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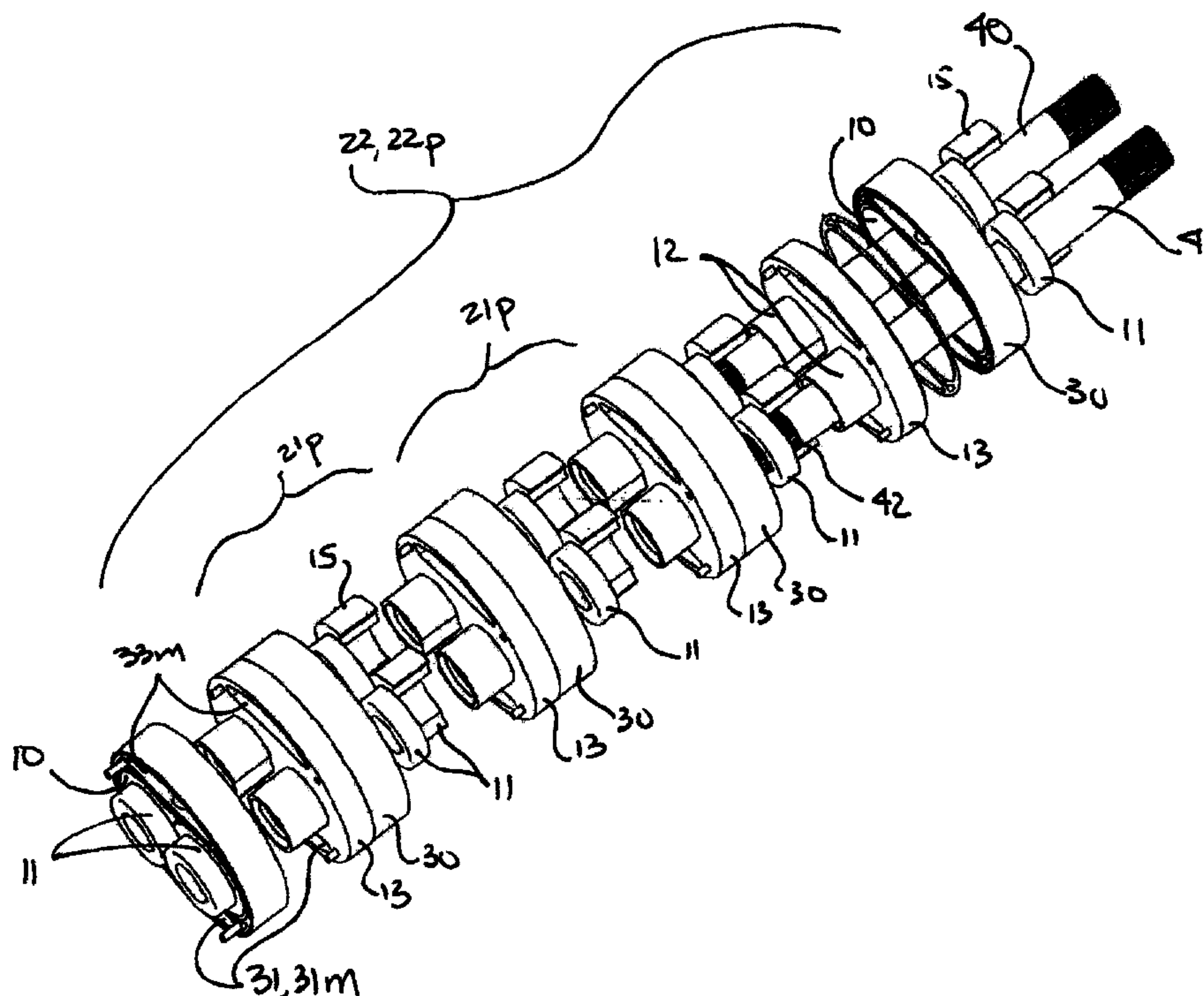
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(54) Titre : DISPOSITIF VOLUMETRIQUE A PLUSIEURS COMPARTIMENTS POUR FLUIDE

(54) Title: MULTI-CHAMBER POSITIVE DISPLACEMENT FLUID DEVICE



(57) Abrégé/Abstract:

A pump comprises multiple, axially stacked positive displacement fluid device sections, such as circumferential piston pumps having chambers and contra-rotating chambers. The device can be similarly employed as a fluid motor. The stacked sections are arranged within an outer retaining barrel in one or more stages. The pump is particularly suitable for installation downhole in the casing of a wellbore. Each section comprises a pair of rotors fit to shafts which are rotatably supported on hard faced bearings between the shafts and the bosses. Each pump section draws fluid from an inlet port and discharges fluid to a common and contiguous discharge manifold. The inlets of the pump sections for a suction stage communicate with a fluid source. Cross-over sections route fluid between stages. Successive pressure stages draw fluid from the cross-over fit to the preceding stage's discharge manifold.



1 ABSTRACT OF THE INVENTION:

2 A pump comprises multiple, axially stacked positive displacement
3 fluid device sections, such as circumferential piston pumps having chambers and
4 contra-rotating chambers. The device can be similarly employed as a fluid motor.
5 The stacked sections are arranged within an outer retaining barrel in one or more
6 stages. The pump is particularly suitable for installation downhole in the casing
7 of a wellbore. Each section comprises a pair of rotors fit to shafts which are
8 rotatably supported on hard faced bearings between the shafts and the bosses.
9 Each pump section draws fluid from an inlet port and discharges fluid to a
10 common and contiguous discharge manifold. The inlets of the pump sections for
11 a suction stage communicate with a fluid source. Cross-over sections route fluid
12 between stages. Successive pressure stages draw fluid from the cross-over fit to
13 the preceding stage's discharge manifold.

1 **“MULTI-CHAMBER POSITIVE DISPLACEMENT FLUID DEVICE”**

2

3 **FIELD OF THE INVENTION**

4 This invention relates to positive displacement fluid devices such as

5 fluid-driven motors and pumps which are operable for pumping high temperature,

6 and contaminated fluids. More particularly, such a fluid device is a

7 circumferential piston pump or motor configured for multi-chambered use in

8 stacked and multi-stage operation.

9

10 **BACKGROUND OF THE INVENTION**

11 Conventional methods and apparatus for bringing well fluids to the

12 surface involve various pump systems of different designs and methods of

13 operation. Restrictions on existing pump systems sometimes include dimensional

14 constraints, the ability to handle high temperature and the need to pump

15 contaminated fluids, e.g. high sand content particularly at high temperature.

16 Conventional pumps are limited by their use at high temperature and with

17 contaminant sensitive polymers.

18 Further, pumps having rotating components must have some form

19 of bearing to separate the moving from the stationary components. It is a

20 constant challenge to maintain bearing integrity in high temperature or

21 contaminated environments. Such environments include those typical in the

22 recovery of high temperature hydrocarbons from Steam Assisted Gravity

23 Drainage (SAGD) wells in the heavy oil and bitumen recovery of northern Alberta,

24 Canada.

1 In downhole operations, such as conventional oil recovery
2 operations, progressive cavity (PCP) pumps have been applied to great
3 effectiveness. However, as the well becomes deeper, as the temperature
4 increases, and as the level of contamination increases, the elastomers used
5 begin to fail resulting in pump failure and more frequent and expensive turnovers.

6 As an alternative, one may consider positive displacement pumps
7 which are applied in food and other fluid industries. Among this class of pumps
8 are circumferential piston pumps which have been known since at least 1935 in
9 US 2,096,490 to Hanson and still in production today by Waukesha Delavan, WI
10 (Universal II Series) and Tuthill of Alsip, IL (HD Series). Conventional
11 circumferential piston pumps utilize opposing, contra-rotating rotors having
12 pistons which are alternately swept through a common chamber. Timing gears
13 coordinate the rotor rotation. Traditionally used in surface applications,
14 significant effort has been applied in order to seal the rotation of the rotors and
15 the resulting pumps to date have been typically used in single stage applications.
16 The rotors are each fitted on a shaft rotatably supported on bearings, either
17 cantilevered or being fit with bearings at each end. The bearings are lubricated
18 and separated from the process fluids by seals (commonly known as external
19 bearings).

20 The usual approach for increasing the volume and fluid flow rate
21 from such positive displacement pumps has been to increase the pump's
22 dimensions. However, in the restricted space of a wellbore, such dimensional
23 scale-up of pumps is not suitable for providing either the necessary pressure or
24 the flows in the wellbore.

1 In some applications, such as hot, contaminated downhole wellbore
2 operations, there is an objective to increase either the volumetric flow rate or to
3 increase the output pressure beyond that which can conventionally be provided
4 using a conventional circumferential piston pump. Conventional pump
5 technology has not fulfilled these objectives. The design challenges are further
6 increased where the fluid is hot and contaminated, further affecting the challenge
7 of sealing the rotors of such pumps. In particular, in the high pressure, high
8 temperature contaminated environment of oil well downhole operations, there is
9 little opportunity to provide an optimum environment for the bearings.

10 The above problems and challenges are equally applicable to the
11 reverse operation in which fluid is forced through such devices so as to drive a
12 shaft and act as a motor.

13 Accordingly, there is a need for a fluid device which can operate in
14 high temperature, contaminated fluids and which can be further adapted to
15 operate in high volume and pressure operations, even in such restricted spaces
16 as a wellbore.

17

1 sections has a common discharge manifold which contributes its incremental flow
2 to the common discharge manifold. The sections can be stacked in any
3 combination of parallel or series arrangements, each of which utilizes a drive
4 shaft which extends co-axially through the stack of sections.

5 If the sections are stacked in parallel, the volumetric flow rate is
6 incrementally increased.

7 If the sections are stacked in series, the discharge pressure
8 capability is incremented. For a series arrangement, the discharge of one section
9 or stack of sections is fluidly connected to the inlet of a successive stacked
10 section through a crossover section. Sections stacked in series with a cross-over
11 form a pumping stage for incrementally increasing the pressure at the fluid
12 destination.

13 Applied as a motor for a given flow rate of fluid, sections stacked in
14 parallel result in a greater torque at the drive shaft and sections stacked in series
15 result in a greater rotation speed.

16 In a multi-section pump, the invention comprises: two or more
17 axially stacked pump sections, each section having a rotor chamber and
18 associated rotors for pumping fluid from an inlet to a discharge manifold and a
19 drive which extends axially through each rotor chamber for rotating the rotors and
20 pumping fluid. Each section comprises a pump housing for housing the rotor
21 chamber and rotors which are sandwiched between end plates and seals.

22 In a multi-stage pump, the invention comprises: a suction stage
23 have having one or more axially stacked suction pump sections, each section
24 having a rotor chamber and associated rotors for pumping fluid from an inlet to a
25 discharge manifold; and at least one pressure stage, each stage having one or

1 more stacked pressure pump sections, each pressure pump section having a
2 rotor chamber for pumping fluid from a suction manifold to a discharge manifold;
3 a crossover section for fluidly connecting the discharge manifold of the suction
4 stage to the suction manifold of the pressure stage; and a drive which extends
5 axially through each rotor chamber for rotating the rotors and pumping fluid.

6 More preferably, the drive comprises a drive shaft or a plurality of
7 co-axially connected drive shafts extending axially and rotatably to the rotor
8 chamber of each section for rotating one of the rotors; an idler shaft or idler shafts
9 extending rotatably to each rotor chamber for rotating the other rotor; and timing
10 means between the drive shaft and idler shaft for contra-rotating the rotors.

11 The entire stack of sections and crossovers between stages can be
12 fit into the bore of a tubular barrel, compressed sealably together and retained
13 therein, the barrel forming a pump having a fluid intake or inlet ports to a suction
14 stage and having a fluid discharge from a pressure stage.

15 Such a pump has great versatility in its designed flow capacity and
16 lift, all of which can be assembled into a small diameter package and which is
17 driven through a single drive shaft connection; ideal for downhole operations or
18 other space restrictive areas. Configured as a motor, the fluid device
19 demonstrates similar same space and performance advantages in meeting
20 desired output torque and rotational speed characteristics.

21

BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1a-1e are schematic views of the sequential operating principles of a circumferential piston pump;

Figure 2 is an exploded perspective view of a multi-stage circumferential piston pump according to one embodiment of the invention;

Figure 3 is a perspective view of an alternate suction stage according to another embodiment, in which the inlets ports for all pump sections draw from a common suction manifold;

Figure 4 is an exploded perspective view of a pump section configured as a fluid suction section;

Figure 5 is an exploded perspective view of a four parallel pressure pump fluid suction sections of Fig. 5, detailing main drive shaft and idler shaft sections;

Figure 6 is an exploded perspective view of a pump section configured as a pressure pump lift section;

Figure 7 is an exploded perspective view of four parallel pressure pump lift sections of Fig. 6, detailing main drive shaft and idler shaft sections;

Figure 8 is an exploded perspective view of a center timing gear assembly;

Figures 9a-9d are various views of a fluid cross-over unit. More particularly, Fig. 9a is a perspective view with internal passageway depicted in hidden lines, Fig. 9b is top view of Fig. 9a, Fig. 9c is a cross-sectional view of Fig. 9b along lines A-A, and Fig. 9d is a cross-sectional view of Fig. 9b along lines B-B;

1 Figure 10 is an exploded perspective view of a top bearing
2 assembly;

3 Figure 11 is an exploded perspective view of a complete pump
4 assembly with outer retaining barrel omitted; and

5 Figures 12a-12c are test results depicting the efficiency, power and
6 torque curves for a five section portion of a pump constructed according to the
7 embodiment of Fig. 2 when pumping water at standard conditions;

8 Figures 13a-13c are test results according to Figures 12a-12c, also
9 depicting the efficiency, power and torque curves when pumping SAE30 oil at
10 70°C; and

11 Figures 14a-14c are test results according to Figures 12a-12c, also
12 depicting the efficiency, power and torque curves when pumping SAE30 oil at
13 190°C.

14

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The principles of positive displacement pumps are hereby adapted and modified for operation in environments known to be challenging to current pumping technologies. Positive displacement pumps include rotary-actuated gear pumps and circumferential piston pumps. When fluid operated in reverse, a positive displacement device can be used as a motor. Unless the context is specifically otherwise, the description herein applies equally to operation as a pump or as a motor.

In one embodiment a circumferential piston pump is applied to overcome the pumping challenges identified by the applicant. The principles of circumferential piston pumps are well known and are summarized briefly herein for reference.

Generally, and using illustrations of a circumferential piston pump as an example (Figs. 1a-1e), a positive displacement pump comprises at least a rotor chamber 10, rotors 11 fitted into the rotor chamber, a fluid inlet 6 and a fluid discharge 7. In a single stage implementation, the inlet 6 is connected to a fluid source and its discharge 7 is connected to a fluid destination. In the case of an elementary gear pump, two rotors 11 such as meshing gears are rotated in the rotor chamber 10. The rotors 11,11 are contra-rotated for effective fluid flow – either being driven by the fluid as is the case for a motor, or driving the fluid as a pump.

Specifically for a circumferential piston pump, two contra-rotating piston rotors 11,11 are rotated in the rotor chamber 10 about cylindrical machined bosses 12. Annular piston bores 14 are formed between the rotor chamber 10 and the bosses 12. Each rotor 11,11 has one or more arcuate pistons 15 which

1 travel in circular paths in their respective annular piston bores 14. The piston
2 bores 14,14 meet at a common point of intersection C in the center of the rotor
3 chamber 10. The center of rotation of each rotor is spaced outside of the major
4 diameter (sometime known as external) of the opposing rotors. The point of
5 intersection C of the piston bores 14,14 is connected at one side to the pump's
6 inlet 6 and at an opposing side to the pump's outlet 7. Each piston 15 alternates
7 passing through the point of intersection C. Each piston 15 has a trailing edge
8 and a leading edge. As the trailing edge of a rotor's piston 15 leaves the point of
9 intersection C, the volume of its piston bore is steadily yet temporarily increased,
10 causing a suction and a resulting inflow of fluid from the inlet 6 or suction side.
11 This is the suction portion of the cycle of each rotor 11. The leading edge of the
12 same piston 15 then seals the piston bore 14 which traps the fluid drawn from the
13 inlet 6 and positively displaces it to the outlet 7 or discharge side. While one
14 rotor's piston 15 is displacing fluid out of its piston bore 14, the other rotor's
15 piston 15 is drawing fluid into its piston bore 14. The suction inlet 6 and
16 discharge outlet 7 are constantly isolated, despite the common point of
17 intersection C, due to the continual presence of one rotor 11 or the other rotor 11
18 sealing between its respective piston bore 14 and against the opposing rotor's
19 cylindrical boss 12.

20 In example sequential steps of operation, starting at Fig. 1a, an
21 Open-to-Inlet (OTI) volume is defined in a rightmost rotor bore 14 by the rotor
22 chamber 10 and by the departing the rightmost rotor piston 15. The rightmost
23 rotor piston 15 fluid seals the OTI volume at the point of intersection C where the
24 piston meets and seals against the opposing rotor's cylindrical boss 12.
25 Comparing Fig. 1a and 1e, the OTI volume alternates between the piston bores

1 14,14 as the pistons 15,15 alternately enter or leave the point of intersection C.
2 Normally, neither the rotors 11,11 nor the pistons 15,15 contact each other and
3 only close tolerance fluid seals exist between the rotor 11 and the opposing
4 rotor's boss 12. As the rightmost rotor bore 14 forms the OTI volume (Fig. 1a),
5 an Open-to-Outlet (OTO) volume is defined in the leftmost rotor bore 14 by the
6 rotor chamber 10 and the surfaces of rotor pistons 15 between their fluid seal
7 contacts with the opposing boss 12 where they leave the point of intersection C.
8 Observing the rightmost piston 15, Figs. 1a and 1b illustrate the OTI suction
9 portion of the cycle, while Fig. 1c illustrates the trapping of the fluid and its
10 positive displacement towards the OTO volume. Figs. 1d and 1e illustrate the
11 continuous discharge of the trapped fluid to the outlet 7. As is shown in Fig. 1c,
12 the OTI suction cycle for the leftmost rotor 11 begins when the rightmost rotor 11
13 is completed its OTI cycle.

14 In the conventional mode of operations, radial surfaces and axial-
15 end surfaces of the rotor pistons 15 run in close-clearance contact with the walls
16 of the rotor chamber 10, and due to the reality of manufacturing tolerances, load-
17 bearing contact may occasionally occur in these zones. Annular apertures
18 defined by the running clearances therebetween determine the amount of fluid
19 leakage from the outlet 7 to the inlet 6, being from the OTO volume to the OTI
20 volume, for a given pressure difference and a given effective viscosity. For each
21 rotor chamber 10, each rotor 11,11 alternately supports the driving torque.

22 This ends a review of the more conventional aspects of the
23 circumferential piston pump, the principles of which are common with positive
24 displacement pumps generally and with the present invention. Such conventional
25 pumps utilize a pump body or housing having a single inlet 6 and an outlet 7.

1 The typical means for increasing a pump's volume (OTI,OTO) and fluid flow rate
2 has been to increase the pump's dimensions. However, in the restricted space of
3 a wellbore, such dimensional scale-up of pumps is not suitable for providing
4 either the necessary pressure or the flows in the wellbore.

5 Therefore, with reference to Figs. 2 for the overall arrangement and
6 Figs. 4 and 5 for details, and turning to a first embodiment of the present
7 invention, a novel pump 20 comprises two or more positive displacement
8 chambers 10,10..., stacked axially one chamber 10 atop another chamber 10.
9 Each chamber 10 is provided with its respective rotors 11,11, bosses 12,12 and
10 an end plate 13 for forming a section 21. In stacking the sections 21 and thus
11 stacking the chambers 10,10..., the respective rotors 11,11 of each discrete
12 chamber 10 are aligned along the same axes and can thereby be driven through
13 a common drive shaft and idler shaft.

14 Two or more stacked sections 21 having their outlets 7 conjoined
15 into a common discharge are stacked to form a pump stage 22. A pump 20 can
16 merely have a single stage 22 of one or more parallel stacked sections 21.
17 Practically however, for increased head or discharge pressure, a pump 20
18 preferably comprises two or more stages; a suction stage 22s (figs. 4 and 5) and
19 at least one pressure stage 22p (Figs. 6 and 7).

20 Each stage 22, whether suction or pressure 22s,22p, comprises
21 one or more pump sections 21 arranged or stacked axially in parallel for obtaining
22 the desired capacity or fluid flow rates. Stages 22 can also be stacked axially in
23 series 22s,22p,22p,... for obtaining the desired discharge pressure from the
24 ultimate outlet from the pump 20.

1 As shown in Fig. 2, a complete pump 20 consists of pump sections
2 21 combined in multiples in a stack 23 and preferably having two or more stages
3 22 operating in series 22s,22p,22p.

4 The stack 23 of pump sections 21 and drive components (described
5 later) are sandwiched together for fluid tight connections therebetween. While
6 other means such as threading section 21 to section 21 together or joining by
7 fasteners could be employed, one convenient means for assembling a multiplicity
8 pump sections 21 and their associated drive components is to fit the stack 23 into
9 an outer cylindrical retaining barrel 24. The length of the outer retaining barrel 24
10 is complementary to the overall height of the stack 23 so that when installed into
11 the outer retaining barrel, end retaining nuts 25 are secured into each end of the
12 outer retaining barrel 24 for engaging the stack ends 26 and retaining them
13 together.

14 While each section 21 may actually be identical, the section's
15 location in the stack can define its role as either a suction or a pressure section
16 21s,21p. A suction section 21s, multiple sections 21s,21s..., or a suction stage
17 22s is located adjacent to and in fluid communication with a fluid source and
18 draws the design flow rate of fluid into the pump 20. As shown in Fig. 2, such a
19 suction stage 22s, can draw fluid independently into each section 21s,21s...
20 through a plurality of corresponding inlets 6,6... in the sections 21 and
21 corresponding inlet ports 27 in the outer retaining barrel 24. Alternately, as
22 shown in Fig. 3, the fluid can be drawn through a combined suction intake 34.

23 With reference to Fig. 4, a section 21s configured for suction is
24 illustrated. Each section 21 comprises a pump body or pump housing 30 forming
25 at least two chambers: a pumping or rotor chamber 10 and a discharge chamber

1 31. For ease of manufacture and assembly, the rotor chamber 31 of each
2 section 21 is sandwiched and sealed between end plates 13. A pair of bosses 12
3 extends from one side of the end plate 13 and project into the rotor chamber 10.
4 The end plate 13 blocks one side of the rotor chamber 10, shown in this
5 configuration as a top end plate for one pump section while also forming a bottom
6 end plate for the next adjacent pump section. At an extreme bottom end of a
7 stack of pump sections, a termination plate 32 without bosses is provided.

8 With reference to Fig. 5, four suction pump sections 21s are shown
9 with the discharges 31 of each of the pump housings 30 and end plates 13 being
10 aligned for forming a discharge manifold 31m for contiguous fluid passage
11 therethrough. Inlets 6 are shown extending from the rotor chamber and through
12 the pump housing 30. The pump housing, may or may not have a suction
13 chamber 33 which mirrors the discharge chamber 31. In this embodiment, a
14 suction chamber 33 would be a mere artifact of the implementation of pump
15 housings which are interchangeable for either suction or pressure section use. As
16 shown in Fig. 2, the assembled suction stage 22s draws fluid from a fluid source
17 outside the pump 20, typically from a wellbore. Fluid enters the suction stage
18 through a series of inlet ports 27 formed in the outer retaining barrel 24. The inlet
19 ports 27 align with corresponding inlets 6 in each of the suction stages 21s;
20 typically one inlet port 27 per suction pump section 21. While this arrangement
21 does require some accuracy in matching inlet ports 27 and pump section inlets 6,
22 use of individual inlet ports 27 does minimize fluid restriction and ensures a
23 substantially equal supply of fluid to each pump section 21. Each suction pump
24 section 21 transports substantially an equal amount of fluid from the inlet 6 and
25 delivers it to the common discharge manifold 31m which is located 180 degrees

1 opposite to the suction manifold 33m. The discharge manifold 31m runs along the
2 full axial length of each pump stage 22s,22p..., through both the pump housings
3 10 and the end plates 13 for accumulating and delivering the discharge fluid to
4 the next pump stage 22.

5 In the alternate embodiment shown in Fig. 3, the multiple-stacked
6 chambers of the suction stage 22s can all draw from suction intake 34. The
7 suction sections 21s,21s... have their inlets 6 extending only from the rotor
8 chamber 10 to a suction chamber 33 as part of an overall common suction
9 manifold 33m. This simplifies the pump assembly and avoids the need to
10 accurately align individual section inlets 6 with the inlet ports 27 in the outer
11 retaining barrel 24. Accordingly, a common or combined suction intake 34 is
12 formed at the initial suction section 21s or the suction stage 22s. The intake 34 is
13 formed in the termination plate 32. In this embodiment, the suction manifold 33m
14 is required to pass the entire design fluid flow rate, and thus the pressure drop
15 therethrough must be considered in the design such as increasing the manifold
16 33m cross-section accordingly. The suction manifold 33m may have sufficient
17 cross-sectional areas to supply fluid to all of the multi-chambers 10 in the stage
18 22 without starving the latter sections 21 of fluid flow. The suction manifold 33m
19 for all pump sections 21 may be increased in size. The inlets 6 for each section
20 21 are all joined through the common suction manifold 33m. In the alternate
21 embodiment in Fig. 3, it is clear that the pressure and suction sections 21p,21s
22 may be identical for simplification and economy of manufacture.

23 Turning to Fig. 6, a pressure pump section 21p is shown herein as
24 differing from an independent inlet operating suction pump section 21s by the
25 absence of an inlet 6 extending through the pump housing 30 which forms a

1 suction manifold 33. As shown individually in Fig. 6 and stacked in Fig. 7, the
2 pressure pump sections 21p correspond in all other respects to the suction pump
3 sections 21s set forth in Figs. 4 and 5 except that the suction chamber 33 now
4 forms the inlet to each section 21. The suction chamber 33 is isolated from the
5 outer retaining barrel 24 and is enclosed wholly within the pump housing 30. A
6 pressure stage 22p is typically configured to accept fluid from the suction stage's
7 common discharge, process the fluid through the one or more sections 21p in
8 parallel and also discharge the fluid through a common discharge 31 or manifold
9 31m.

10 The end plates 13 are also fitted with suction and discharge
11 chambers 33,31 which are complementary to the pump housing's suction and
12 discharge chambers 33,31 for forming respective suction and discharge
13 manifolds 33m,31m extending continuously along the pump 20 for contiguous
14 fluid communication between stacked pump stages 22s,22p,22p... . As noted
15 above, end plates 13 throughout a suction stage 22s may or may not include a
16 suction chamber 33 as the suction section's pump housing 30 may be absent
17 such a chamber, being fitted only with an inlet 6.

18 With reference to Fig. 7, four pressure pump sections 21p,21p... are
19 shown with each of the respective suction and discharge manifolds 33,31 of the
20 pump housings 30 and end plates 13 being aligned for contiguous fluid passage
21 therethrough.

22 Rotors 11 and their pistons 15 are mounted rotatably over the
23 bosses 12 for rotation in the rotor chamber 10. Single lobed rotors 11 are shown
24 although double lobed or other rotor arrangements are possible. In US 2,642,808
25 to Thomas, the entirety of which is incorporated herein by reference, double-

1 lobed rotors are implemented. Further, the circumferential piston 15 can extend
2 axially from the rotor 11 to overhang the boss 12, as illustrated herein, or can be
3 cantilevered, as taught by Thomas.

4 Accordingly, and referring to Figs. 2 and 4-7, when assembled into
5 a typical pump 20 configuration, a suction stage 22s is demonstrated as having
6 fifteen stacked suction pump sections 21s and fifteen corresponding inlet ports
7 27. All fifteen suction pump sections 21s discharge to the common discharge
8 manifold 33m. The fluid in the suction stage's discharge manifold 31m is directed
9 to a first pressure stage 22p. The first pressure stage 22p is also illustrated as
10 having fifteen stacked pressure pump sections 21p. All fifteen pressure pump
11 sections 21p draw from a common suction manifold 33m and discharge to a
12 common discharge manifold 31m. The fluid in the first pressure stage's
13 discharge manifold 31m is directed to a second pressure stage 22p. The second
14 pressure stage 22p is also illustrated with fifteen pressure pump sections 21p. All
15 fifteen pressure pump sections 21p also draw from a common suction manifold
16 33m and discharge to a common discharge manifold 31m.

17 Turning to Figs. 7 and 8, one rotor 11 is driven by one or more drive
18 shafts 40,40... which extend through each rotor chamber 10 and which are
19 connected end to end for co-rotation. The opposing rotor 11 is driven by one or
20 more idler shafts 41,41... which are also connected end to end for co-rotation.
21 The one or more drive shafts 40 and one or more idler shafts 41 are hereinafter
22 referred to collectively and simplistically as singular drive shaft 40 and idler shaft
23 41 respectively.

24 As shown in Figs. 7 and 8, the pump sections 21 are driven using
25 the drive shaft 40, extending axially through each pump section 21 and

1 connecting driven rotors 11 in each stacked pump stage 22. The rotors 11 in
2 each pump stage 22 rotate in the same contra-rotating directions as they are
3 driven by one common input main drive shaft 40. The opposing rotor 11 in each
4 pump section 21 is driven by paired sets of timing gears 50, connected to the
5 drive shaft 40 and the parallel idler shafts 41. The plurality of discontinuous, yet
6 co-axial, conjoined idler shafts 41 each being driven through the timing gears 50.
7 The timing gears 50 have a dual function: to drive the idler shaft 41 and their
8 associated rotors 11, and to ensure that the rotors' pistons 15 are timed correctly
9 so that they do not contact or clash.

10 A person of skill in the art can design one or more shafts 40,40...
11 and 41,41... for assembly into a single co-rotating shaft 40 or 41. As shown in
12 Fig. 7, an individual shaft 40 or 41 may be conjoined at splined connections 42 at
13 its respective and common rotor 11. For example, the ends of the shafts 40,41
14 can be fitted with an external involute spline 42 which fits cooperatively with an
15 internally splined coupling bushing (or rotor 11 or gear 50) to co-axially connect
16 the shaft sections of each of the stacked pump stages 22. Further, as shown in
17 Fig. 8, the shafts may be conjoined with splined connections at the timing gears
18 50.

19 The timing gears 50 are housed in timing assemblies 51,51... which
20 are located at regular intervals between multiple stacked pump sections 21, and
21 thereby provide accurate timing for the piston sections 21,21... . Typically, a
22 timing assembly 51 is sandwiched between every four of five pump sections 21.
23 The timing gears 50 are contained in separate timing assemblies 51, fully
24 integrated in each pump stage 22.

1 Regardless of the form of connection to a fluid source, the common
2 discharge manifold 31m of the suction stage 22s delivers pumped fluid to the
3 next successive pump stage 22, in this case being the first pressure pump stage
4 22p. The first pressure stage 22p and successive pressure pump stage 22p is
5 similar in design and construction to the previous suction pump stage 22s,
6 excluding the suction inlets 6 and inlet ports 27.

7 At the discharge of each stage 22, such as between the suction
8 stage 22s and a pressure stage 22p, the discharge manifold 31m is routed to the
9 suction manifold 33m of the successive pump stage. In order to maintain
10 common rotational axes for the drive shaft 40 and idler shaft 41, and to pump the
11 discharge flow to the common suction manifold 33m of the successive stage 22p,
12 the fluid needs to cross-over 180 degrees to flow into the common suction
13 manifold 22s of the successive stage 22.

14 With reference to Figs. 2 and 9a-9d, a fluid flow cross-over section
15 60 comprises a cylindrical block forming an end wall 61 for blocking the
16 preceding stage's suction manifold 33m and a fluid inlet 62 for accepting fluid
17 flow from the preceding stage's discharge manifold 31m. The fluid from the
18 preceding stage's discharge manifold 31m is routed through a fluid flow passage
19 63 to a fluid outlet 65. The fluid outlet 65 is arranged for discharge into the
20 suction manifold 33m of the successive stage 22. As shown in Figs. 9b and 9d,
21 the cylindrical block is fitted with a bore 66 for forming a through passage for the
22 drive shaft 40. The idler shafts 41, being driven by timing assemblies 51
23 positioned periodically along the pump, are able to terminate either side of the
24 cross-over section 60. Accordingly, the fluid flow passage 63 is neither
25 obstructed nor interrupted by the drive shaft 40 or idler shafts 41,41.

1 Sockets 67 and bearings (not shown) are provided for the
2 termination of a preceding idler shaft and for the termination of a successive idler
3 shaft. Such sockets 67 can be machined into the cross-over section 60 or into
4 specialized end plates (not shown) which can be provided as matter of
5 economics so as to avoid further machining of the cross-over section 60.

6 As known by those of skill in the art of positive displacement
7 pumps, each rotor 11,11 is rotated in close non-contacting tolerance to their
8 respective bosses 12,12 and to the rotor chamber 20 and the opposing rotor 11
9 so as to effect a positive displacement motoring or pumping action. To maintain
10 such operational tolerances, the rotors 11,11 are mounted securely to their
11 respective shafts 40,41 and the shafts themselves are supported concentrically in
12 the bosses 12,12 using bearings 70. Unlike the conventional wisdom applied to
13 such circumferential piston pumps, the bearings 70 employed herein are not
14 supported external to the rotor chamber in a protected environment. Recognizing
15 the oft times harsh conditions experienced by pumps in hot, or contaminated
16 environments, face-to-face hard bearing surfaces, including tungsten carbide,
17 silicon carbide, and ceramics are provided inside each boss 12,12 and on the
18 corresponding locations on the main drive shaft 40 and idler shaft 41. Best
19 shown in Figs. 6 and 8, bearings 70 are fit into each boss 12. Mating bearings 70
20 are also fit to the shafts 40,41 (obscured in Figs. 6 and 8 - an example shown in
21 Fig. 8). Similar complementary bearings 70 are employed in each timing
22 assembly 51.

23 Best seen in Figs. 4 and 6, sealing between the individual
24 components of the pump housings 30, end plates 13, timing assemblies 51, and
25 fluid cross-over sections 60 is accomplished using specially molded high

1 temperature O-ring seals 90. The seals 90 are fitted in corresponding shaped
2 grooves 91 formed in each pump housing 30, providing full sealing around the
3 perimeter of each chamber 30, each stacking interface and each individual
4 lubricant and instrumentation port hole 80, running through the full length of the
5 pump stage 22.

6 As discussed earlier, each complete assembled pump stage 22 is
7 mounted inside an outer retaining barrel 24 for supporting the complete
8 assembly. Accordingly, each complete stacked pump stage 22 is free of any
9 internal mechanical fasteners.

10 The outside pump retaining barrel 24 is precision ground and
11 polished on its inside diameter, and provides close tolerance support for each
12 internally mounted section 21,21 and stage 22. The extreme ends 29 of the outer
13 retaining barrel 24 are internally threaded, and each match with the externally
14 threaded retaining nut. The retaining nut 25 can also be provided by a threaded
15 fluid cross-over 60. Once the retaining nuts 25 are threaded into each end of the
16 outer retaining barrel, they sandwiches the stacked pump sections 21 and stages
17 23 together, compressing the O-ring seals 90 and thereby providing full internal
18 sealing of the internal pump stage components 21,51,60.

19 The assembly is aided by compressing the stack of pump
20 components 21,51,60 using opposing mandrels. The end retaining nuts 25 are
21 then threaded into each end of the outer retaining barrel to retain the compressed
22 stack in the outer retaining barrel 24. Depending upon the number of sections 21
23 for the particular pump configuration, and as an example, for three stages of
24 fifteen sections/stage about 10,000 to 20,000 pounds force is applied.

1 In operation, each stage of a circumferential piston pump produces
2 a characteristic pulsing at each discharge. Accordingly, and in a preferred
3 aspect, such pulsing is minimized by slightly rotationally incrementing each pair
4 of rotors 11,11 for each successive section 21,21. One approach is to mount the
5 rotors 11,11 on the drive shafts 40 and idler shafts 41 such that the pump
6 OTI/OTO timing for a complete pump stage 22 is incremented, at equal angular
7 intervals throughout the entire 360° shaft circumference, so as to equally divide
8 the pulsing throughout each 360 degrees revolution. The resulting fluid flow has
9 an overall reduced variation in pulsation at the discharge manifold 31m and
10 provides continuous low pulsation fluid intake and fluid flow discharge
11 characteristics. For example, for a stage 22 having fifteen pump sections 21,
12 each rotor 11 of a rotor pair would be incrementally rotated about 24 degrees on
13 the main drive shaft (360/15). The rotors 11 are connected to the drive and idler
14 shafts 40,41 by means of splines 42 and shaft keys (not shown). As is the
15 convention in rotating machines, shaft keyways are rounded with radius ends, to
16 reduce stresses on the shafts 40,41.

17 Referring to both Figs. 2 and 10, the drive shaft 40, running through
18 the full length of the complete pump 20, is supported at the discharge end of the
19 pump 20 by a thrust/radial bearing assembly 100 . The thrust bearing assembly
20 comprises a bearing housing 101 located on top of the uppermost pump stage
21 22p, and forms an integral part of the pump 20 when installed into the outer
22 retaining barrel 24 . The thrust bearing assembly 100 contains double thrust
23 bearings 102,102 and double radial bearings 103,103 fit with bearing housings
24 104 to prevent axial and radial driveshaft movement. The bearing assembly 100
25 is a sealed unit, with high temperature mechanical seals 105,105 located at the

1 upper and lower end of the drive shaft bearing assembly 100. The bearing
2 assembly 100 is filled with high temperature lubricant oil to lubricate the bearings
3 102,103. The bore of the bearing housing 101 contains the combined stack of
4 bearings 102,103 and has an additional lubricant oil reservoir 106 surrounding
5 the bearing assembly 100. The reservoir 106 can be refreshed or topped up
6 through a lube oil connection (not shown) at the top of the pump 20 adjacent the
7 production line connection 110.

8 Alignment of the stacked components 21,51 is accomplished by
9 hollow alignment dowels 80, located in integral lubricant / instrumentation
10 galleries 81 running through the full length of the complete pump 20. Each pump
11 housing 30, end plate 13, timing assembly 51 and fluid cross-over section 60
12 have such galleries 81 into which are fit hollow dowels 81 for alignment as well as
13 for lubricant/ instrumentation purposes. Each pump section 21 is located and
14 rotationally locked to the adjacent section 21 using the dowels 80. Further,
15 through the use of hollow dowels 81, one through four galleries 80 can be formed
16 along the length of the pump 20. For example, the oil reservoir 106 surrounds
17 the bearing assembly 100 and is also supplied with lubricant externally through
18 one of the galleries 80 running through the full length of the pump 20.

19 As shown in Fig. 11, assembly of the pump sections 21 comprises
20 first stacking each of two or more pump housings 30 and rotors 11,11 between
21 end plates 13,13. The end plate's bosses 12,12 center and locate the rotors
22 11,11 in the pump housing 30, and also rotatably support the main drive shaft 40
23 and idler shaft 41 bearings 70. Pump housings 30 and end plates 13,13 are
24 stacked back to back, with timing assemblies 51 at regular intervals, to form one
25 or more stages 22. As shown in Fig. 2, the entire stack 30,13,51... is

1 compressed and installed in the outer retainer barrel 24 for form the complete
2 pump 20.

3 The discharge fluid is delivered from the uppermost pump stage
4 22p via the common discharge manifold 31m to a last cross-over section 60,
5 connecting to the production pipe line 110 for directing the fluid to the fluid
6 destination. In a pump 20 fit to a wellbore, the fluid destination would be the
7 earth's surface.

8

9 Example

10 Operations for a pump 20 capable of operation in a 9-5/8" wellbore
11 casing include a plurality of 8" diameter pump housings 30 comprises a suction
12 stage 22s and two pressure stages 22p,22p. Each pump section 20 has a rotor
13 chamber 10 and rotor 11,11 combination having a displacement of 0.833 liters
14 per rotor revolution. Timing gears 50 are provided every five pump sections 21,
15 or three assemblies 51 per stage 22. Rotational speed of the pump sections 21
16 can vary between about zero to over 600 rpm, limited only by mechanical
17 constraints such as the means for driving the drive shaft and depending on the
18 characteristics of the fluid. Operating with drive means such as conventional top
19 drives rotating at 400 rpm, such a pump 20 can produce flow rates of about 1000
20 liters/minute at 4500 kPa on fluid such as oil having gravity and viscosity
21 equivalent to fluid similar to a SAE30 oil.

22 Having reference to Figs. 12a-12c, a single stage 22 having five
23 sections 21 of the above pump 20 was manufactured, assembled and operated
24 on water at 30°C. The water had a viscosity of less than about 1 mPa•s. The
25 figures are graphs of pump performance versus fluid discharge flow rates and

1 discharge pressure. Fig. 12a demonstrates test results for pump efficiency
2 pumping water at 30°C. Figs. 12b and 12c illustrate the pump power and torque.
3 Figs. 13a-13c illustrate the same parameters of efficiency, power and torque
4 curves when pumping SAE30 oil at 70°C and Figs. 14a-14c illustrated efficiency,
5 power and torque curves when pumping SAE30 oil at 190°C.

6 With oil at 70°C, the 5 stages produced flow rates in the order of
7 340 – 300 l/min at between 350 – 1400 kPa respectively. Through extrapolation
8 to 15 sections 21 per stage 22, one would expect to get about three times the
9 flow rate or upwards of 1000 liters/min, and when pumped through two additional
10 pressure stages, each having 15 sections for maintaining the flow rates, one
11 could expect discharge pressures of up to about 4200 kPa.

1 **THE EMBODIMENTS OF THE INVENTION IN WHICH AN**
2 **EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS**
3 **FOLLOWS:**
4

5 1. A multi-chamber positive displacement fluid device
6 comprising:

7 at least two sections stacked axially together, each section having a
8 chamber for moving fluid from an inlet to a discharge, at least one section having
9 an inlet adapted for fluid connection to a fluid source, and at least one section
10 having its discharge adapted for fluid connection to a fluid destination;

11 a pair of parallel and contra-rotating rotors operable in the chamber
12 of each section for displacing fluid from each chambers' inlet to its respective
13 discharge when rotated, the pair of rotors for each section being aligned axially
14 with the pair of rotors for each other section;

15 a drive shaft extending axially and rotatably into each chamber for
16 rotating one rotor of the pair of rotors in each section;

17 an idler shaft parallel to the drive shaft and extending axially and
18 rotatably into each chamber for the other rotor of the pair of rotors; and

19 timing means between the drive shaft and idler shaft for contra-
20 rotating the drive and idler shafts and the pair of rotors.

21
22 2. The positive displacement fluid device of claim 1 wherein
23 fluid is driven from the fluid source to the fluid destination for fluidly driving the
24 pair of rotors so as to motor the drive shaft.

25

1 3. The positive displacement fluid device of claim 1 wherein the
2 fluid device is a pump and the chambers are rotor chambers and wherein the
3 drive shaft is driven for contra-rotating the pair of rotors so as to cause fluid to be
4 pumped through the rotor chambers from the fluid source to the fluid destination.

5

6 4. The positive displacement pump of claim 3 wherein each of
7 the pair of rotors comprises a circumferential piston, further comprising:

8 a pair of bosses extending into each rotor chamber, each boss
9 having a cylindrical bore for rotatably passing the drive and idler shafts; and

10 bearings fit into the bore of each boss for rotatably supporting the
11 drive and idler shafts.

12

13 5. The positive displacement pump of claim 4 wherein the
14 bearings are complementary facing hard bearing surfaces in the boss and on the
15 drive and idler shafts.

16

17 6. The positive displacement pump of claim 5 wherein the
18 complementary facing hard bearing surfaces are manufactured from material
19 selected from the group consisting of tungsten carbide, silicon carbide and
20 ceramics.

21

1 7. The positive displacement fluid device of claim 3 wherein at
2 least one section is a suction stage and at least one section is a pressure stage
3 further comprising a cross-over section sandwiched between the suction and
4 pressure stages for fluidly connecting the discharge of suction stage to the inlet of
5 the pressure stage.

6
7 8. The positive displacement fluid device of claim 7 further
8 comprising seals sandwiched between each suction section, each crossover
9 section and each pressure section.

10
11 9. The positive displacement fluid device of claim 3 further
12 comprising:

13 at least one suction stage having one or more suction pump
14 sections stacked together, the discharges of which are fluidly connected to form a
15 discharge manifold;

16 at least one pressure stage, each having one or more pressure
17 pump sections stacked together, the inlets of each pressure pump section being
18 fluidly connected to form a suction manifold and the discharges of which are
19 connected to form a discharge manifold; and

20 a cross-over section sandwiched between the suction stage and
21 each successive pressure stage, the cross-over section having passage for fluid
22 connection of each stage's discharge manifold to the suction manifold of each
23 successive pressure stage.

24

1 10. The positive displacement fluid device of claim 9 wherein two
2 or more pressure stages are stacked successively together, further comprising a
3 cross-over section sandwiched between each successive stage, the cross-over
4 section having a passage for fluid connection between one pressure stage's
5 discharge manifold and the successive pressure stage's suction manifold.

6

7 11. The positive displacement fluid device of claim 9 further
8 comprising:

9 a tubular housing having a wall and a bore, the one or more suction
10 stages, one or more cross-over sections and one or more pressure stages being
11 sandwiched sealingly together and housed within the bore, the housing being
12 adapted for immersion in the fluid source;

13 inlet ports formed in the wall corresponding to and in fluid
14 communication with each of the inlets of the at least one suction section; and

15 a discharge port in fluid communication with the discharge of the
16 pressure stage and with the fluid destination.

17

1 12. The positive displacement fluid device of claim 9 further
2 comprising:

3 a tubular housing having a wall and a bore, the one or more suction
4 stages, one or more cross-over sections and one or more pressure stages being
5 sandwiched sealingly together and housed within the bore, the housing being
6 adapted for immersion in the fluid source;

7 a suction manifold which fluidly connects the inlets of the suction
8 sections in the suction stage;

9 an inlet port in fluid communication with the suction manifold of the
10 suction stage; and

11 a discharge port in fluid communication with the discharge of the
12 pressure stage and with the fluid destination.

13

14 13. The positive displacement fluid device of claim 4 wherein as
15 the drive shaft rotates, the first and second rotors of each pumping section rotate
16 and each pumping section discharges fluid pulses according to the angular
17 position of the rotors and wherein the first rotor of two or more of the pumping
18 sections are angularly incremented on the drive shaft so that discharge pulses
19 from the two or more pumping sections occur at different angular positions of the
20 drive shaft; and

21 a cross-over section sandwiched between each successive stage,
22 the block having passage for fluid connection between one pressure stage's
23 discharge manifold and the successive pressure stage's suction manifold.

24

1 14. The positive displacement fluid device of claim 13 wherein
2 each pump section further comprises:

3 a pump housing forming a rotor chamber and a discharge chamber;
4 first and second end plates for enclosing the rotor chamber and at
5 least one of the end plates between adjacent pump housings having a discharge
6 chamber which is in communication with the discharge chamber of the pump
7 housing for forming a discharge manifold;

8 first and second cooperating rotors operable in the rotor chamber to
9 displace fluid from the inlet to the discharge chamber of the pump housing and to
10 discharge manifold.

11

12 15. The positive displacement pump of claim 14 further
13 comprising:

14 a drive shaft extending through at least one end plate for rotating
15 one rotor;

16 an idler shaft extending through the at least one end plate which is
17 driven by the drive shaft for rotating the other rotor; and

18 timing means between the drive shaft and idler shaft for contra-
19 rotating the first and second rotors so that they cooperate to pump fluid.

20

1 16. The positive displacement fluid device of claim 15 wherein
2 the rotors are first and second circumferential pistons mounted for co-rotation
3 with the drive shaft and idler shaft, further comprising:

4 first and second bosses extending from an end plate, the first and
5 second rotors being positioned in the rotor chamber and about the first and
6 second bosses for pumping fluid through the rotor chamber; and

7 bearings rotatably supporting the drive and idler shafts in the
8 bosses.

9

10 17. The positive displacement fluid device of claim 16 wherein
11 the bearings are complementary facing hard bearing surfaces.

12

13 18. The positive displacement fluid device of claim 17 wherein
14 the complementary facing hard bearing surfaces are manufactured from material
15 selected from the group consisting of tungsten carbide, silicon carbide and
16 ceramics.

17

18 19. The positive displacement fluid device of claim 18 further
19 comprising a cross-over section between the discharge of the at least one suction
20 pump section and the inlet of the at least one pressure pump section.

21

22 20. The positive displacement fluid device of claim 19 wherein
23 the seals comprise high temperature O-ring seals.

24

1 21. A multi-stage positive displacement pump comprising:
2 a suction stage having one or more axially stacked positive
3 displacement suction pump sections, each suction pump section having a rotor
4 chamber for pumping fluid from an inlet adapted for connection to a fluid source
5 to a discharge manifold;
6 at least one pressure stage, each stage having one or more
7 stacked positive displacement pressure pump sections, each pressure pump
8 section having a rotor chamber for pumping fluid from a suction manifold to a
9 discharge manifold adapted for connection to a fluid destination;
10 a crossover section for fluidly connecting the discharge manifold of
11 the suction stage to the suction manifold of the pressure stage; and
12 drive means extending axially into each suction pump section and
13 into each pressure pump section which rotates for moving fluid from the fluid
14 source to the fluid destination.

15

16 22. The positive displacement fluid device of claim 21 further
17 comprising:

18 a tubular housing having a wall and a bore, the suction stage, cross-
19 over section and pressure stage being sandwiched sealingly together and housed
20 within the bore, the housing being adapted for immersion in the fluid source;

21 an inlet port formed in the wall of the housing and corresponding to
22 each pump section, the inlet ports being in fluid communication with each pump
23 section inlet; and

24 a discharge port formed in the housing and in fluid communication with
25 the discharge of the pressure stage and with the fluid destination.

1 23. The positive displacement fluid device of claim 21 further
2 comprising:

3 a pair of cooperating rotors operable in the rotor chamber of each
4 section for displacing fluid from the inlet to the discharge when rotated; and
5 wherein the drive means comprises:

6 a drive shaft extending rotatably into the chamber of each section
7 for rotating the first rotors of each section,

8 an idler shaft extending rotatably into each rotor chamber for
9 rotating the second rotors of each pumping section, and

10 timing means between the drive shaft and idler shaft for contra-
11 rotating each of the rotors.

12

13 24. A method of pumping fluid comprising the steps of:

14 providing at least two positive displacement pump sections, each
15 pump section having at least two rotors in a rotor chamber and each rotor being
16 rotational about an axis for pumping fluid from a fluid suction to a fluid discharge;

17 stacking each pump section axially and sealably together so that so
18 that the respective axes of the rotors align and the discharges form a contiguous
19 discharge manifold;

20 driving the rotors of each pump section with a timed drive shaft and
21 cooperating idler shaft each of which extend axially and drivably through the axis
22 of each rotor of each pump section so, that when the rotors are rotated, the pump
23 sections draws fluid through their inlets and discharges the fluid through the
24 discharge manifold.

25

1 25. The method of claim 24 further comprising:
2 providing a cross-over section which, when sandwiched between
3 two pump sections, fluidly connects the discharge of a pump section to the inlet
4 of a successive stacked pump section;
5 forming a suction stage by stacking each pump section within the
6 suction stage so that the respective axes of the rotors align and the discharges
7 forming a contiguous discharge manifold;
8 forming a pressure section by stacking each pump section within
9 the pressure stage so that the respective axes of the rotors align and also align
10 with the axes of the rotors of the suction section, the inlets form a contiguous
11 suction manifold and the discharges forming a contiguous discharge manifold;
12 drawing fluid through the inlets of each pump section in the suction
13 stage and discharging the fluid through the discharge manifold, through the
14 crossover section to the suction manifold of the pressure stage.

Application number / numéro de demande: 2387635

Figures: 1(a-b-c-d-e) 10

Pages: _____

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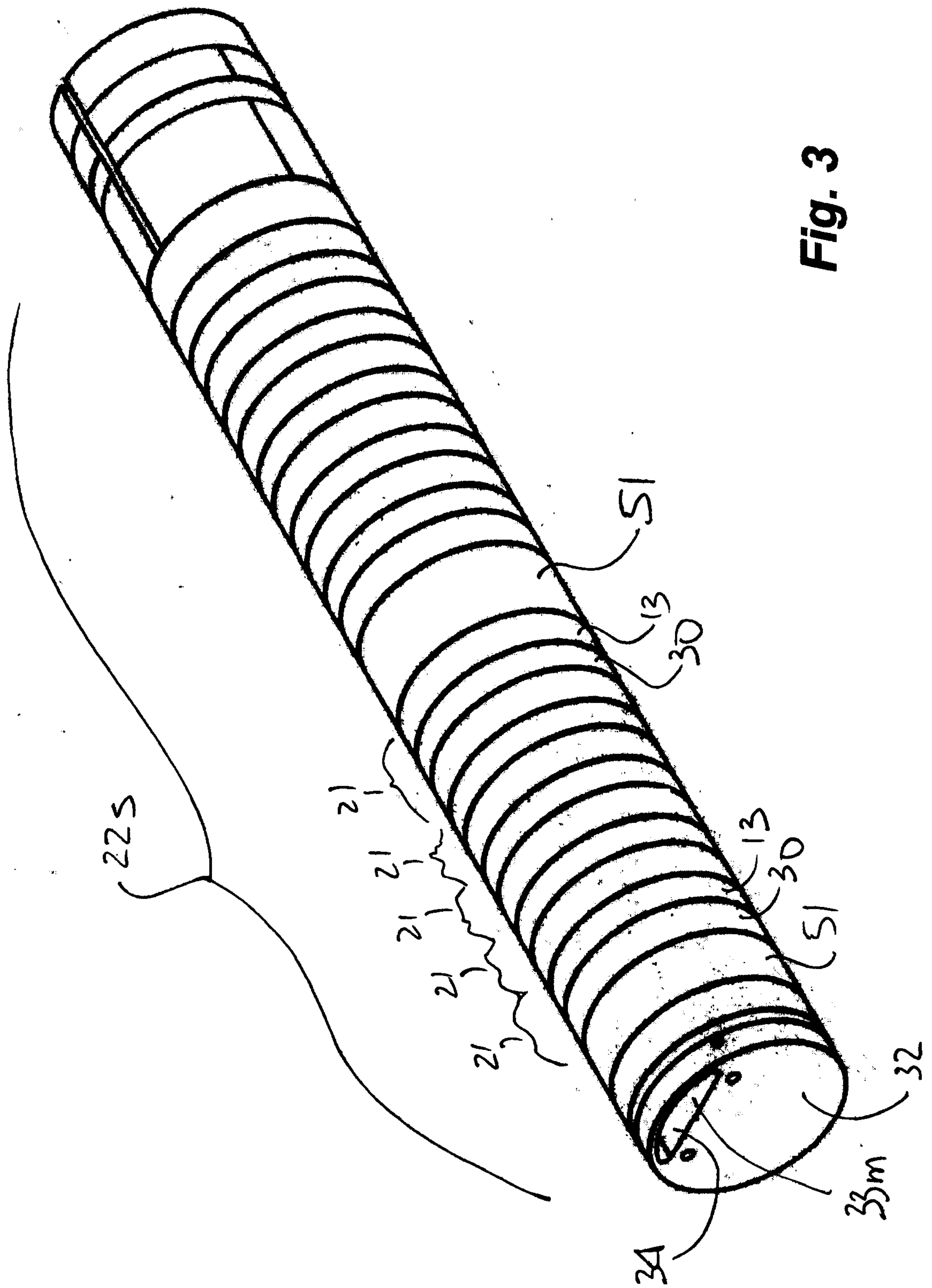


Fig. 3

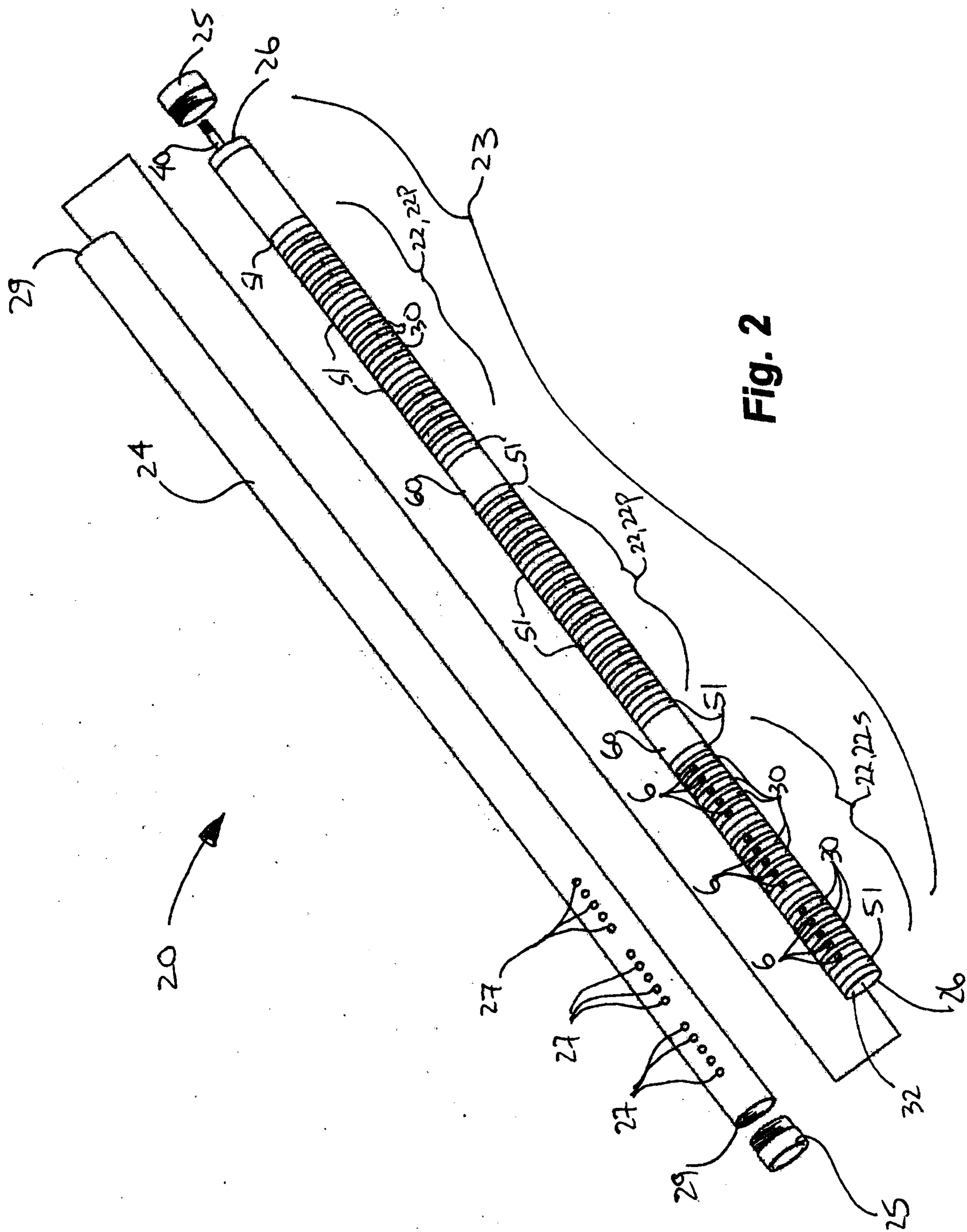


Fig. 2

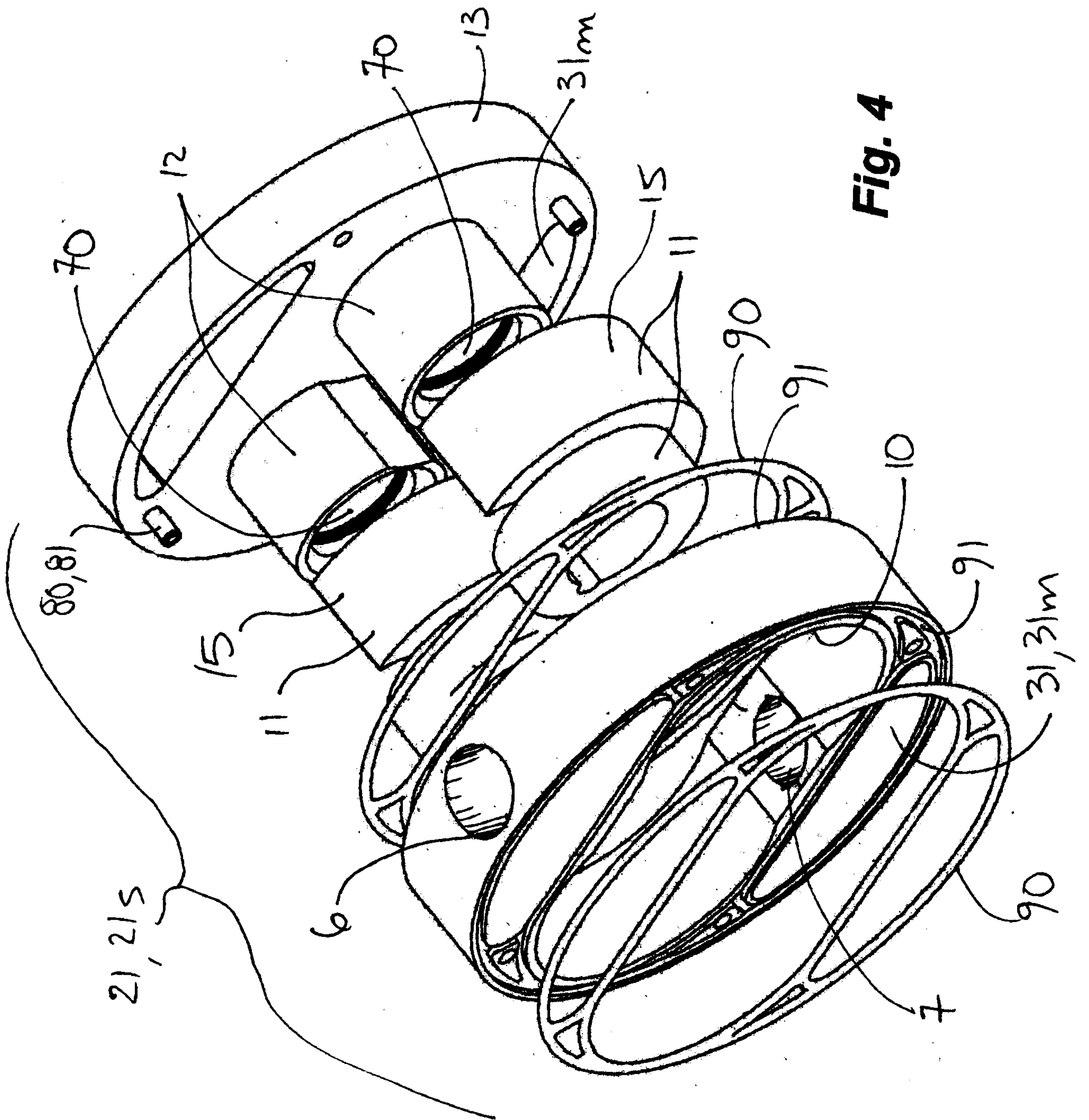


Fig. 4

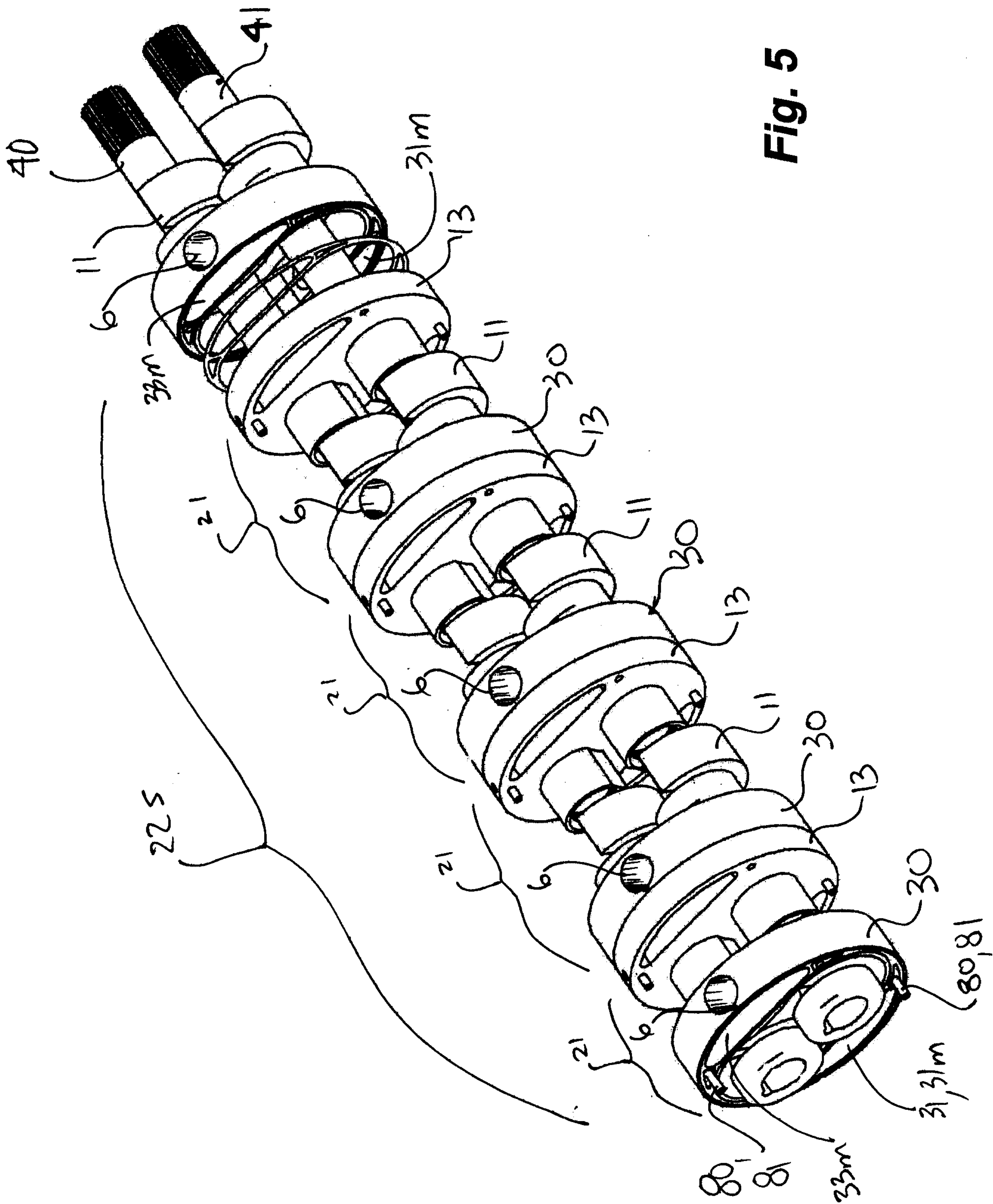


Fig. 5

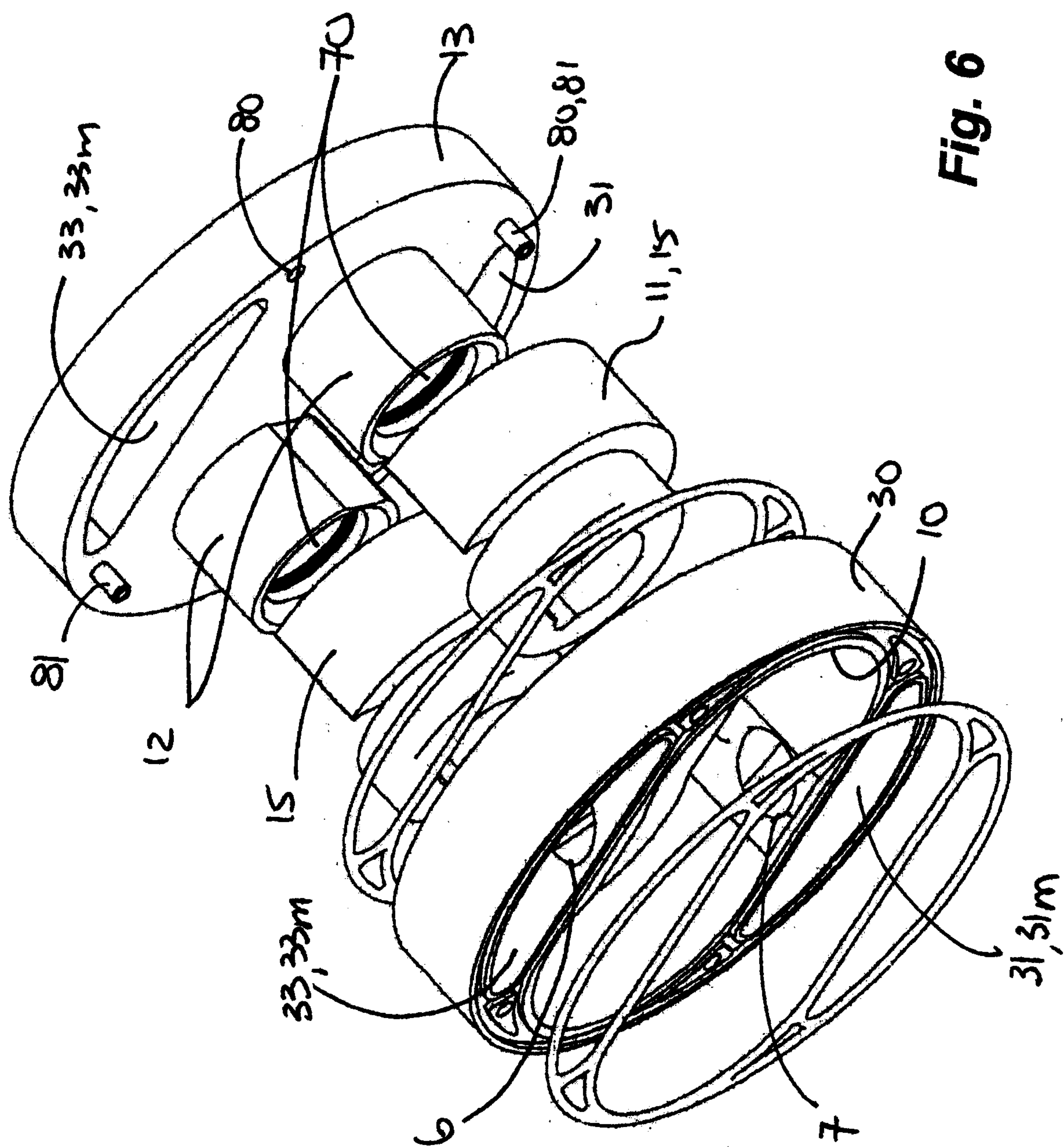


Fig. 6

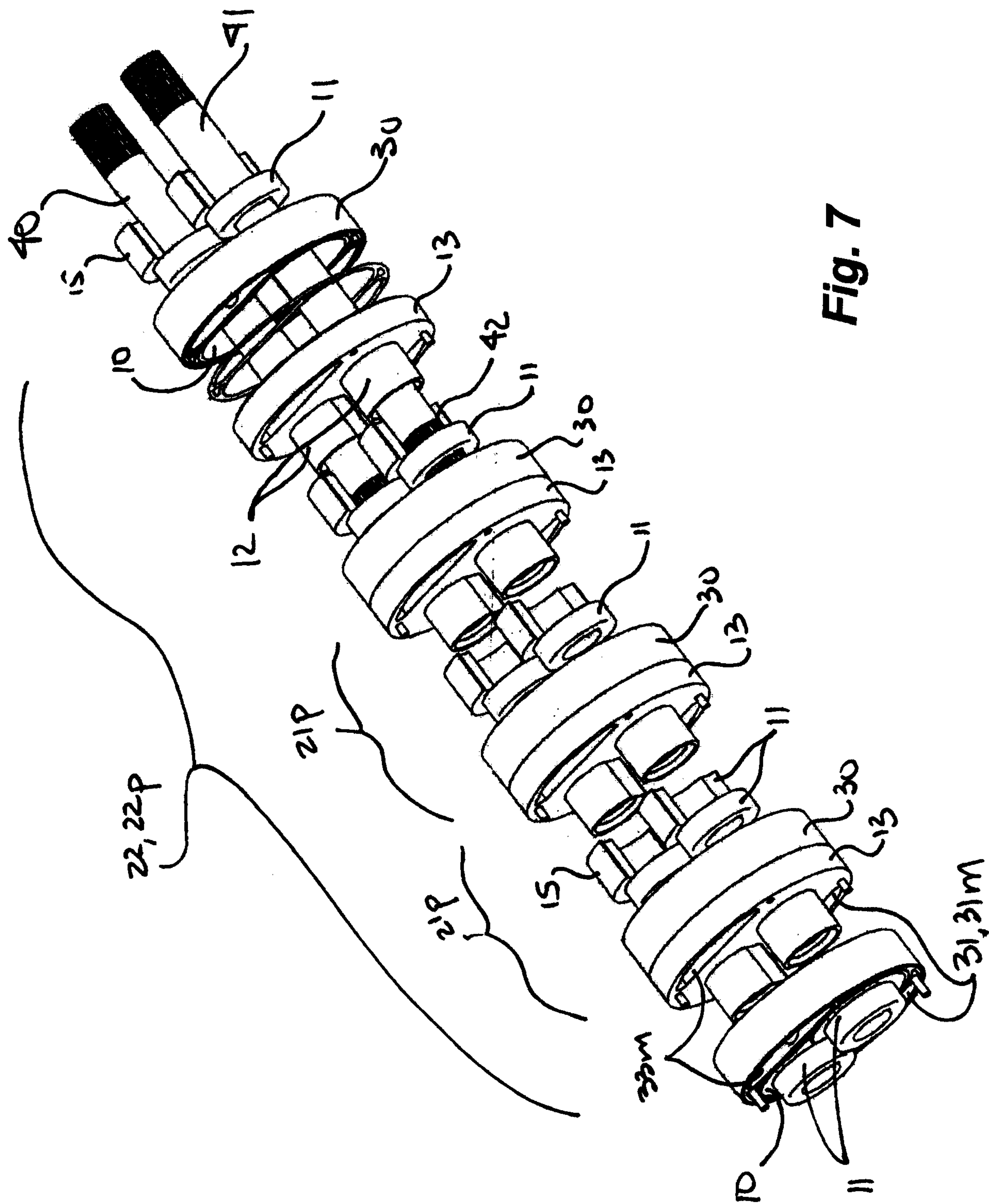


Fig. 7

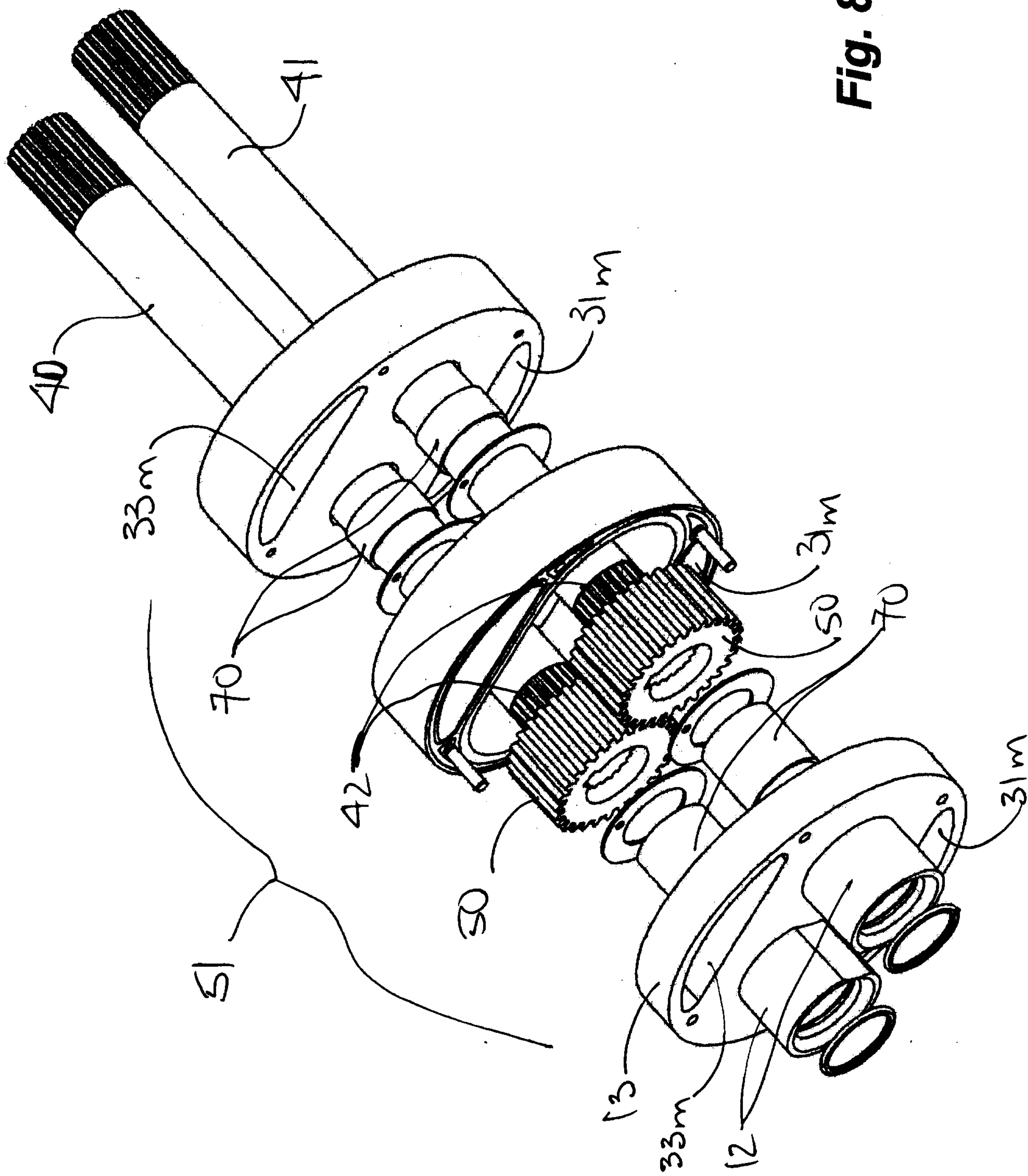


Fig. 8

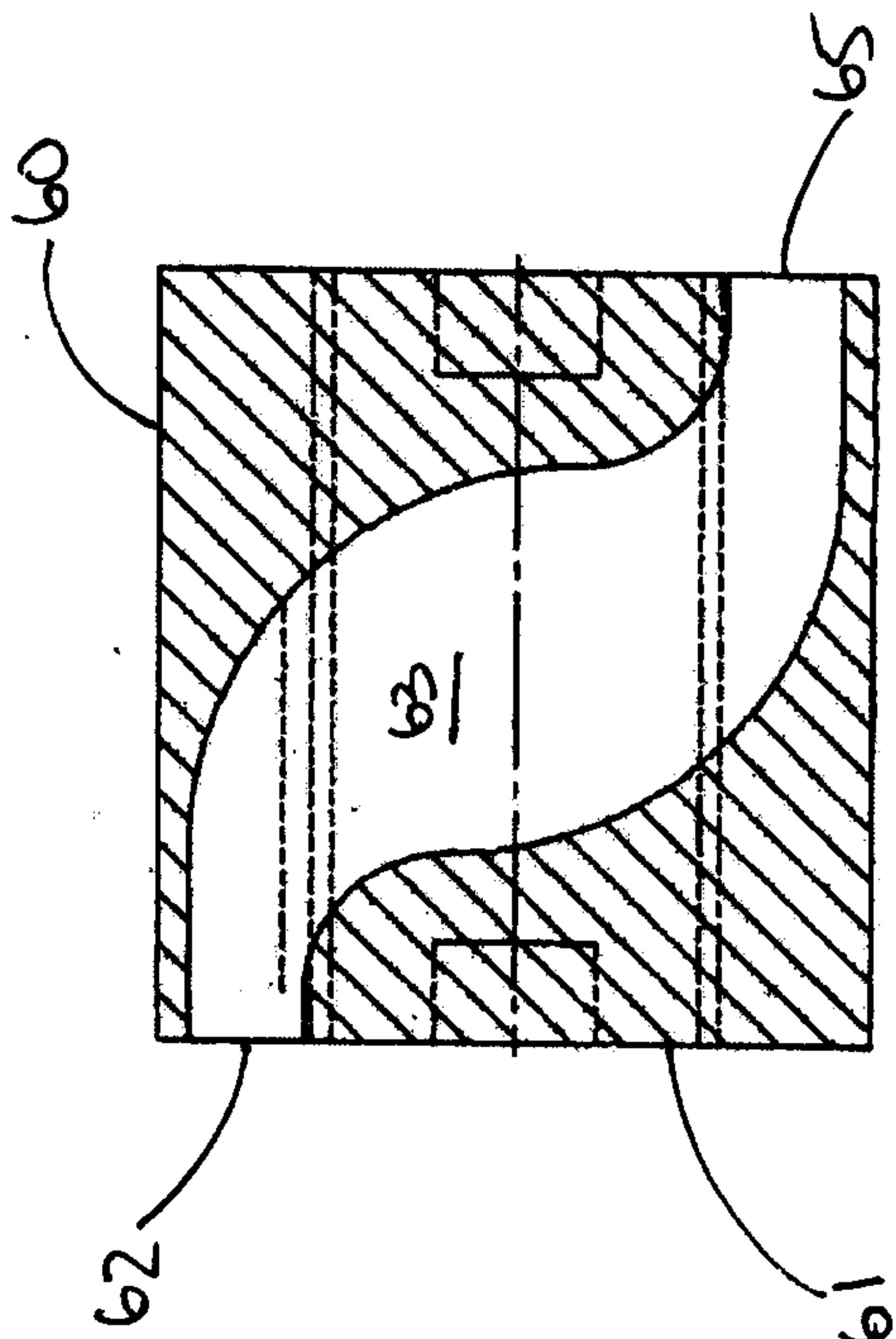


Fig. 9c

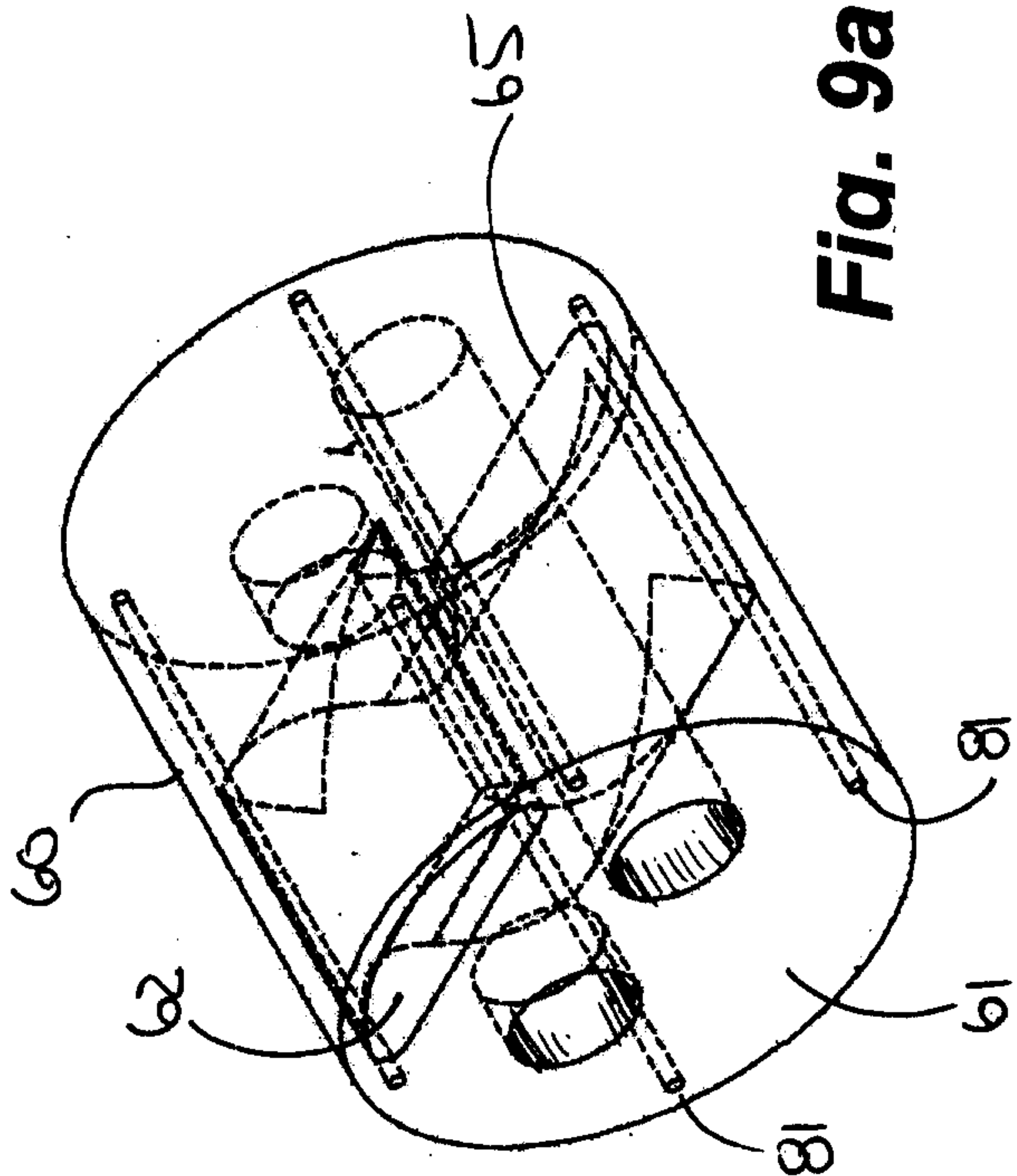


Fig. 9a

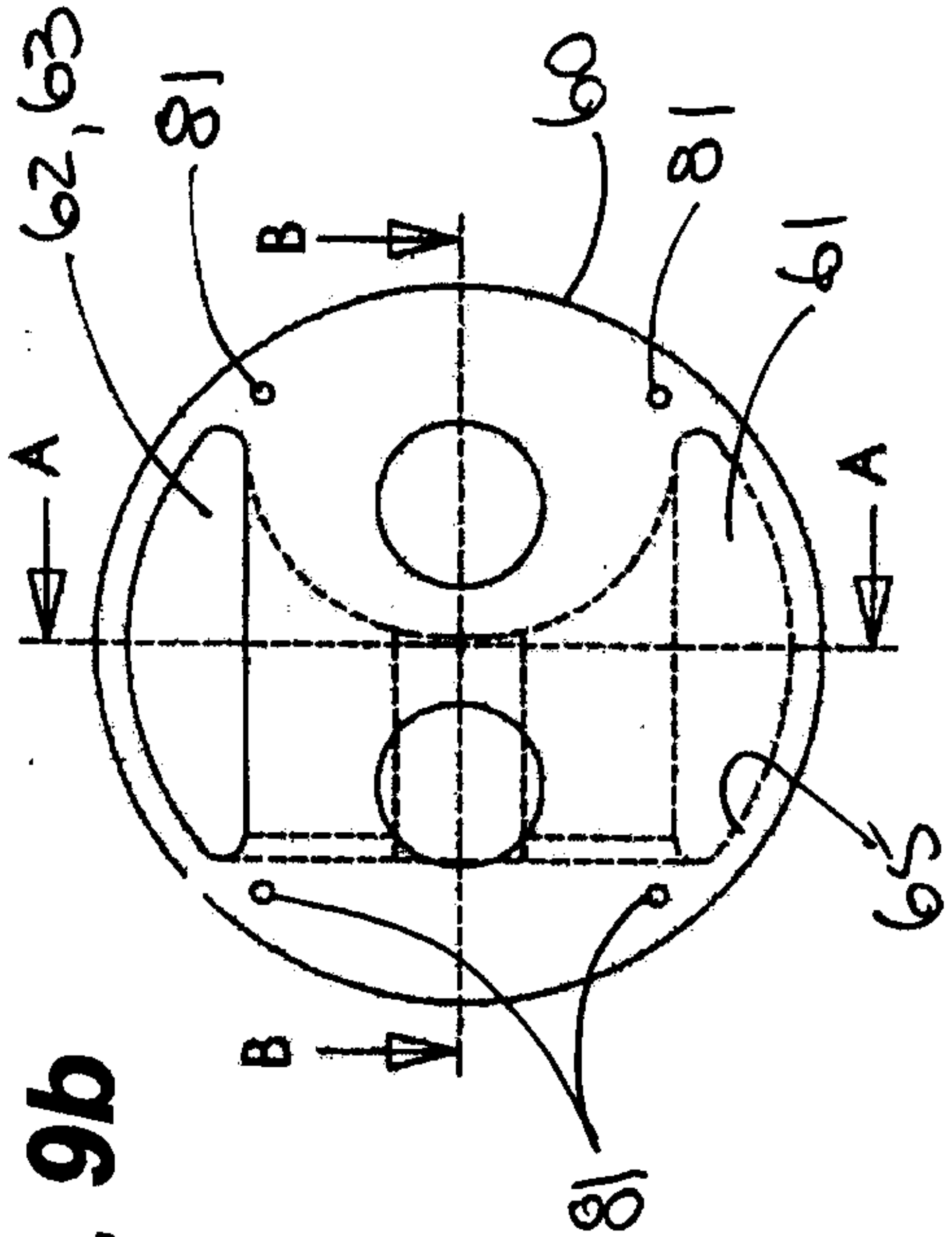


Fig. 9b

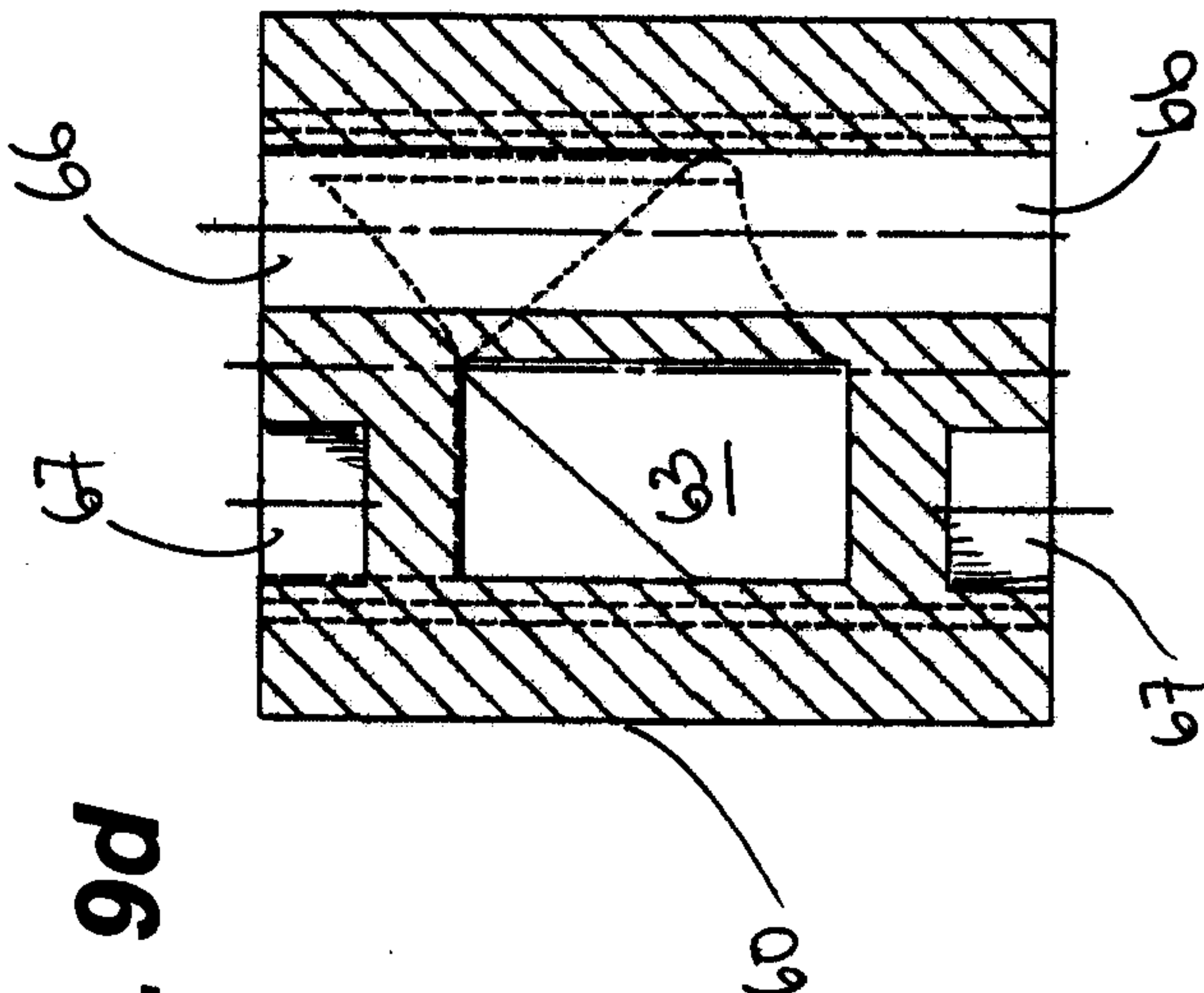


Fig. 9d

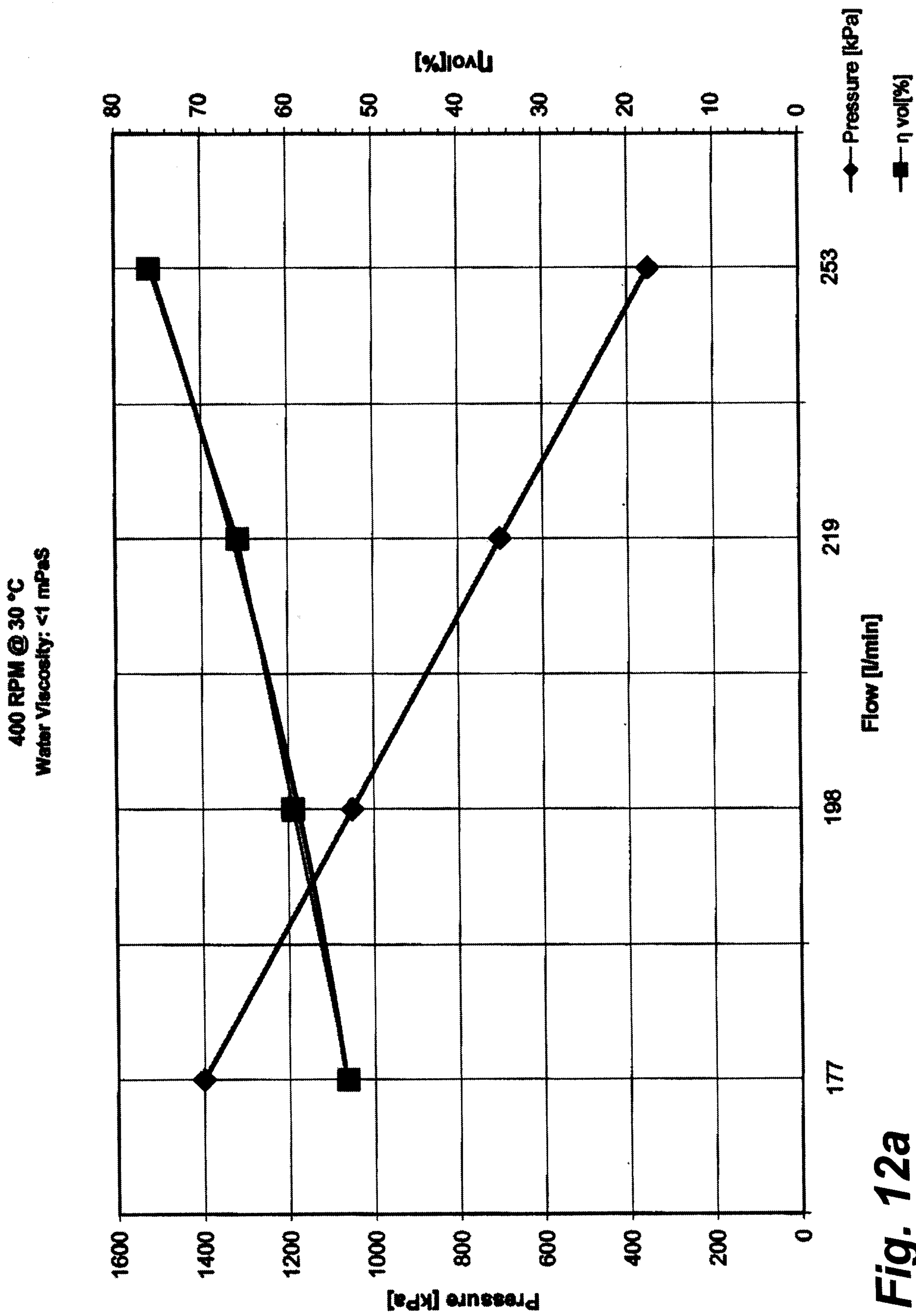
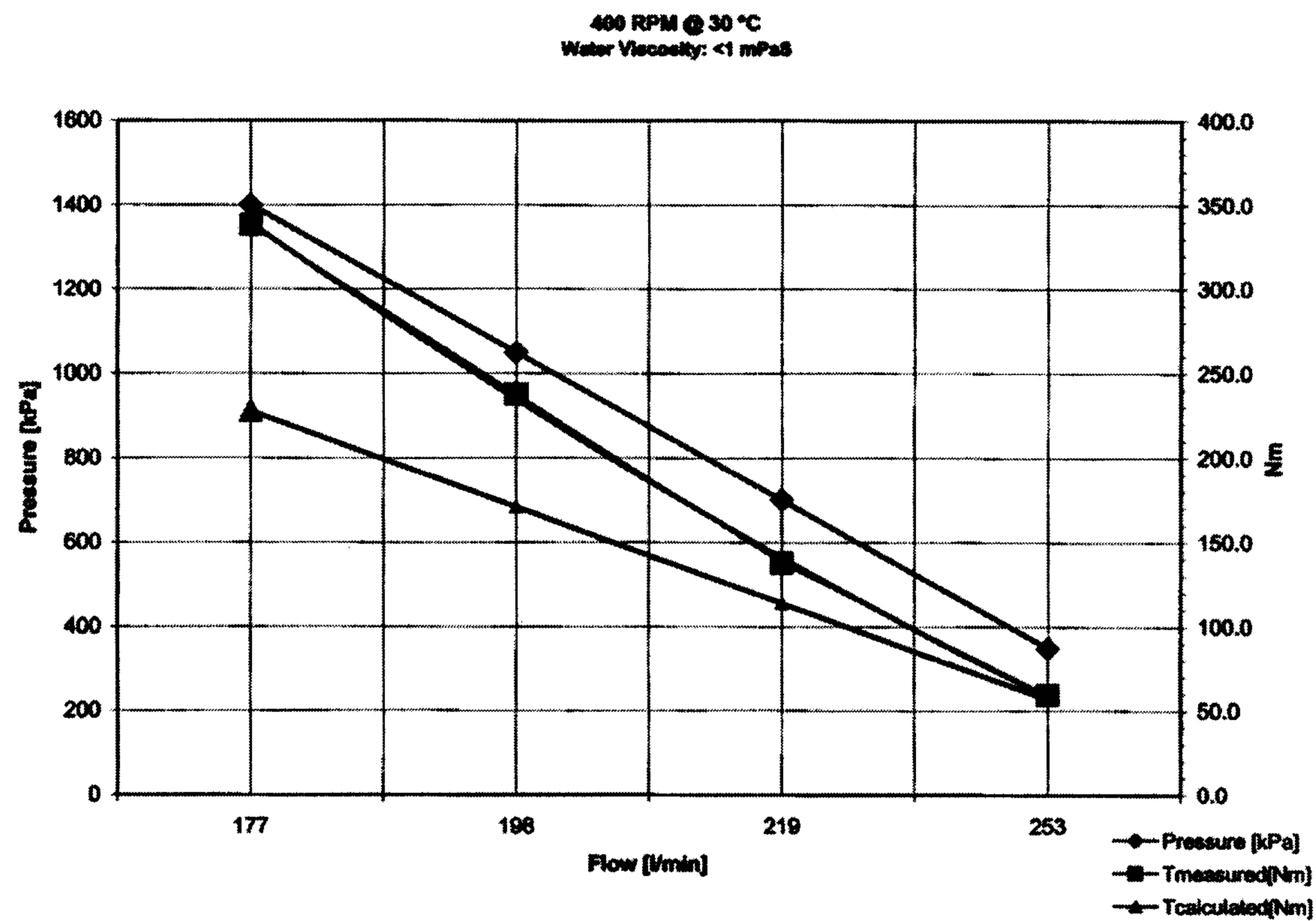
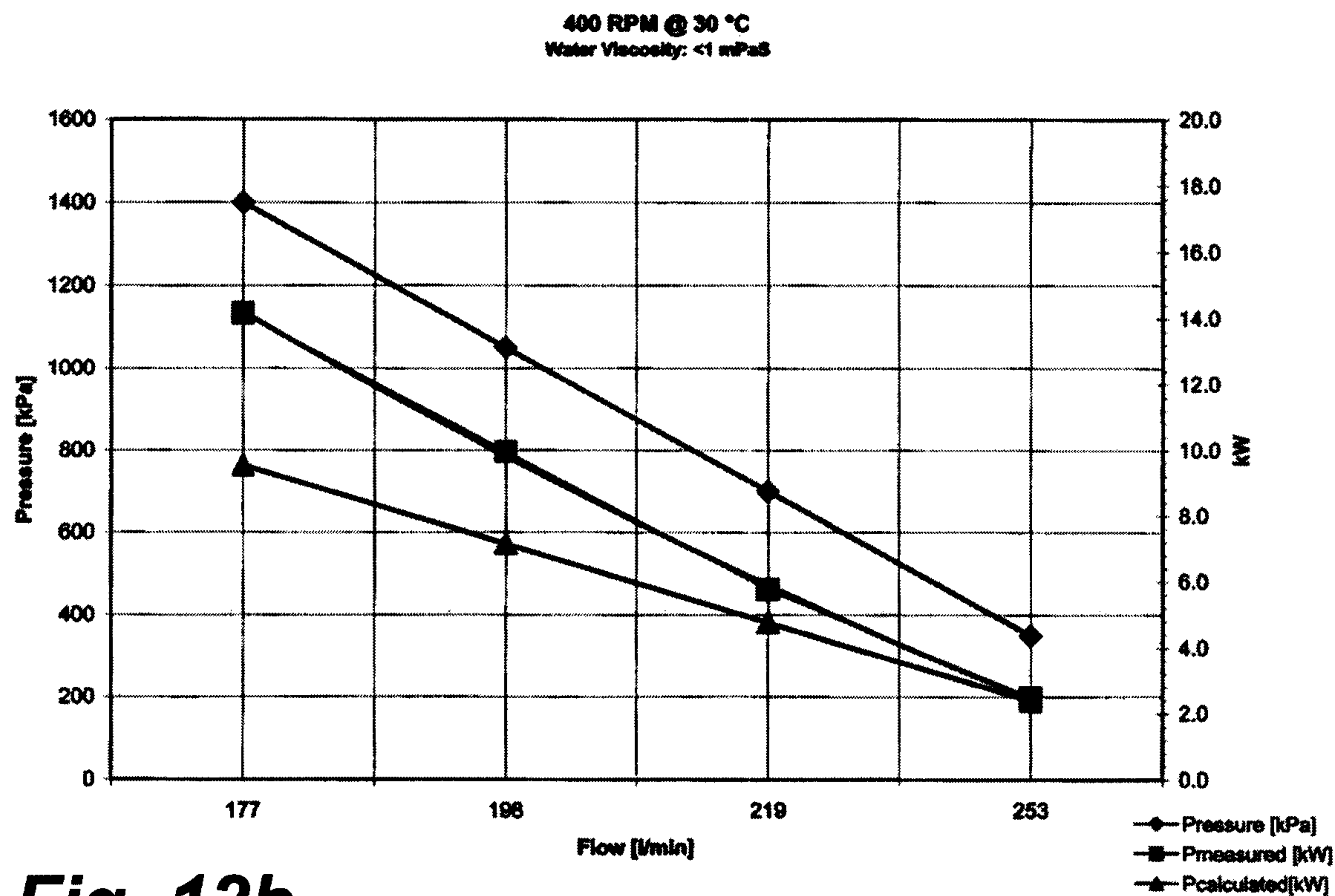


Fig. 12a



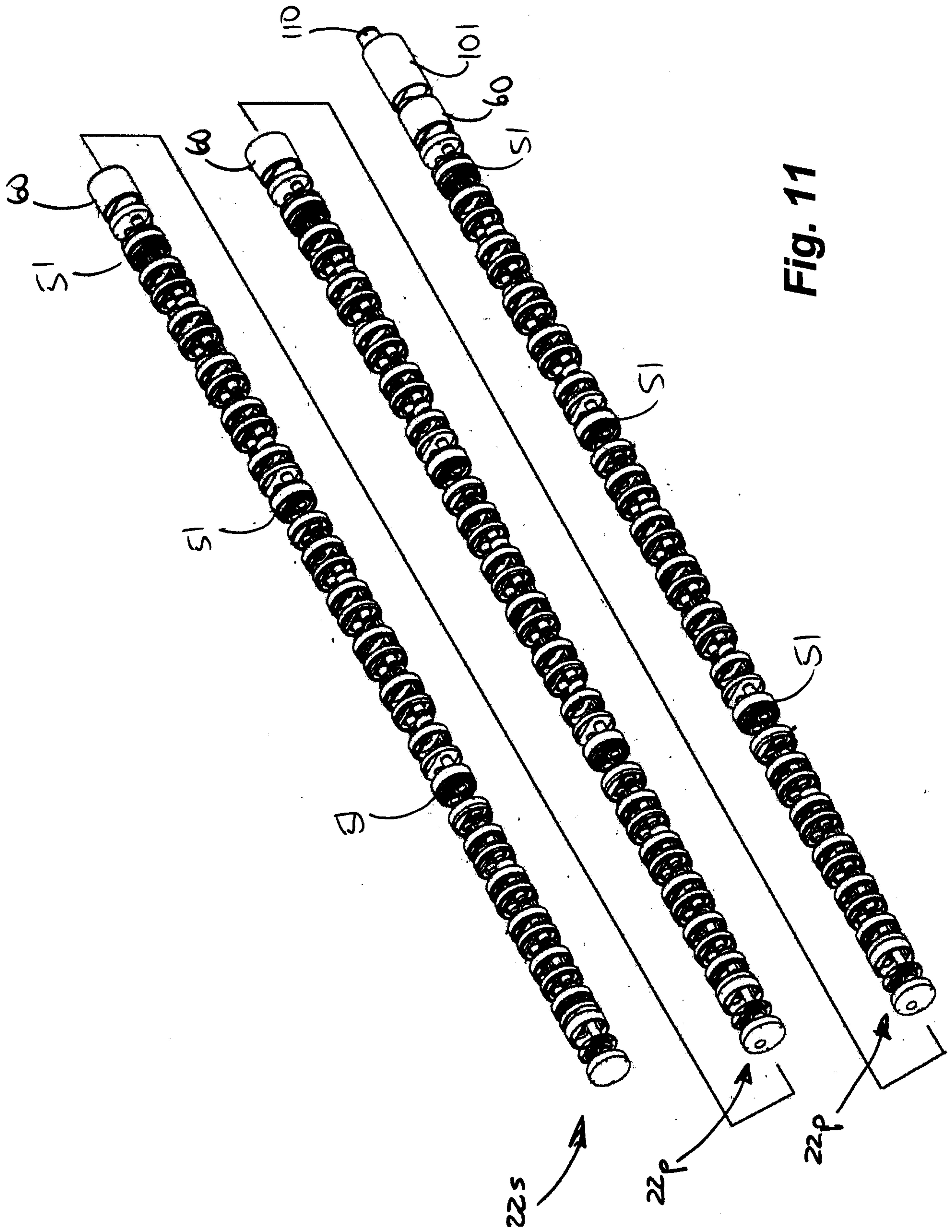


Fig. 11

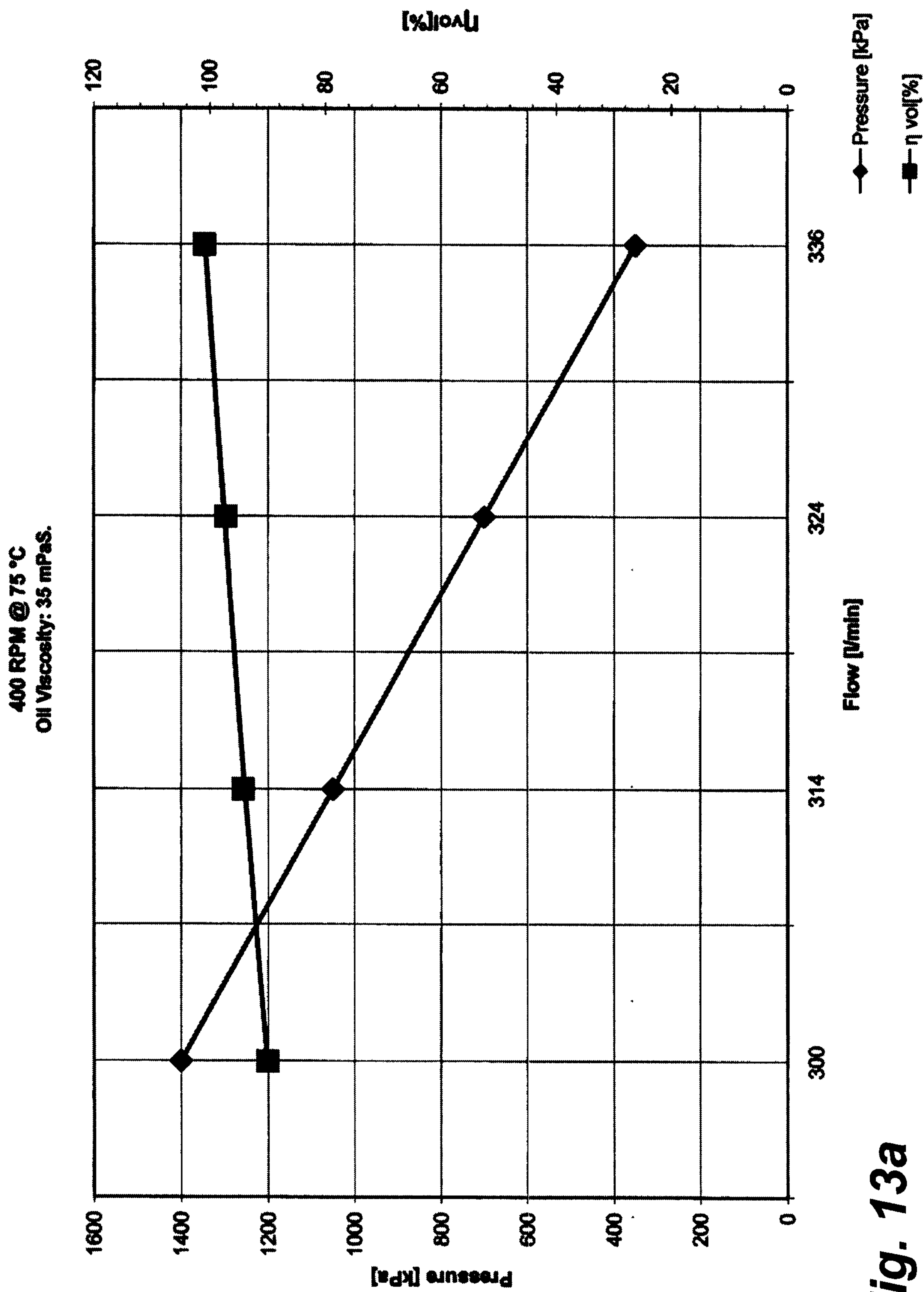
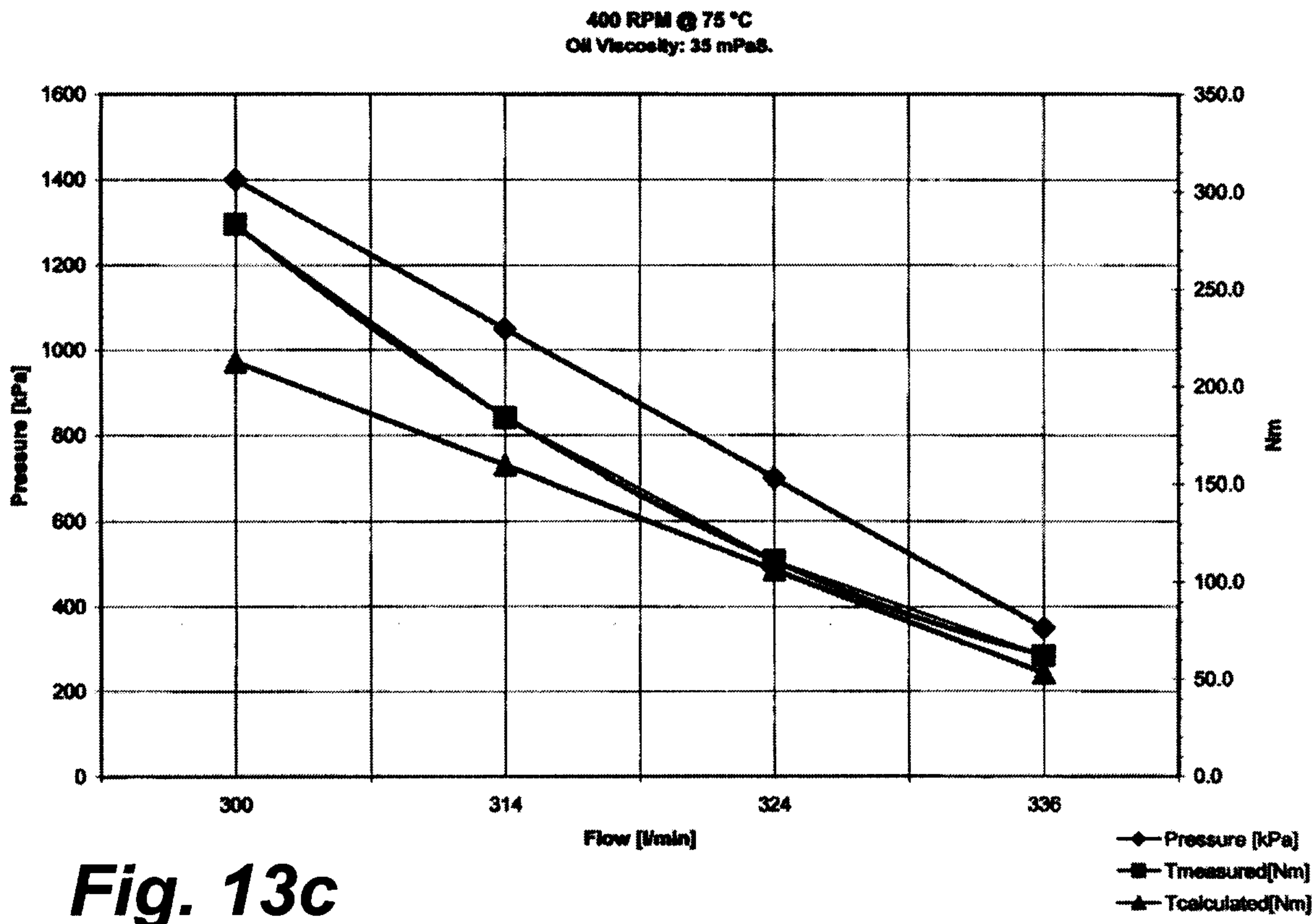
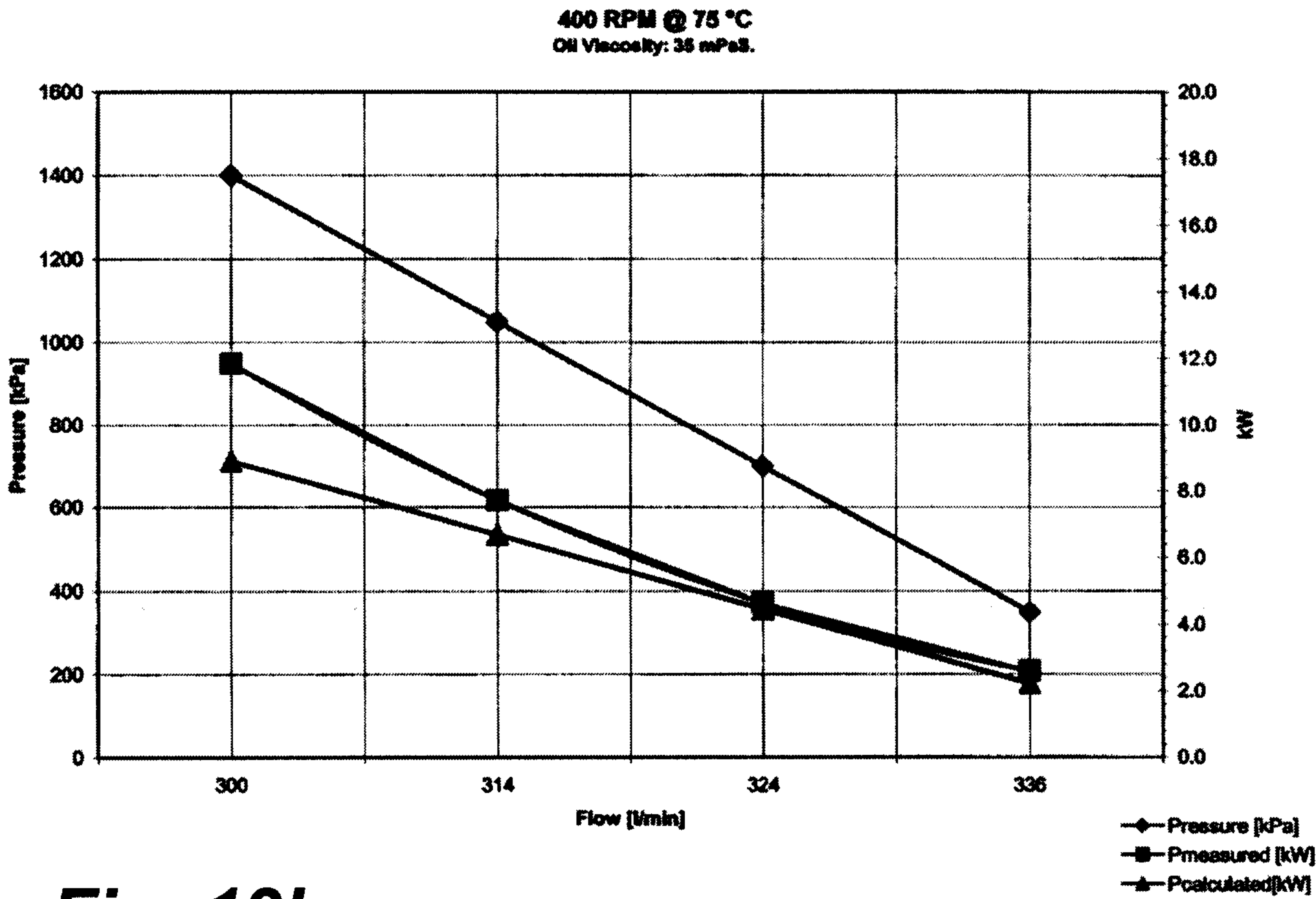


Fig. 13a



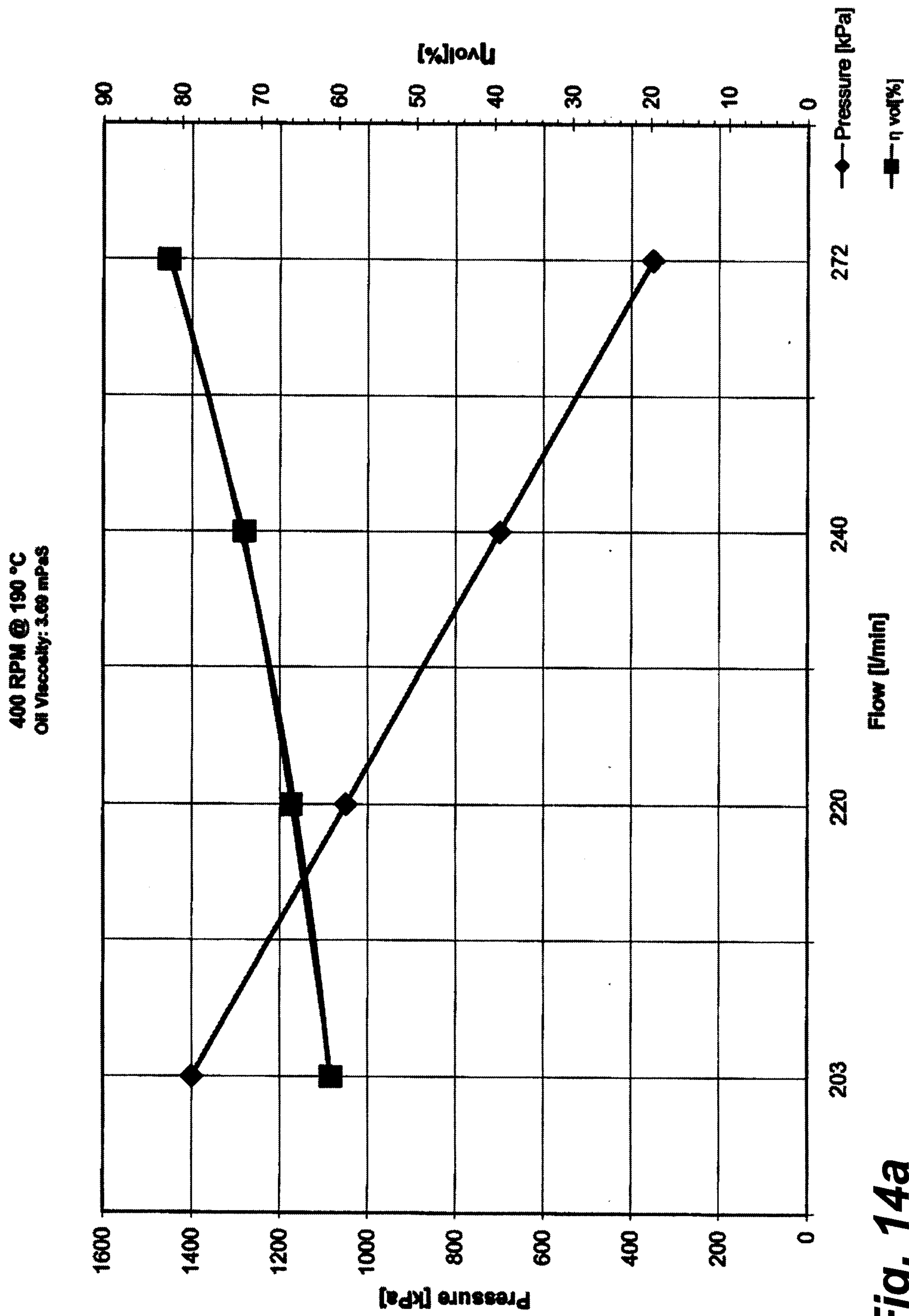


Fig. 14a

