & **42**).

[**0053**] Referring to **FIG. 2**, additional details of construction of the pump **10** are illustrated. The follower **24** has a hole **54** in which is received the axle **26**. A bore **56** in the follower **24** receives the complement **17** in a substantially sealed, rotating relationship. The complement **17** is restrained from axial displacement from the bore **56** by a suitable retainer, such as a snap ring (not shown) located in a groove **57**. The rotatable seal prevents significant fluid escape from the sender cavity **34** (**FIG. 1**) between the bore **56** and the complement **17**.

[**0054**] The inner surface of the complement **17** fits in sealing relation to the toothed surface of the gear **16**. The complement **17** is sized to have a thickness to fit between the snap ring and the distal face of the follower **24**. Such a thickness provides a sealing surface on its distal face being oriented in a plane at the distal face of the follower **24**.

[**0055**] As illustrated, a portion of the proximal end of the sleeve **22** maintains the complement **17** in registration between the retaining snap ring at the groove **57** and the distal face of the follower **24**. The follower **24**, in combination with the complement **17** and a cross-section through the gear **16**, essentially forms a sliding and sealing plug in the sender cavity **34**. The proximal end of a pumping chamber (**FIG. 7**, denoted by area **104**) is defined by the alignment and seal provided by the distal ends of the follower **24** and the complement **17**.

[**0056**] Continuing to refer to **FIG. 2**, the interface between the gear **16** and the sleeve **22** may be readily visualized. A bore **58** is sized to fit the perimeter of the gear **16**. The bore **58** receives teeth of the gear **16** in a sliding, wiping, sealed relation. The sleeve center **20** also is sized to slidingly seal against the bore **58** of the sleeve **22**.

[**0057**] One way to attach the sleeve **22** and the follower **24** is illustrated as a set of pins **60**. In the illustrated apparatus, the pins **60** may be press-fit or otherwise secured to a depth of about half their length into a set of receiving holes **62** in the sleeve **22**. The remaining portions of the pins **60** are received in a suitable supporting relation (e.g. a press fit) into corresponding receiving holes (not shown) in the follower **24**. Alternate methods for forming the resulting structure may be used, including welding the components together, or machining the follower assembly **25** (**FIG. 1**) from solid stock.

[**0058**] Referring now to **FIG. 3**, additional structural details of the construction of the pump **10** will be described. **FIG. 3** is a side elevation view of a cross-section taken approximately through a midplane of the pump **10**. The drive shaft **12** drives the gear **16**, which in turn drives the idler gear **28**. A single gear tooth face **74** located at the top of the gear **16** is visible in the Figure. A corresponding gear tooth face **76** is illustrated at the top of the timing gear **18**. **FIG. 3** illustrates how the gears **16** and **18** are oriented in meshing alignment, with gear teeth of both gears being located at identical azimuths relative to the drive shaft **12**. In the configuration depicted in the illustration, a second gear tooth **76** is also visible at the bottom of the gear **18**. A tooth of the gear **28** (shown in cross-section) obscures most of the tooth located at the bottom of gear **16**.

[**0059**] Still referring to **FIG. 3**, the receiver housing **36** is shown to have a bridge element **78** that serves to form a sealing and supporting structure. To facilitate manufacturing, a bridge element **78** may be formed as an insert, press-fit or otherwise fastened to the receiver housing **36**. A portion of a proximal end of the bridge **78** receives the complement **30** in rotating and sealing relation.

[**0060**] The complement **30** is seen, in the illustration, to be prevented from axial motion by a shoulder **79** in the proximal end of the housing **36** (including the bridge element **78**) in combination with the distal end of the sender housing **32**. The shoulder **79** prevents motion of the complement **30** toward the distal end of the pump **10** and is spaced from the proximal end of the receiver housing **36** by the thickness of the complement **30**.

[**0061**] The gear **28** may slide axially through the complement **30** while substantially maintaining a fluid seal therebetween. It may now be realized that the bridge element **78** may have a length, extending from the proximal end of the receiver housing **36**, that is shorter than illustrated. A minimum length for the bridge element **78** may be selected to be sufficient to provide a portion of the rotatable seal between the receiver housing **36** and the complement **30** at the proximal end of the receiver housing **36**. However, the bridge element **78** may reasonably have a minimum length equal to the axial thickness of the complement **30**. The complement **30** may be sufficiently retained axially by the shoulder **79** in the receiver housing **36** separate from any supporting contribution from the bridge element **78**.

[**0062**] The proximal face of the complement **30**, a cross-section through the gear **28**, and the proximal face of the receiver housing **36** cooperatively form a substantially planar sealed surface. The plane containing the proximal faces of the complement **30**, bridge element **78**, and sleeve center **20**, defines a sealed region with the distal end of the gear **16**. This collection of elements may therefore be regarded as a close follower to the gear **16**. In this case the close follower is axially stationary.

[**0063**] Further in reference to **FIG. 3, a** bushing **80** ray provide a sealed bearing support to the shaft **12** passing through the cap plate **40**. A similar bushing **82** may be provided in the cap plate **42**. On the subject of sealing, note that the illustrated embodiment is simplified to present certain inventive concepts. It is recognized that additional sealing elements may prove useful. For example, various surfaces, such as the parting line between housings **32** and **36**, may be effectively sealed with o-rings or gaskets, including adhesives, silicones, shellacs, and the like, which are not shown. Various wiping seals may also be employed throughout, as on gear teeth, or shafts and rotating surfaces. Such details are generally known, obvious variations of the illustrated embodiments need not be catalogued herein.

[**0064**] Continuing to refer to **FIG. 3**, note that no structure is illustrated with which to move the follower **24** and associated structure such as the gear **28**. Methods and mechanisms for moving such structure back and forth are generally known. Appropriate methods to move the pump structures back and forth include applying differential hydraulic pressure between proximal end of the cavity **34** and the distal end of the cavity **38**. A metering valve may be installed in-line with the pump output stream, or in association with an independent high pressure source, to direct fluid to the desired cavity as required. Internal pump structure may then act as a variable position piston in such case. Mechanical linkages including elements such as push rods and jack screws being operated by various mechanical, manual, and electrical actuators may also be employed. Various combinations of mechanical and hydraulic elements may also be employed to advantage.

[**0065**] Reference will now be made to **FIG. 4, a** cross-section through section **4-4** in **FIG. 3**. The follower **24** fits in sealing relation along the profile of the cavity **34** (see also **FIGS. 1 and 3**). The follower **24**, a cross-section through the shaft **26**, the complement **17**, and a cross-section through the gear **16** and drive shaft **12**, effectively act in concert as a slidable stopper in the sender cavity **34**. A keyway **84** is shown as one way to transfer power from the shaft **12** to the gear **16** without allowing the gear **16** to slip relative the drive shaft **12**. Recall that the gear **16** is axially fixed in place, and that the complement **17** may slide in sealed relation along the gear **16**. It can now be visualized that this "stopper" assembly functions as a moving wall, and defines one movable wall of the pump chamber (**FIG. 7**, denoted by area **104**).

[**0066**] **FIG. 5** is a cross-sectional view in elevation through section **5-5** in **FIG. 3**. **FIG. 5** shows additional details of the pump chamber. For convenience, directions of rotation of the gears **16** and **28** are assigned, and are indicated by arrows **86** and **88**. Teeth of the gears **16** and **28** are seen to be in wiping sealed relation with respect to the sleeve **22** and the sender cavity **34**. Under the illustrated conditions, a low pressure zone **90** is created where teeth of the gears **16** and **28** rotate out of mesh. The low pressure area **90** is accessed for fluid supply by an input port **92**. A high pressure zone **94** is created where the gear teeth come into mesh. The high pressure zone **94** is in open fluid communication with an exhaust port **96**.

[**0067**] Referring to **FIG. 6, a** cross-sectional view in elevation through the section **6-6** in **FIG. 3** illustrates a fixed wall of the pump chamber. The receiver cavity **38** is sealed by structure including the sleeve **22**, the sleeve center **20**, the drive shaft **12**, the bridge element **78** of the receiver housing **36**, the complement **30**, the gear **28**, and the axle **26**. The sleeve **22** and gear **28** move axially in sealed relation with the remaining structure. This arrangement provides a fixed wall forming a sealing plane defining the distal end of the pump chamber.

[**0068**] Referring now to FIGS. **7-10**, the change in length of the pump chamber **104** is illustrated. FIGS. **7-10** illustrate cross-sectional side views in elevation of selected internal operating elements of the pump **10** according to the present invention. Notably, the cap plates **40** and **42** and the sender housing **32** are not illustrated in these Figures. In **FIG. 7**, the elements are arranged in a position to define the maximum pump chamber length **104**. Note that the complement **17** is located at the proximal end of the gear **16**. **FIG. 8** illustrates an arrangement to provide approximately a one-half the maximum flow rate per revolution. Note that the follower **24** has been displaced toward a distal end **106** of the receiver housing **36**, and the complement **17** is approximately at mid-span of the gear **16**.

[**0069**] **FIG. 9** illustrates an arrangement that provides a substantially reduced flow rate compared to the maximum flow rate. In this circumstance, the follower **24** is displaced an additional amount toward the distal end **106**, compared to the position illustrated in Figure **8**. Note also that distal end of the gear **28** has come into engagement with the timing gear **18**. Of note also, the distal end of the follower **24** is approaching the distal end of the sender housing **32** (not shown in FIGS. **7-10**, see **FIG. 1** or **3**). The distal end of the follower **24** may obscure the opening of either or both of the ports **92** and **96** (see **FIGS. 3 and 5**). In this circumstance, the follower **24** may interact with a particularly formed and cooperative structure of the ports **92** and or **96** to also form a metering valve or orifice. Such a metering valve may come into actuation at the lower flow configurations of pump structure. Such an arrangement may also enable controlled relief of pressure in closed regions between teeth as closed in by other intermeshing teeth.

[**0070**] **FIG. 10** illustrates a zero flow arrangement of pump elements. In this circumstance, the pump "chamber length"**104** is effectively zero. The distal end of the complement **17** is illustrated in contact with the sleeve center **20**, and no free volume in which to transfer fluid exists in the pump chamber. The gear **28** may be completely disengaged, moving in an axial direction away from the gear **16**. The full length of the timing gear **18** is now engaged by the gear **28**, and maintains orientation of the gear **28** relative to the gear **16**.

[**0071**] The illustrated example of the pump **10** has the drive shaft **12** axially fixed relative to the housing elements **32** and **36**, and the movable idler axle **26** carried by the follower assembly **25** (**FIG. 1**). It is within contemplation to provide an idler axle, axially fixed in position, and a movable drive shaft. By way of example, the axle **26** may be lengthened to protrude from one or both cap plates **40** and **42**. In such a configuration, pump flow rate may be controlled either by displacing the entire pump housing relative to the drive source, or by fixing the pump in place and moving the driving source (typically a motor) relative to the pump housing.

[**0072**] Certain other modifications to the illustrated apparatus **10** are also within contemplation, including without limitation, forming a secondary pump within the receiver cavity **38**. This secondary pump may easily be formed by engagement of the timing gear **18** and the gear **28**. With reference to **FIG. 3**, the timing gear **18** may be moved from its illustrated position to place its proximal end in sealing relation with the distal end of the complement **30**. The gear **28** may be lengthened to always engage the gear **18**.

[**0073**] A third complement, similar to the complement **30**, may form a distal seal to the newly created secondary pump chamber. The sleeve center **20** may then be formed as two sleeve centers disposed on opposite sides of the gear **18**. The sleeve **22** and the receiver cavity **38** may be appropriately lengthened to accommodate the increase in length of gear **28** and to allow full range in length of the main pump chamber. The secondary pump output may be used as a pressurized fluid source to control the length of the main pump chamber.

[**0074**] Pump elements may be formed from any appropriate materials, including, without limitation, ferrous and nonferrous metals, and engineered plastics or polymers. Depending upon output pressure requirements, working fluids, and desired pump life, pump gears may advantageously be formed from stainless steels, cast iron, or engineered plastics and the like. Seals may be formed throughout the pump structure by closely fitting the illustrated components, or by way of strategically added sealing elements. Housings may alternatively be formed with integral caps and assembled like opposed cups. A housing may also alternatively be structured as one deep vessel having a single lid on a single open end. Such construction details may be driven by manufacturing concerns.

[**0075**] In summary, it will be appreciated that the present invention provides a positive displacement pump having a variable output flow. The instant pump is a gear pump capable of varying its displacement, and therefore its output at a given rotation rate. The instant gear pump provides axial displacement of pump gears with respect to one another, and includes a close follower to maintain an end seal for each gear. A complement is included to provide an end seal for a pump cavity having a variable length. To the extent that an engagement region of the pump gear is reduced, a liquid seal against leakage in the axial direction past each gear closes off the engaged (fluid driving) portion of the respective gears.

[**0076**] The instant pump provides an ability to vary displacement of a gear pump through a full range from zero (idling, no pumping occurring) at operational rotational speeds, to 100 percent of a maximum capacity when the pumping gears are fully engaged to their maximum extent. Furthermore, the instant gear pump provides a timing gear to maintain synchronization between the two pumping gears, even when the pumping gears are not engaged.

[**0077**] The present invention may be embodied in other specific forms without departing from its structures, methods, or other essential characteristics as broadly described herein and claimed hereinafter. The described embodiments are to be considered in all respects only as illustrative, and not restrictive. The scope of the invention is, therefore, indicated by the appended claims, rather than by the foregoing description. All changes within the meaning and range of equivalency of the claims are to be embraced within their scope.

What is claimed and desired to be secured by United States Letters Patent is:

1. A pump having a positive displacement per cycle that is continuously variable between a maximum flow rate and a zero flow rate comprising:

a housing;

a first driven gear rotatably movable with respect to the housing;

a second gear rotatably movable with respect to the housing and meshing with the first gear, wherein the first and second gears are axially movable relative to each other;

a first complement, secured to rotate with and slide axially along the first gear;

a second complement, secured to rotate with and slide axially along the second gear;

a movable follower sealably engaged to the first complement and second gear, and slidably engaged with the first gear, wherein the first complement and second gear are configured to move continuously between a first position corresponding to the maximum flow rate and a second position corresponding to the zero flow rate;

a fixed follower sealably engaged with the second complement and slidably engaged with the second gear; and

a timing gear configured to rotate in correspondence with said first driven gear.

2. The pump of claim 1, further comprising:

a drive shaft carrying said first driven gear in driving relation.

3. The pump of claim 2, further comprising:

an idler axle carrying said second gear.

4. The pump of claim 3, wherein the timing gear is spaced axially from the first driven gear by the stationary follower.

5. The pump of claim 4, wherein the stationary follower further comprises:

a sleeve center positioned to cooperate with the second complement.

6. The pump of claim 5, wherein the sleeve center has an axial length at least equal to a thickness of the second complement.

7. The pump of claim 6, wherein the movable follower further comprises:

a sleeve positioned to slide axially over said sleeve center in a sealed relation, further adapted to travel with the movable follower.

8. The pump of claim 7, further comprising a pump chamber having a continuously variable length defined by a distance between the first and second complements.

9. The pump of claim 8, wherein said pump chamber length varies continuously between a maximum length corresponding to the length of said first driven gear less the length of the first compliment and a minimum length, including zero, corresponding with said zero flow rate.

10. The pump of claim 9, further comprising:

an adjuster configured to continuously vary the length of said pump chamber between said maximum length and said minimum length.

11. The pump of claim 10, wherein said adjuster comprises:

a mechanical linkage configured to displace the movable follower.

12. The pump of claim 10, wherein said adjuster comprises:

a fluid applied to exert a differential pressure between a proximal piston face and a distal piston face, wherein the proximal piston face comprises a proximal end of the follower and a proximal end of the first complement, and wherein the distal piston face comprises a distal end of said first driving gear and a distal end of said sleeve.

13. The pump of claim 10, further comprising a metering valve found between the movable follower and an output port, wherein said metering valve operates at reduced chamber length.

14. The pump of claim 11, wherein the timing gear is configured to reduce energy applied to fluid within the housing.

15. An improved pump, having axially translatable gears, to reduce energy applied to a working fluid during conditions of reduced pump output and full drive shaft speed, the improvement comprising:

a pump chamber comprising a sleeve and having a variable length to proportionally control pump output, the length variable between a maximum length and a minimum length, the minimum length corresponding to an effectively zero pump output;

the sleeve forming a pumping seal with a gear when the pump is configured to produce an output flow;

a timing arrangement adapted to keep a plurality of gears in constant synchronization, whether the gears are engaged or fully disengaged; and

an adjuster to vary the chamber length between the maximum and the minimum.

16. The pump of claim 15, wherein the chamber length is a distance between a proximal seal and a distal seal.

17. The pump of claim 16, wherein:

the distal seal comprises a stationary follower to form an effective axial seal with an axially fixed gear; and

the proximal seal comprises a movable follower to form an effective axial seal with an axially translating gear.

18. The pump of claim 17, wherein the stationary follower comprises a portion of a gear complement, a sleeve center, and a housing bridge element.

19. The pump of claim 15, wherein the sleeve is cantilevered from a movable follower and journaled in a housing for axial translation.

20. The pump of claim 19, wherein a sleeve center, coaxial with the sleeve, axially spaces a timing gear from another gear.

21. The pump of claim 15, wherein the adjuster comprises a mechanical linkage structured to translate a movable follower.

22. The pump of claim 15, further comprising a metering valve between a movable follower and an output port, the metering valve operable during conditions of reduced chamber length.

23. The pump of claim 15, the timing arrangement comprising:

a timing gear maintained in meshing agreement with a first gear, and axially spaced apart from the first gear.

24. The pump of claim 15, wherein the adjuster comprises:

a working fluid applied to exert a differential pressure between a proximal piston face and a distal piston face;

the proximal piston face comprising a proximal end of a follower and a proximal end of a complement; and

the distal piston face comprising a distal end of a gear and a distal end of the sleeve.

25. The pump of claim 24, wherein the working fluid is pressurized by a secondary pump between a gear and a timing gear.

26. A method to vary a fluid output rate, between a maximum rate and essentially zero, during a constant operational speed for a positive displacement pump, the method comprising:

providing a pump comprising:

gears, including first and second pump gears, and a timing gear to maintain synchronization between the pump gears; with

the first pump gear in pump sealing relation to a sleeve cantilevered from a movable follower;

the pump gears arranged for meshing engagement and mounted for relative axial translation between a position of maximum length engagement to complete disengagement; and

axially translating the second pump gear relative to the first pump gear such that the engagement length therebetween correspondingly changes between a maximum length and zero.

27. The method of claim 26, wherein the axial translation is effected by a mechanical linkage element arranged to translate the movable follower.

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