Dec. 3, 1935. R. J. S. PIGOTT 2,022,781

DEEP WELL PUMPING AND PUMP

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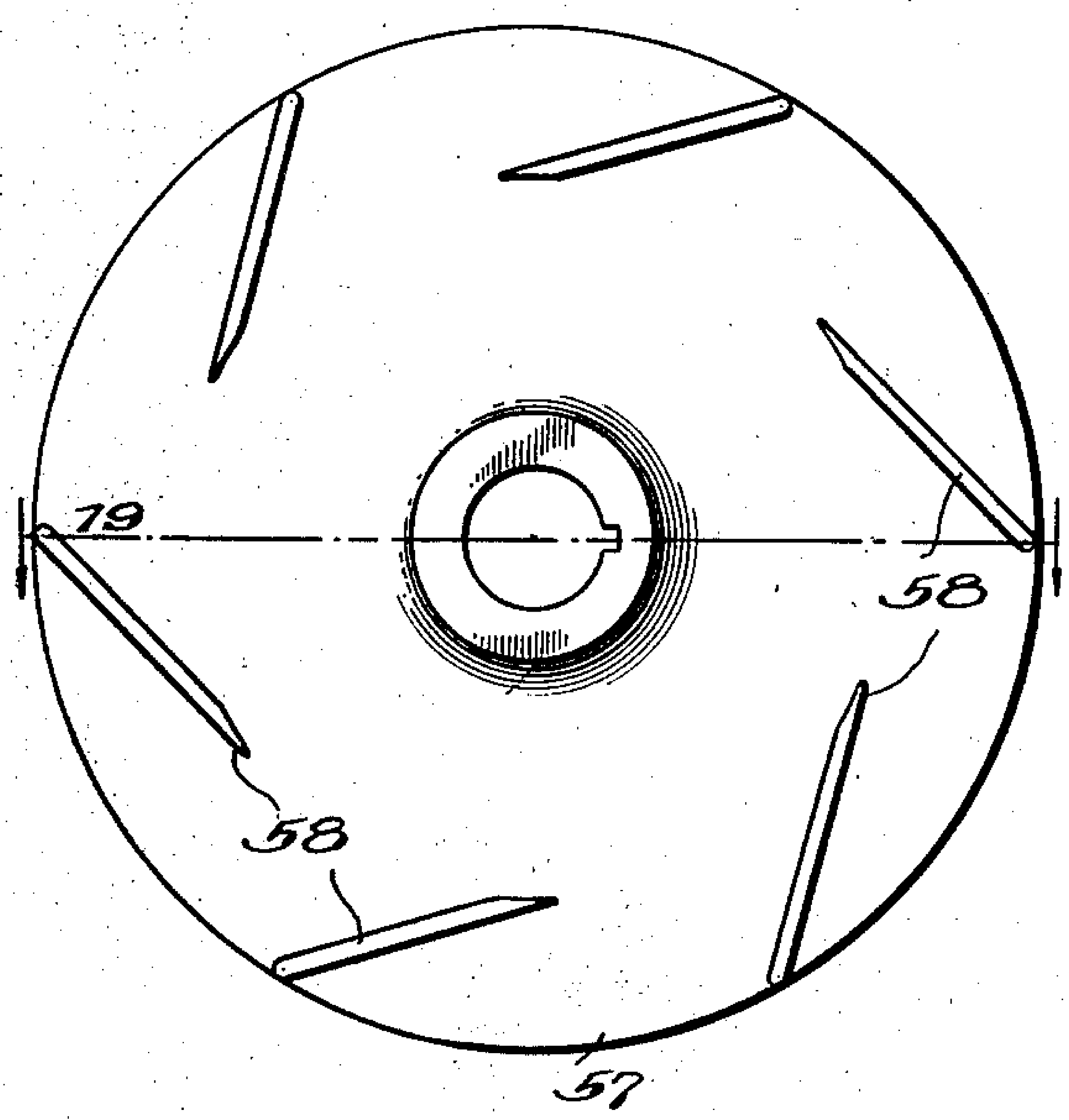
Fig. 18.



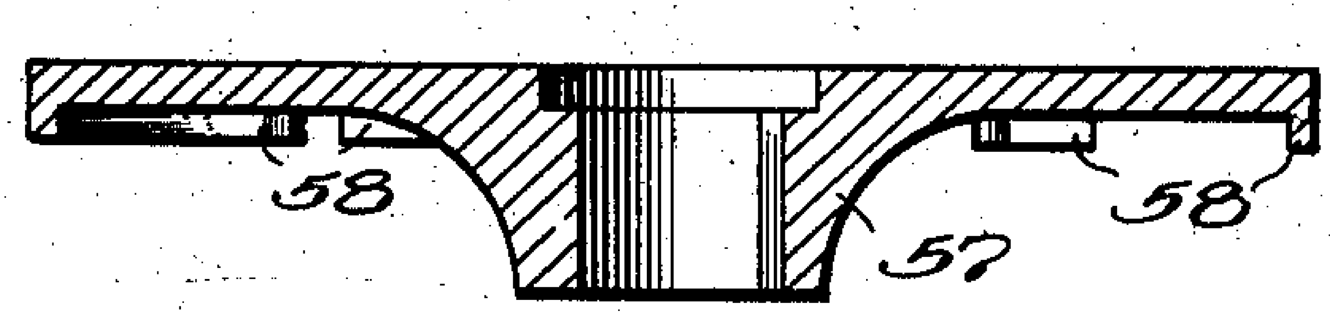


Fig. 19.

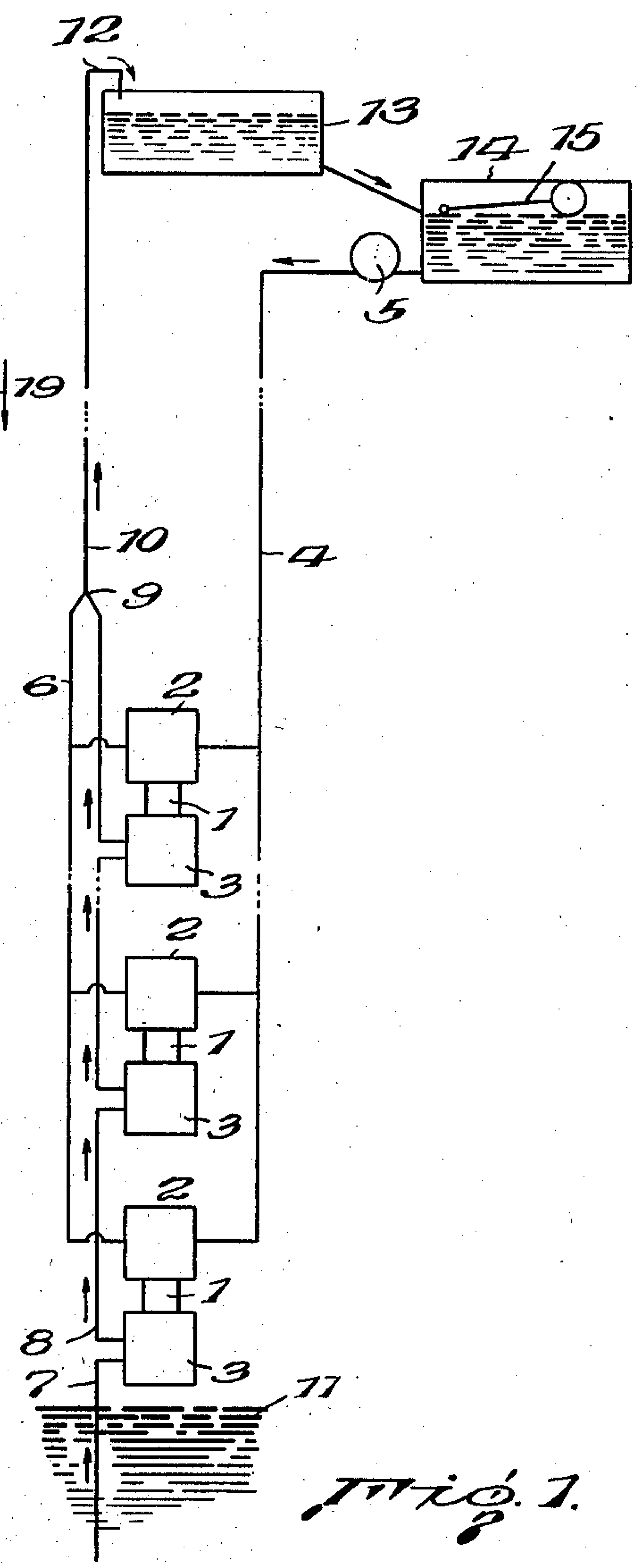


Fig. 1.

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DEEP WELL PUMPING AND PUMP

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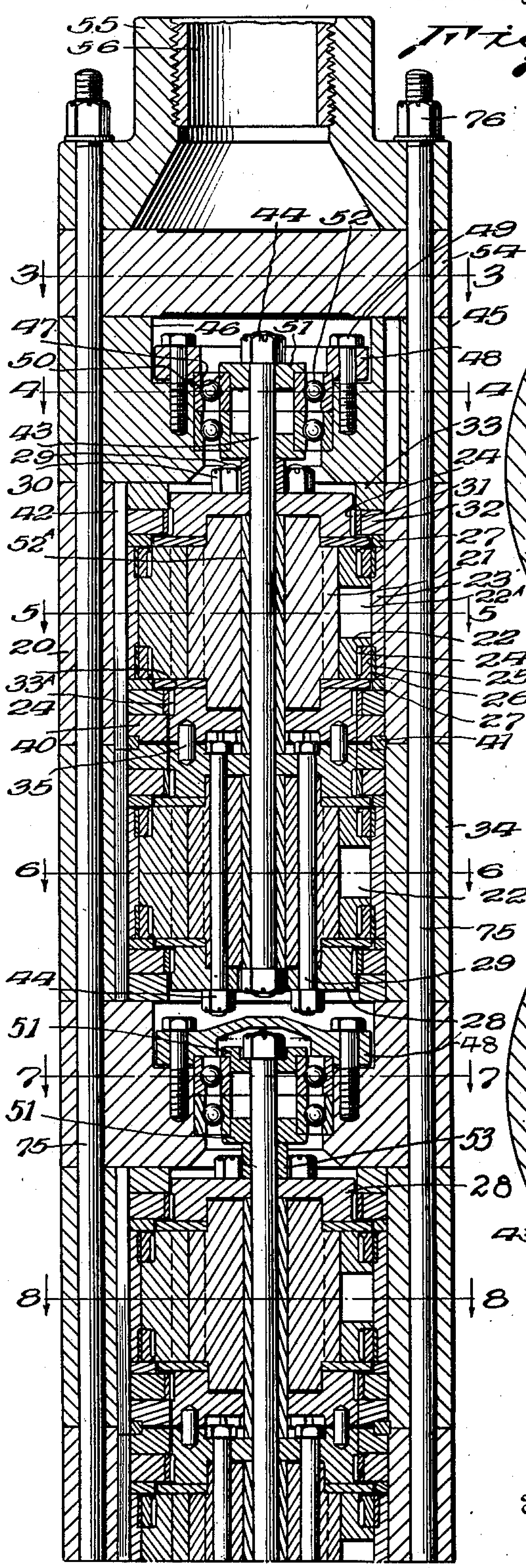

FIG. 2.

FIG. 3.

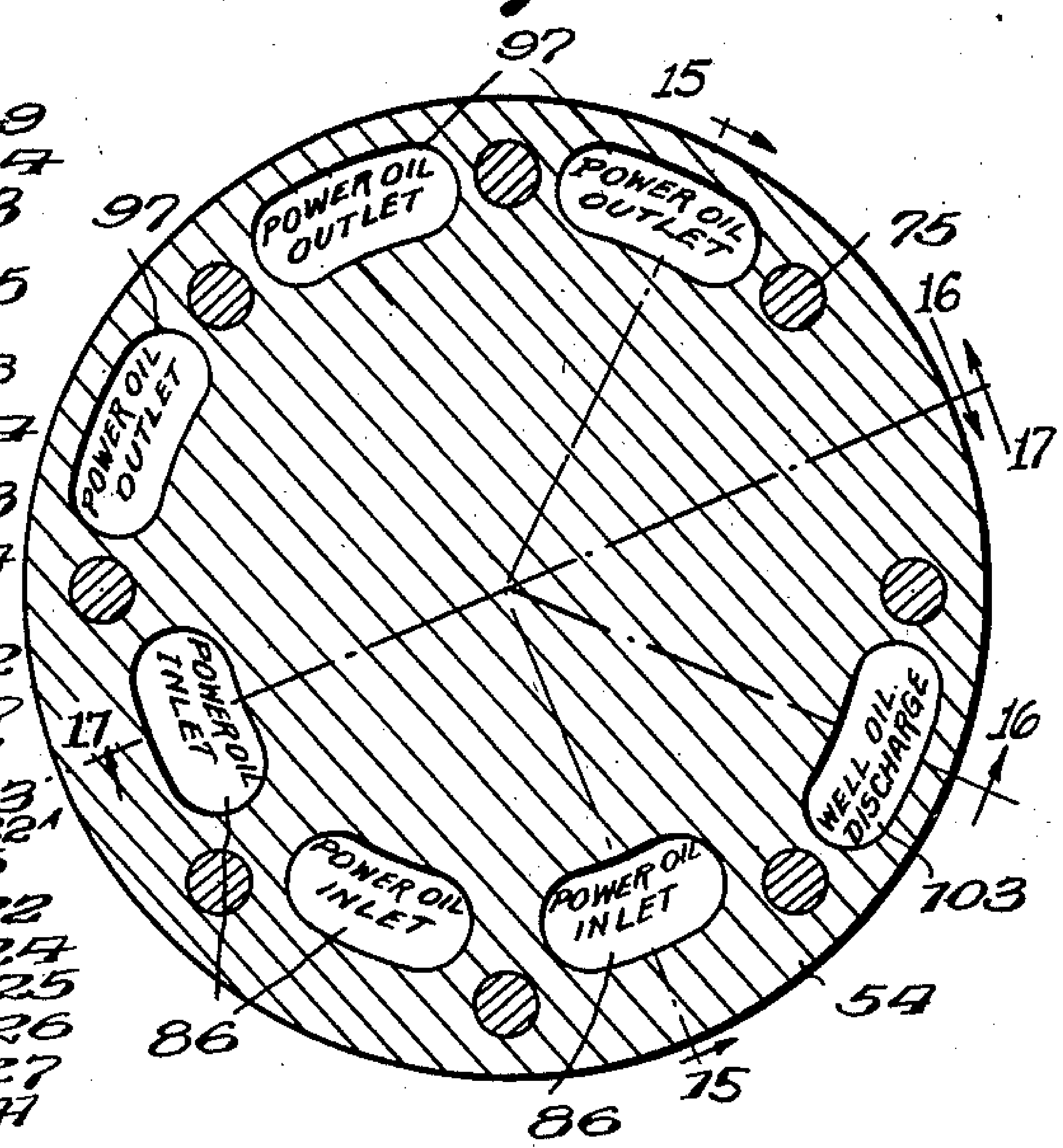

FIG. 4.

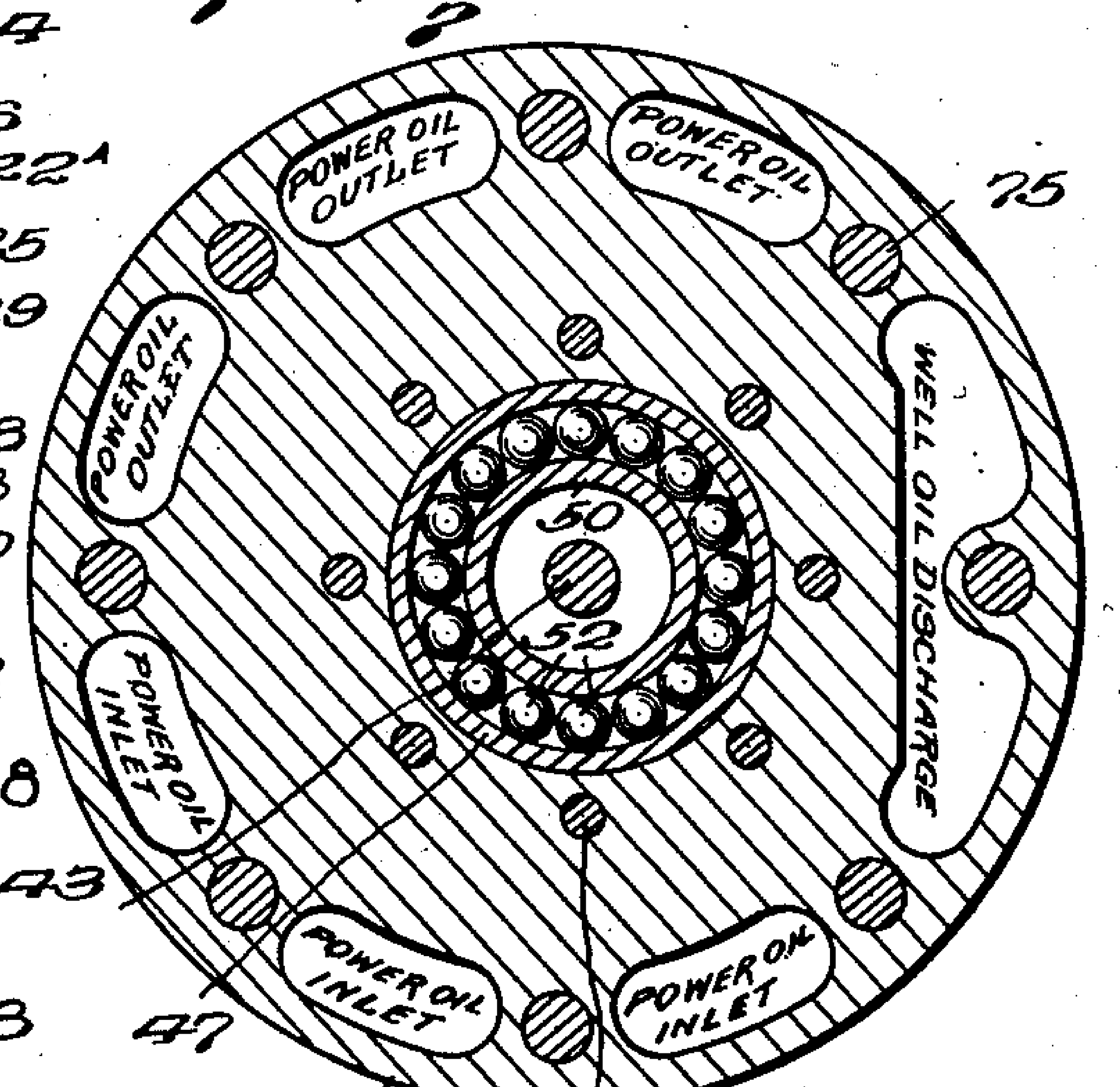

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Fig. 2a

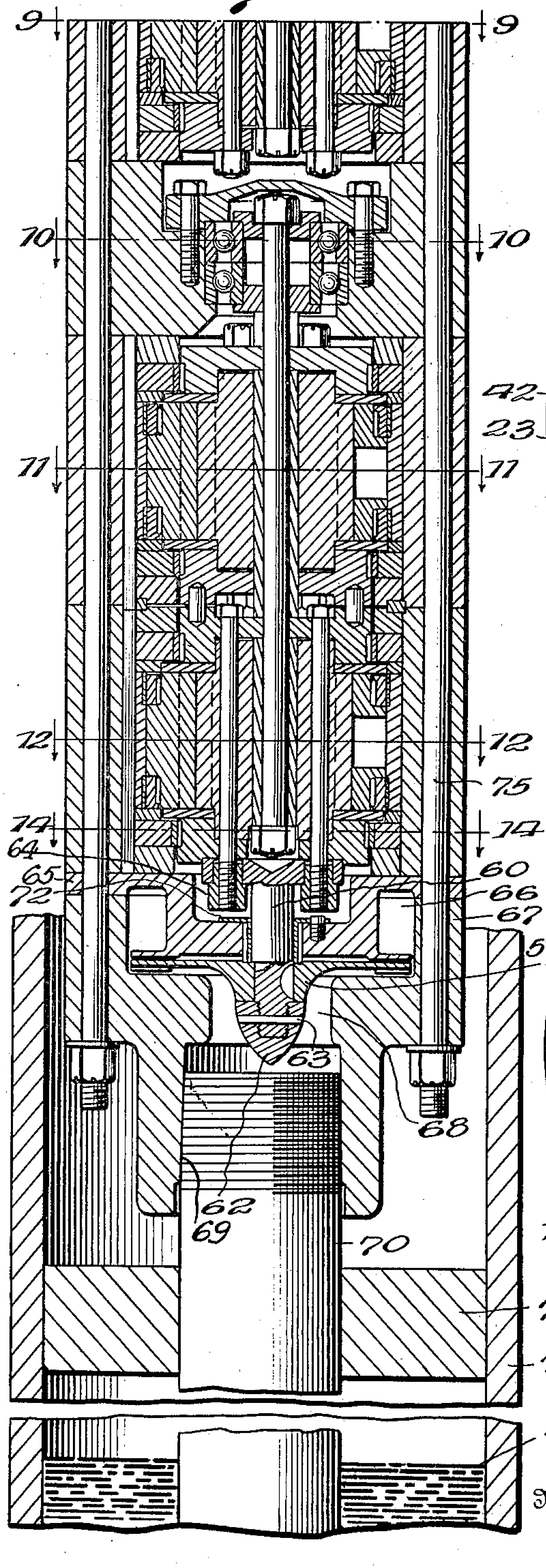


Fig. 5.

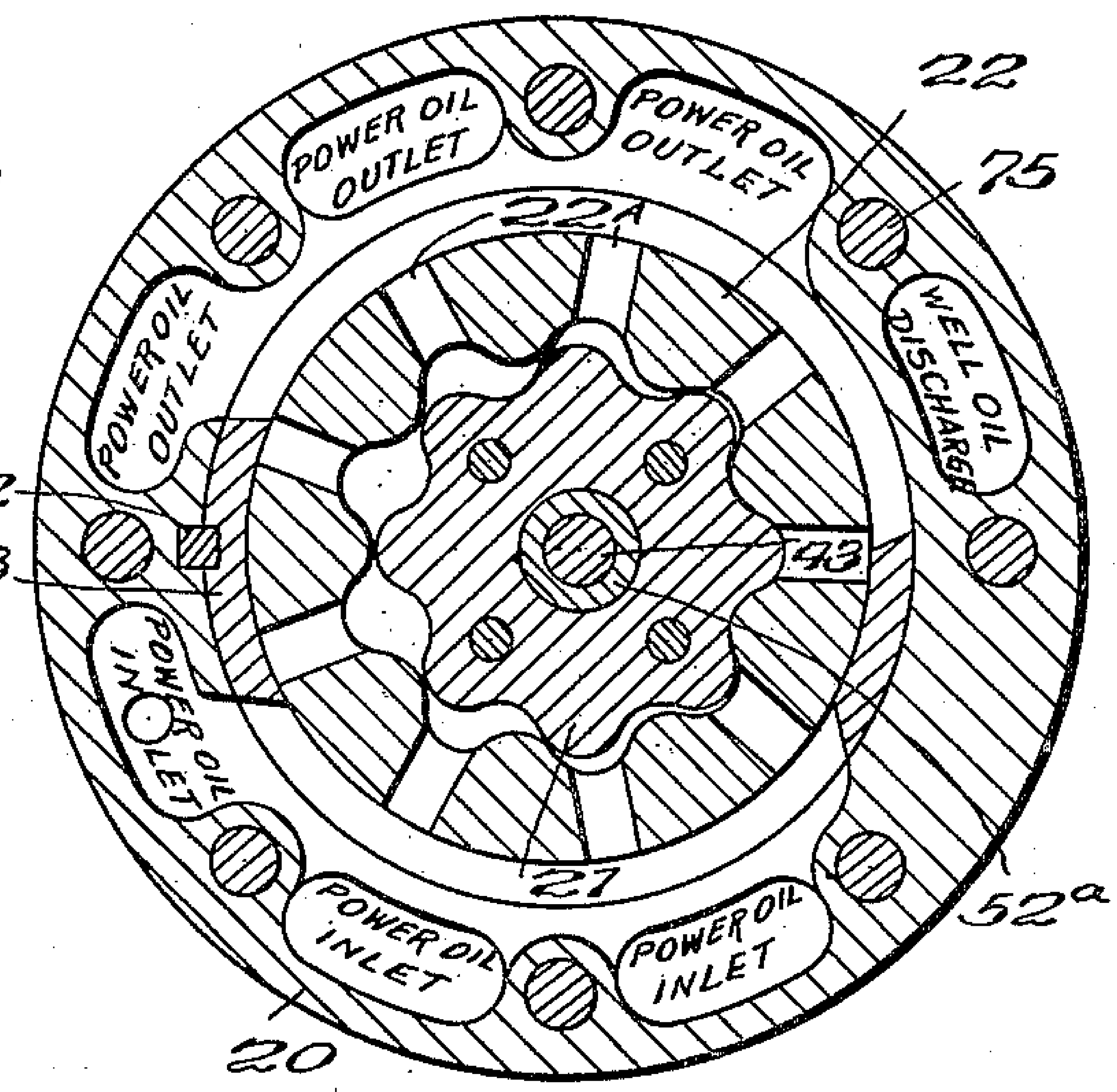
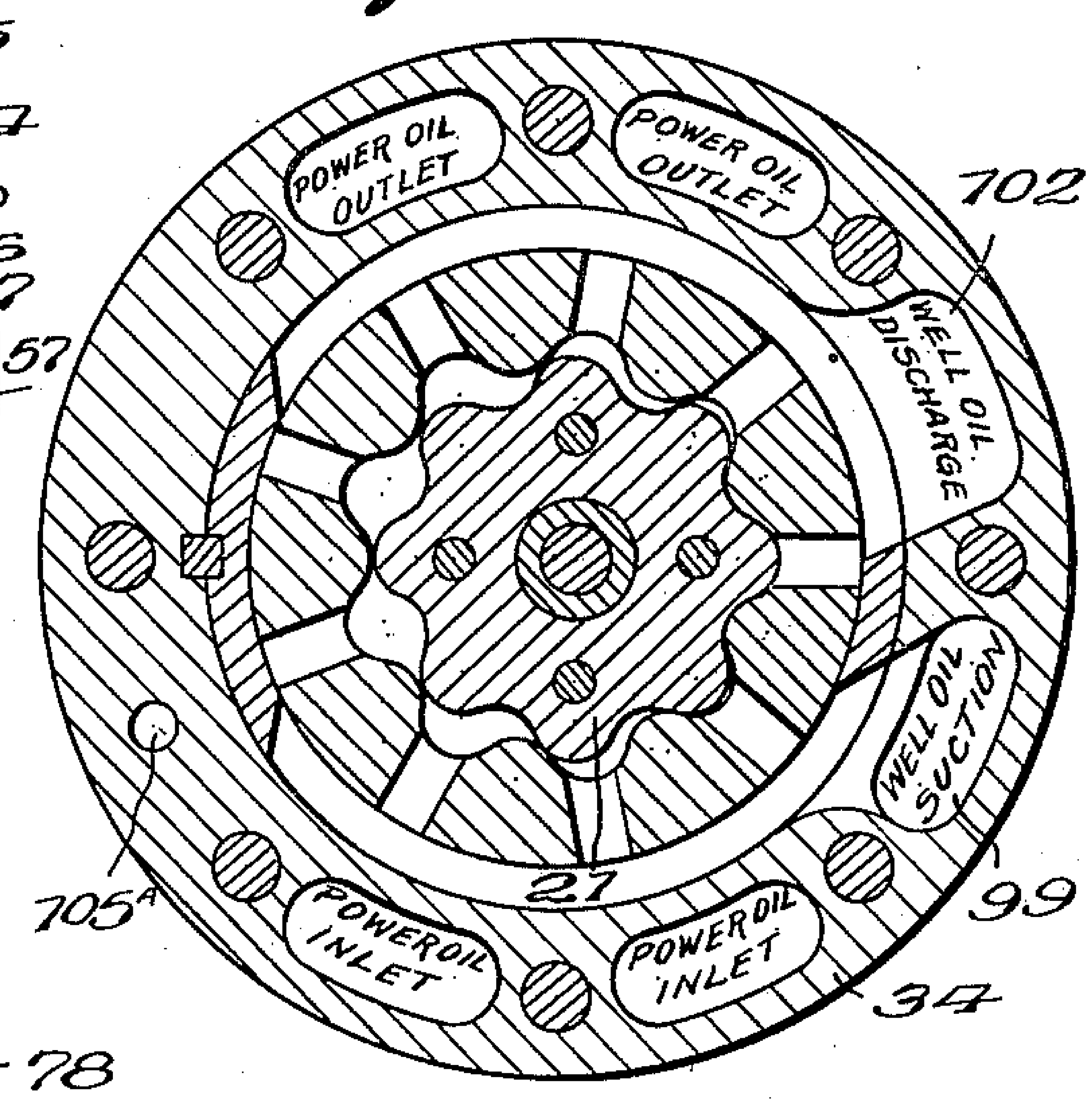


Fig. 6.



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DEEP WELL PUMPING AND PUMP

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Fig. 7.

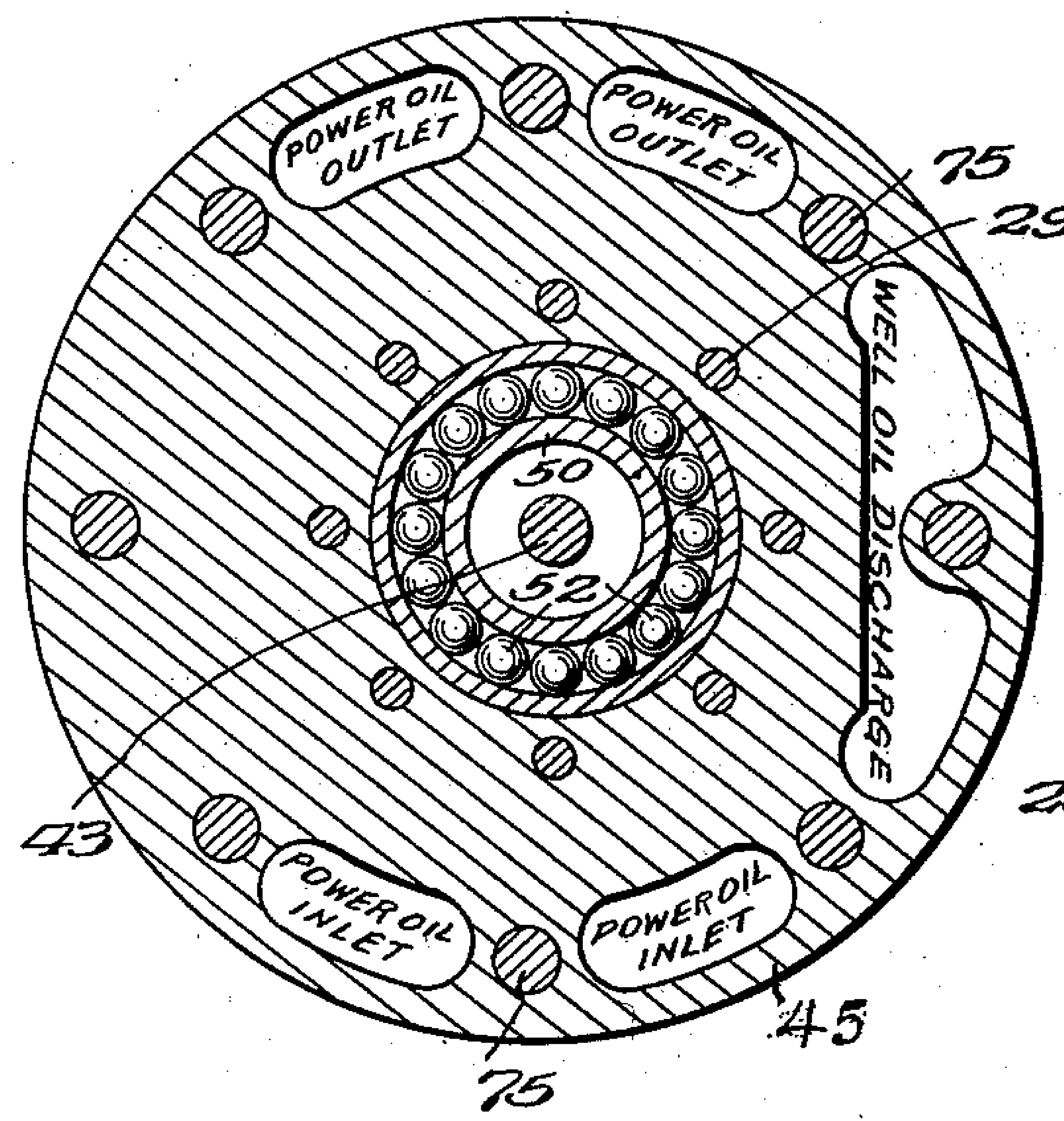

Fig. 8.

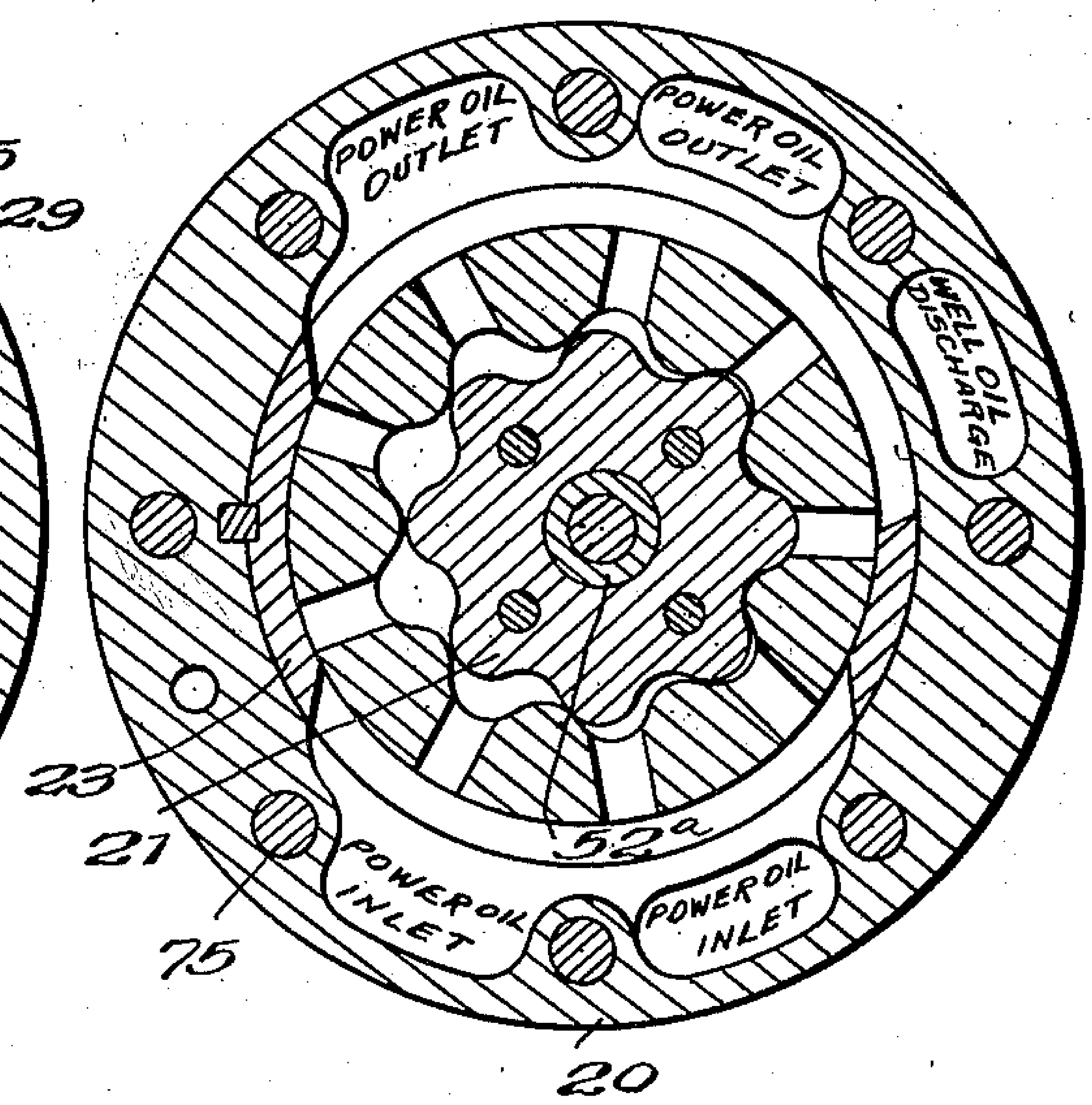

Fig. 9.

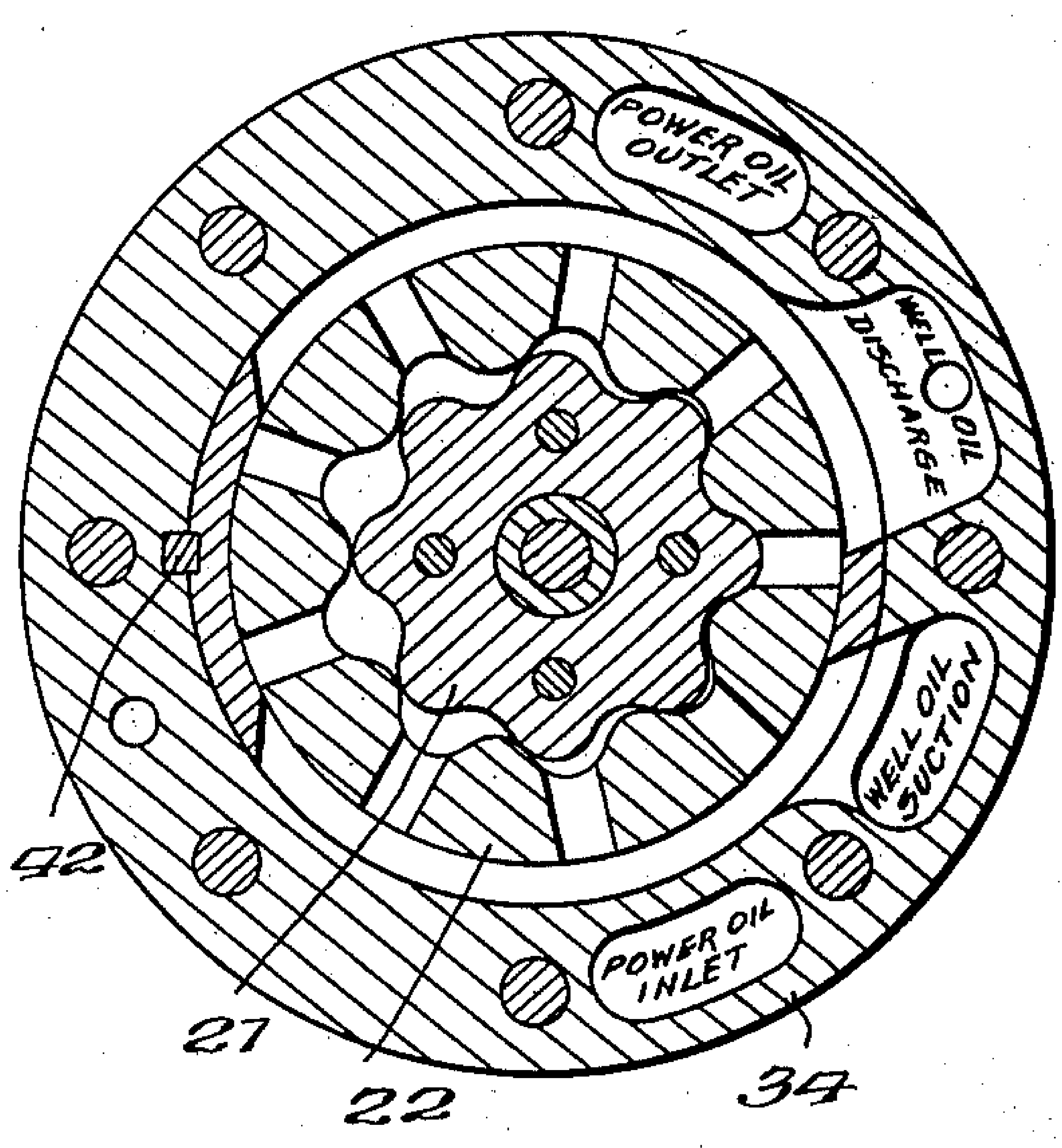

Fig. 10.

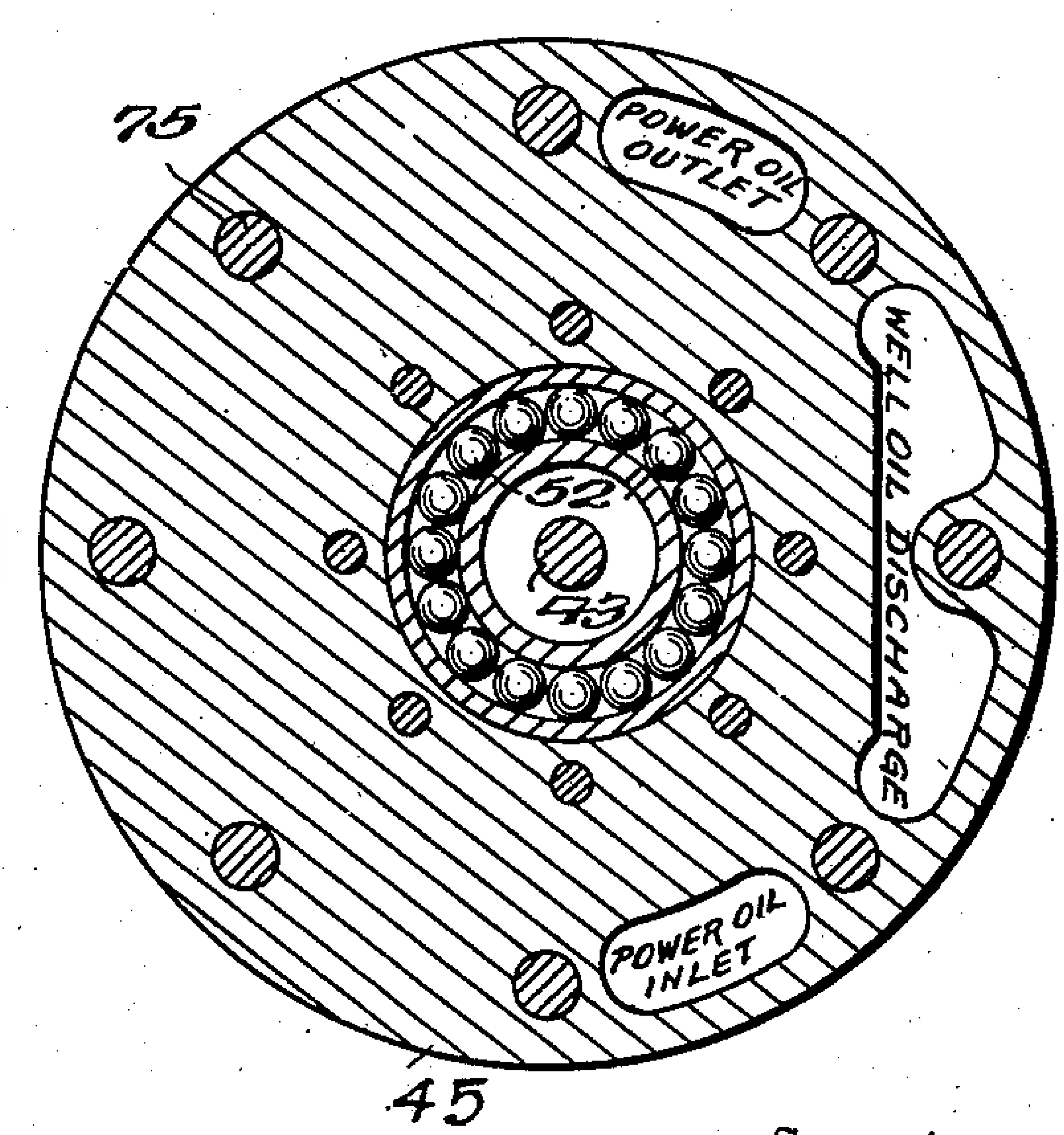

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Fig. 11.

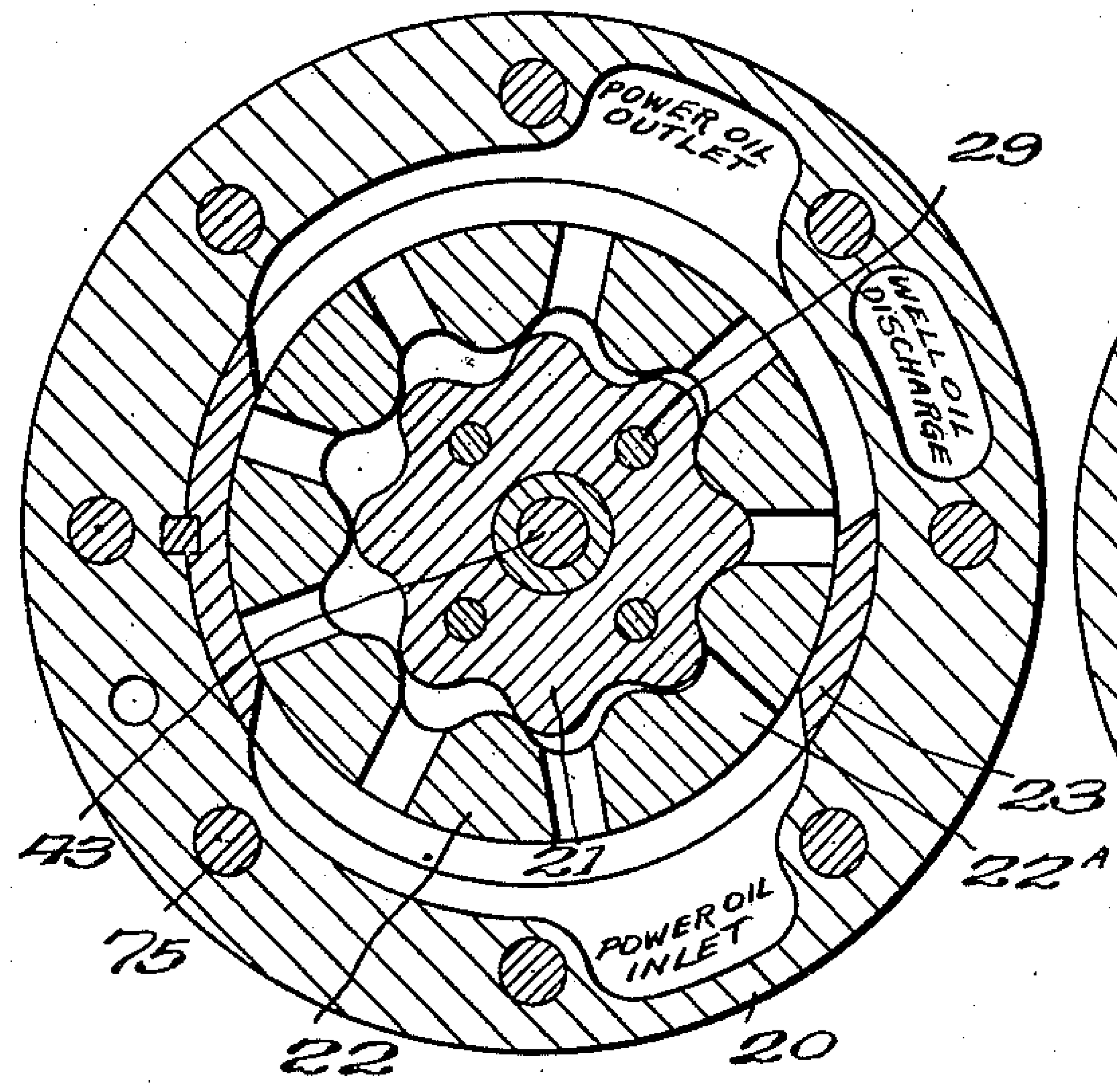


Fig. 12.

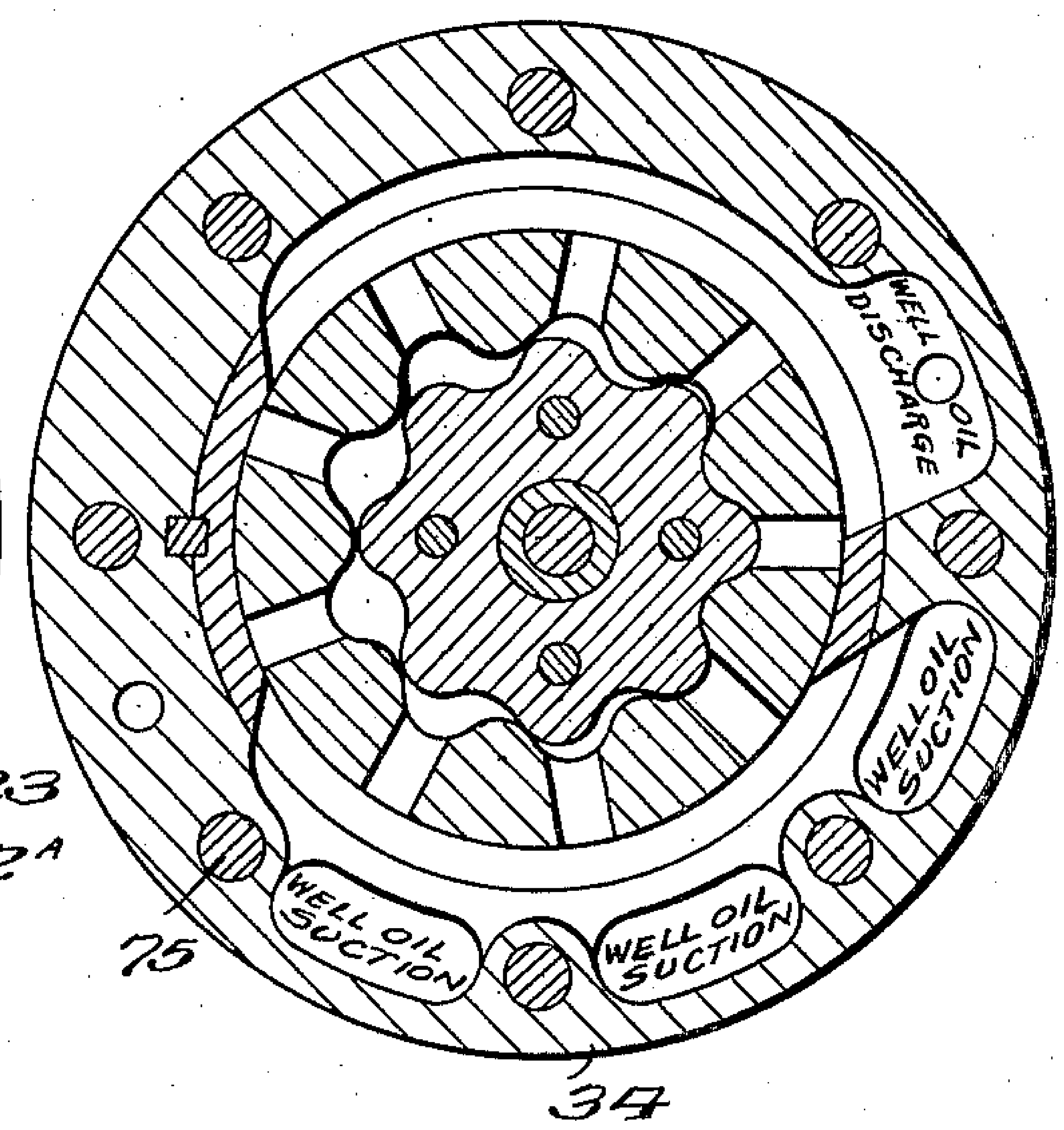


Fig. 13.

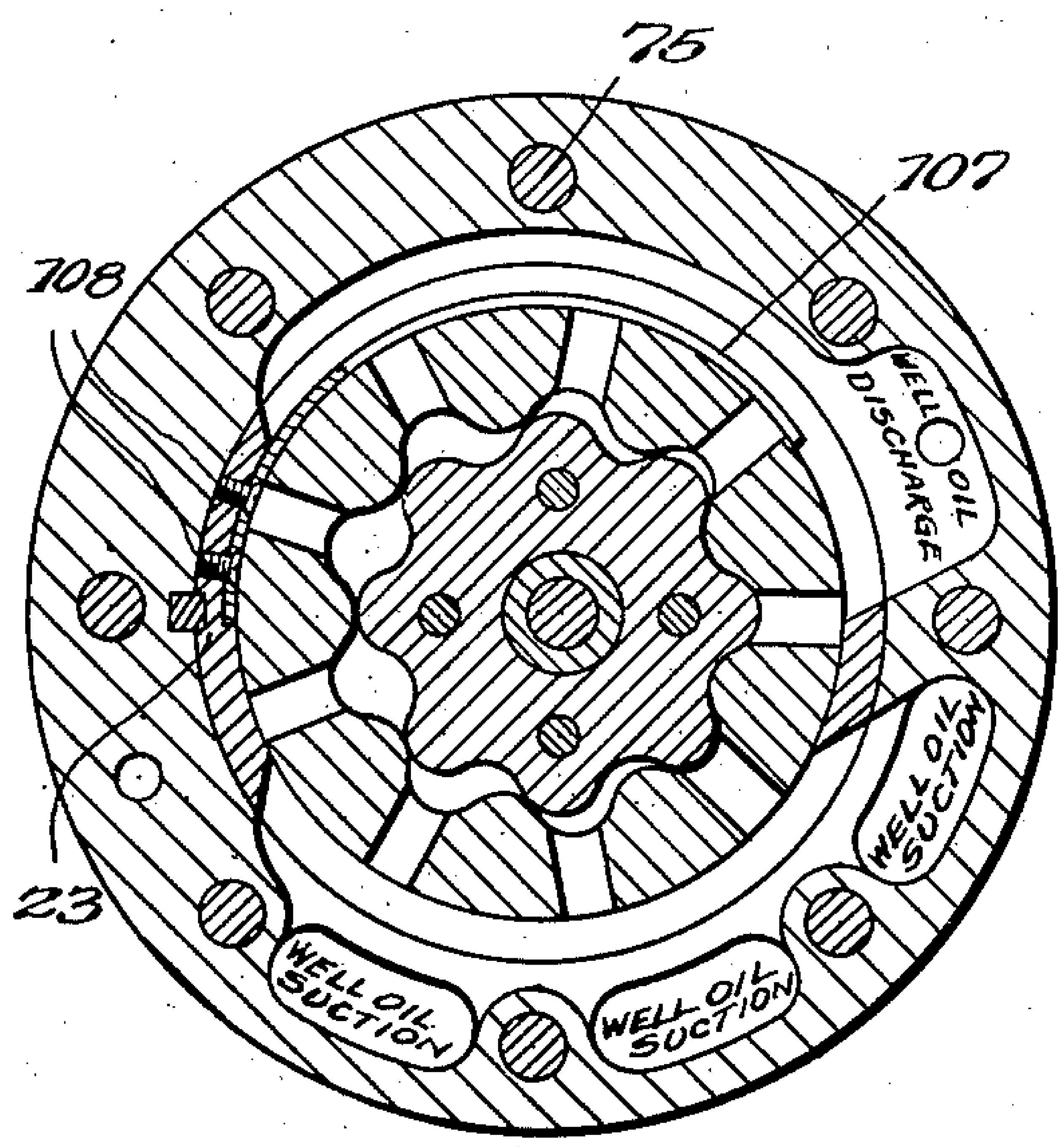
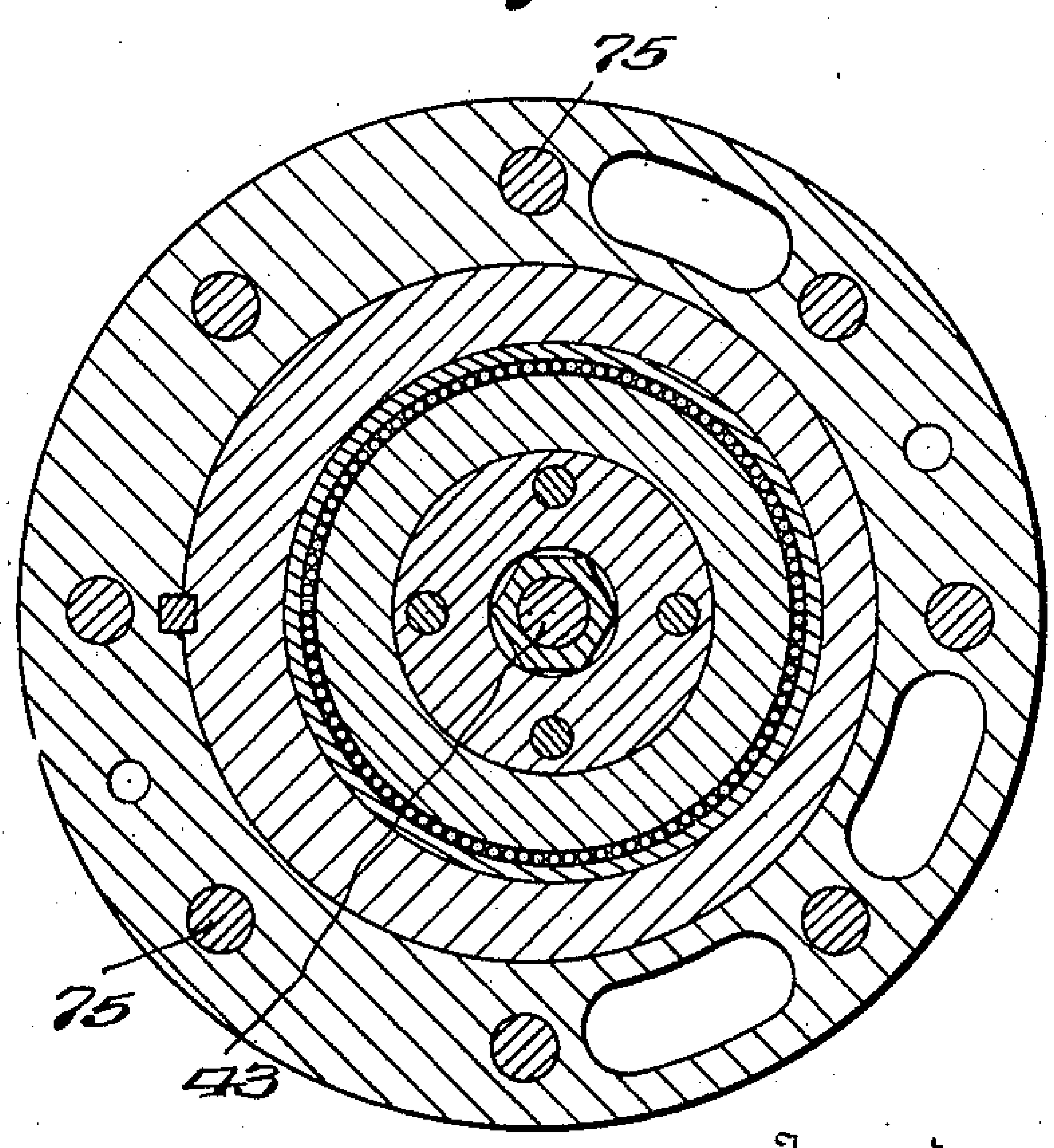


Fig. 14.



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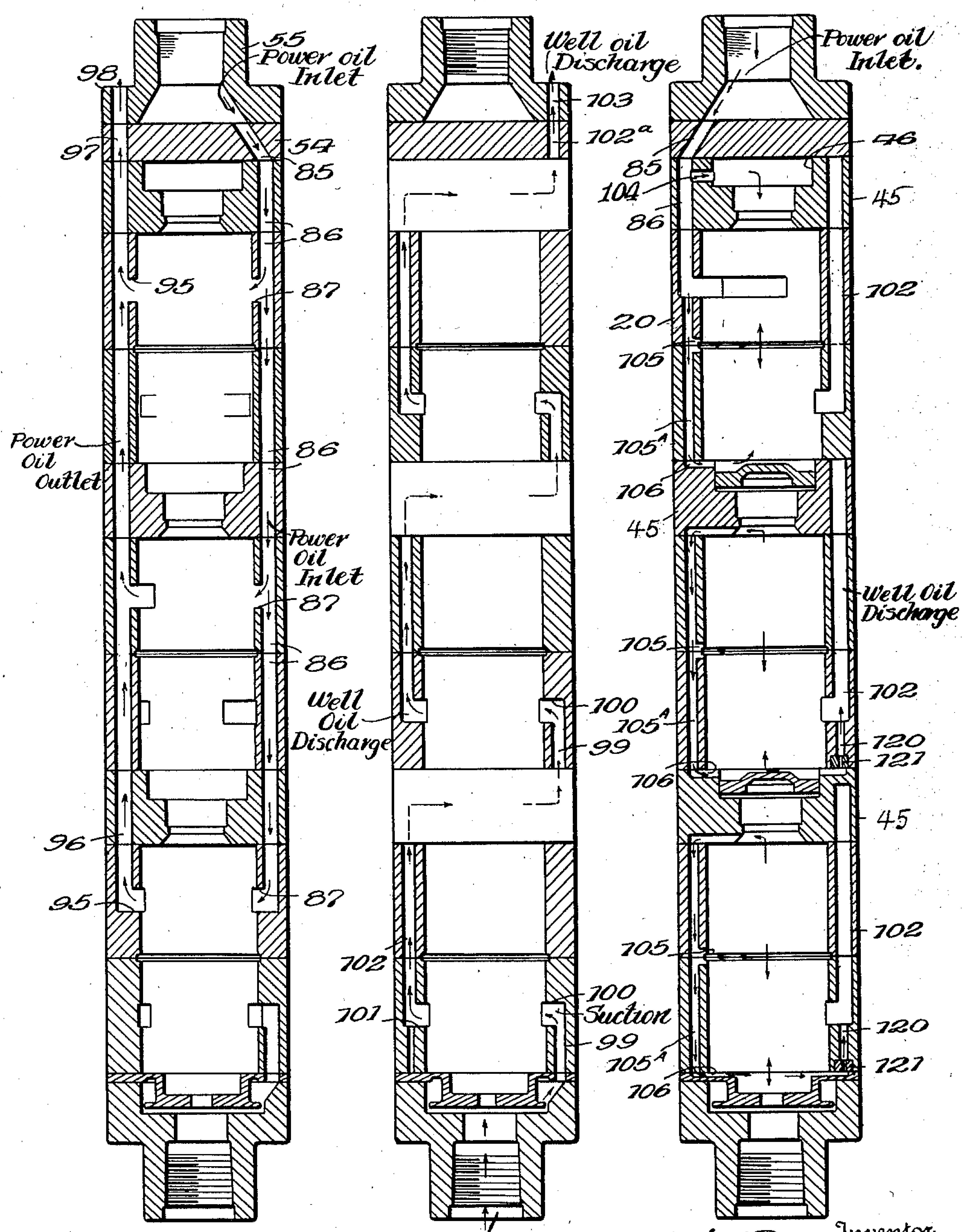

Fig. 15. Fig. 16. Fig. 17.

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Fig. 21.

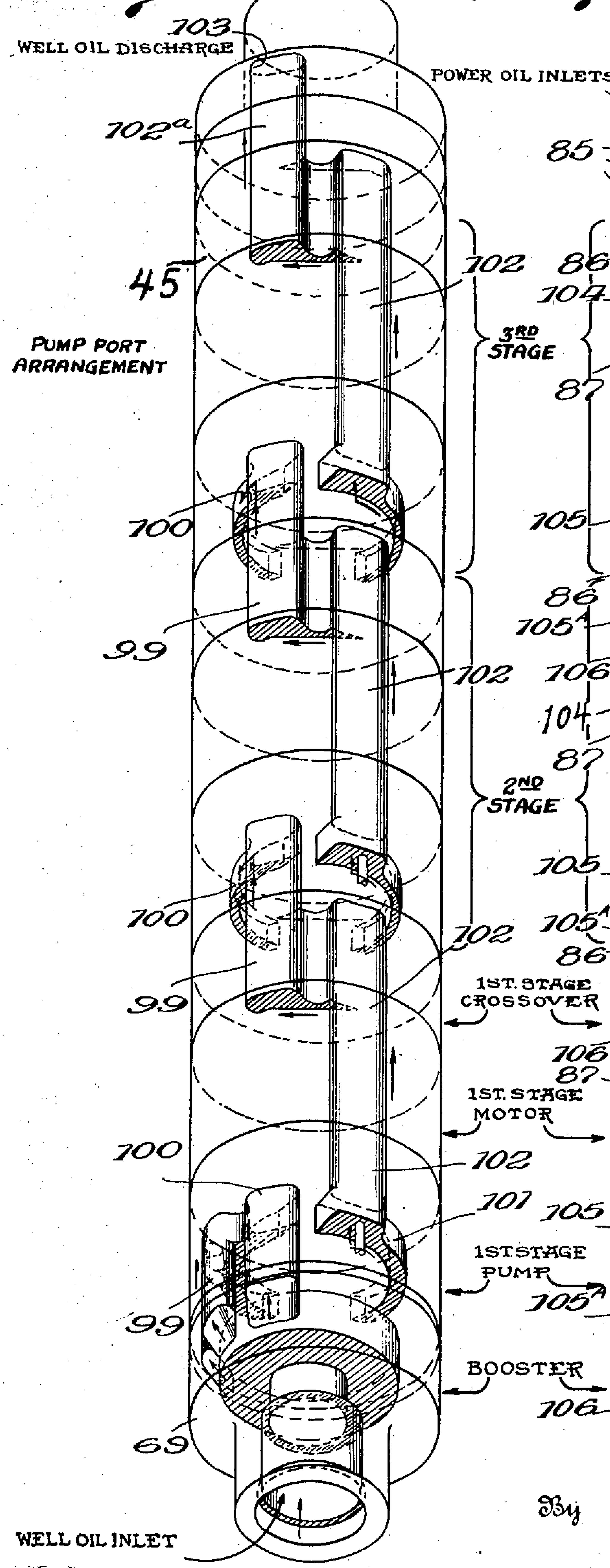
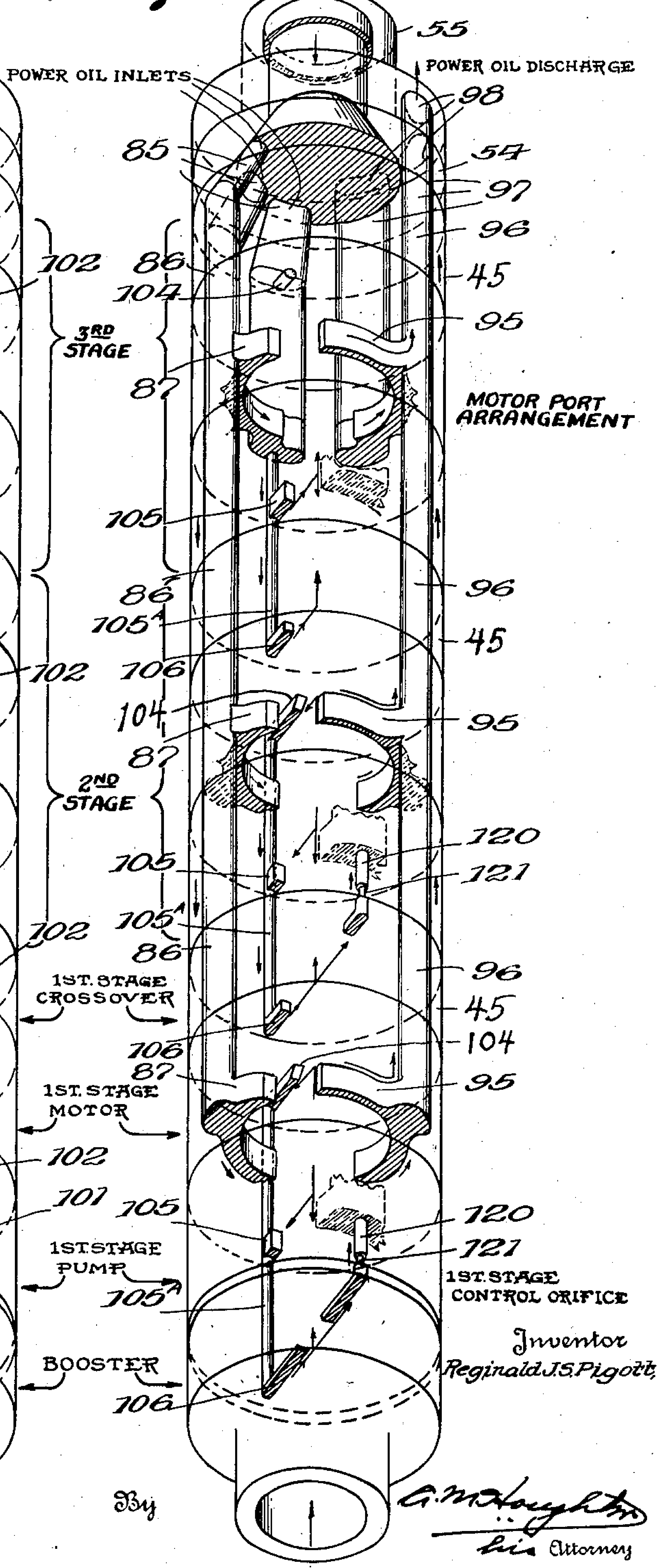


Fig. 20.



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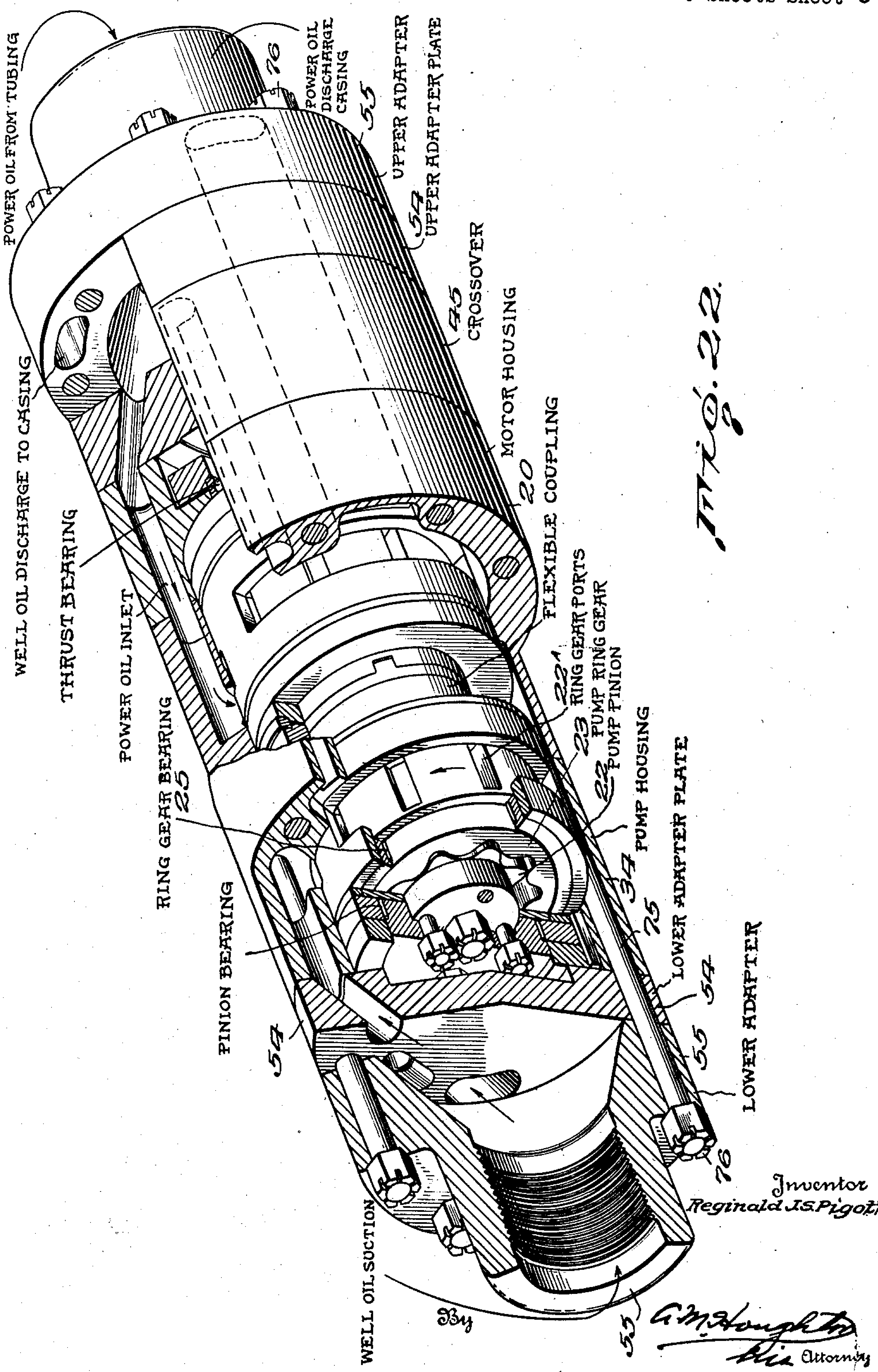

Fig. 22.

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DEEP WELL PUMPING AND PUMP

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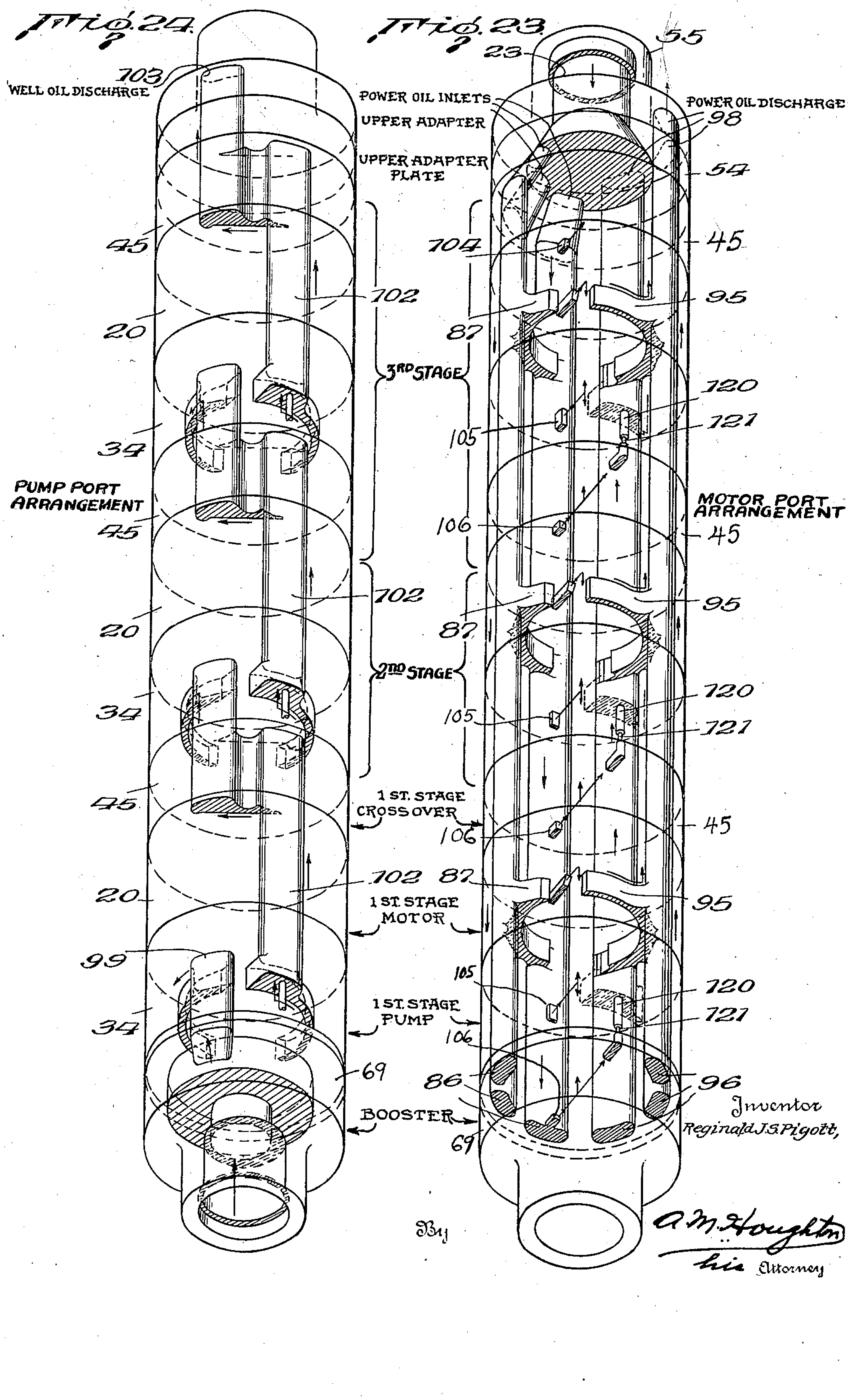

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Patented Dec. 3, 1935 2,022,781

UNITED STATES PATENT OFFICE

2,022,781

DEEP WELL PUMPING AND PUMPS

Reginald J. S. Pigott, Pittsburgh, Pa., assignor to Gulf Research & Development Corporation, Wilmington, Del., a corporation of Delaware

Application August 7, 1934, Serial No. 738,883

21 Claims. (Cl. 103—46)

This invention relates to deep well pumping and pumps; and it has for its primary objects the provision of an improved, efficient method for pumping oil from deep wells and the provision of an improved compact, efficient, high output deep well pumping apparatus adaptable for use in accordance with the method.

Another object is the provision of a pumping method wherein oil is pumped from deep wells by means of motor-driven pumps positioned far down the well and driven by a flow of motive fluid pumped down from the surface under a moderate pressure, considerably less than the hydrostatic head of oil in the well.

Another object is the provision of a hydraulically operated pumping apparatus adapted to be lowered far down the well and comprising a battery of high volume hydraulic-motor-driven pumps and means for supplying the motors with motive fluid under pressure from the surface.

With these and other objects in view, according to the method a battery of hydraulic-motor-driven pumps is positioned far down the well and clean motive fluid is forced down from the surface, through the motors in parallel. The pumps are connected in series and are adapted to suck oil from the well bottom and force it upwards in the well. The pressure on the power fluid supplied to the motors is such that the total resultant pressure developed by the pumps (the sum of the pressures developed by each pump) is sufficient to overcome the hydrostatic head of oil in the well, so that the well pumps force oil upwards and out. Motive fluid exhausted from the motors is allowed to mingle with the well oil and returns to the surface therewith. The battery of motors, as distinguished from the pumps, run at a fraction of the hydrostatic pressure in the well.

In the method, the motive fluid for the motors is advantageously the same fluid as is being pumped from the well. In oil well pumping, the well oil pumped up by the well pumps may be returned to the motors under pressure, after being cleaned or settled to remove sand, brine, etc.

The method is applicable to any type of pumps and hydraulic motors, but I have developed a pumping apparatus which presents particular advantages in performing the method. The apparatus comprises a plurality of hydraulic motor operated pumping units in an integral combination. Ports and passages are provided in the units so that power oil may be forced through all the motors in parallel by a force pump at the surface, and well oil is pumped through the pumps in series. The apparatus, when positioned in a deep well and run from the surface, pumps oil upwardly; power oil exhausted from the motors is mingled with the pumped oil.

In some embodiments, the apparatus is made up of interchangeable pump-motor units. The units are alike and are adapted to be bolted together in any number and to function as a combination.

In pumping oil from deep wells it is the general practice to position a reciprocating pump of the piston and cylinder type in or near the bottom of the well, and to work the piston of the pump, and thereby pump oil, by means of a string of sucker rods attached to the piston and operated from the top of the well. The rods are operated by means of a pumping rig, which usually comprises a walking beam worked by an engine.

This system presents several disadvantages. The frictional losses in the sucker rods and pumping rig ordinarily amount to as much as eighty to ninety per cent of the power input. Breakage or uncoupling of the sucker rods often occurs, and withdrawing broken rods from the well is a difficult task. Wire cables are sometimes substituted for the rods, but this requires modification of the pump to adapt it for one-way operation, inasmuch as wire cables cannot transmit a pushing force. An additional disadvantage of reciprocating pumps in this relation is that they are not well adapted for gas bearing oils, and considerable loss of efficiency occurs when gassy oils are pumped.

Various attempts have been made to improve on the ordinary pumping devices and methods to avoid these disadvantages. One proposal is the substitution of hydraulic means for reciprocating the pump in the bottom of the well, the hydraulic means comprising a hydraulic reciprocating power device of some sort at the top of the well, a suitable piston-and-cylinder reciprocating device on the well pump, and a conduit from the power device to the pump operating device in the well. This system avoids the use of a reciprocating sucker rod, but certain disadvantages are introduced. The power supply pump at the surface must exert a high pressure; in some designs a pressure sufficient to overcome the static head in the well (equal to 1800 pounds per square inch in a 4000 foot well). This is apt to cause leakage in the power supply conduit. Moreover, in some designs the entire column of liquid in the power supply conduit must be reciprocated, with accompanying high drag and frictional losses.

It has also been proposed to employ a single rotary pump in the well bottom, operated by a single hydraulic motor supplied with fluid from the surface. Here again, in deep wells the pressure which must be applied to the motive fluid is exceedingly high. In order to avoid the disadvantages of high pressure force-pumping down the well, it has been proposed to employ an electric motor on the well pump and supply power to it by means of an electric cable. While this system would appear to avoid the disadvantages of mechanical or hydraulic transmission of power to the deep well pump, in practice many difficulties are encountered. The electric motor can not conveniently be lubricated by means of the well fluid, and a separate lubrication supply must be provided. Well oil often contains water or brine, which is destructive to electrical equipment. This type of pump must be raised to the surface every little while, to be inspected and to have the lubricating supply renewed. This is a tedious job, requiring hoisting and replacing of a mile or so of tubing; a job which is made even more difficult by the fact that the electrical cable must also be handled at the same time. The bottom of a deep well is not a good environment for an electric motor. Also, the available space is small and cramped, the interior diameter of the bottom well casing being only six to eight inches in most cases. A motor to fit in this space and yet give sufficient power requires special design.

By the present invention I provide a pumping system which avoids the disadvantages of these prior systems and secures new advantages not attained in these systems. In my pumping method I provide a plurality of pumping units adapted to be positioned at or near the bottom of the well. Each unit comprises a pump and a hydraulic motor adapted to drive the pump. The pumps of the several units are connected in series, and are adapted upon being operated to draw oil from the well bottom and force it upwards. The pumps and motors are designed so that the net pressure developed by the plurality of pumps in series is sufficient to overcome the hydrostatic head in the well.

The motors are hydraulically connected in parallel, and oil is forced to them under pressure by means of a conduit in the well and leading to the motors. This power oil is advantageously oil pumped from the well which is cleaned before being returned. The power oil exhausted from the motors is allowed to mingle with the well oil being pumped upward and passes with the well oil into a storage tank or pool at the top of the well. A portion of this oil, after being cleaned of sand, salt water, etc., is used for the power oil supply. Thus a portion of the oil is continuously circulated through the pumps, the storage tank, the surface force pump, the hydraulic motors, and the well casing.

In my method the several well pumps are connected in series. Thus each pump is required to develop only a fraction of the total pressure necessary to overcome the hydrostatic head in the well. In the case of similar sized pumps the pressure to be developed by each pump, in order to equal the hydrostatic head, is equal to P/n, where P is the hydrostatic head in the well and n is the number of pumps. The motors being connected in parallel, then in the case of similar sized motors and pumps, the pressure necessary for the surface force pump to exert on the motors is equal to the pressure developed by each pump, that is P/n. In other words, the pressure required for the motive fluids furnished to the well motors is only a fraction of the hydrostatic pressure in the well. The advantages of this will be obvious to persons skilled in the art. In a well 4000 feet deep, say, the hydrostatic pressure at the bottom is about 1800 pounds per square inch. If a single pump-and-motor unit were used in the well, supplied from a single force pump at the top of the well, each pump and motor would have to work at the full 1800 pounds. Leakage, strains, excessive bearing loads and loss of efficiency occur at these high pressures, which are avoided in my method and apparatus.

In the accompanying drawings I have shown more or less diagrammatically a diagram of my pumping method, and detail views of two modifications of pumping apparatus for a well. In these showings,

Fig. 1 is a diagram illustrating my method in a complete oil well pumping system;

Fig. 2 is a view in vertical section of the upper portion of one form of well pump;

Fig. 2A is a similar view of the lower portion, being a continuation of Fig. 2;

Fig. 3 is a section taken along the line 3—3 of Fig. 2;

Fig. 4 is a section taken along the line 4—4 of Fig. 2;

Fig. 5 is a section taken along the line 5—5 of Fig. 2;

Fig. 6 is a section taken along the line 6—6 of Fig. 2;

Fig. 7 is a section taken along the line 7—7 of Fig. 2;

Fig. 8 is a section taken along the line 8—8 of Fig. 2;

Fig. 9 is a section taken along the line 9—9 of Fig. 2A;

Fig. 10 is a section taken along the line 10—10 of Fig. 2A;

Fig. 11 is a section taken along the line 11—11 of Fig. 2A;

Fig. 12 is a section taken along the line 12—12 of Fig. 2A;

Fig. 13 is a section similar to Fig. 12, of a modification employing a flexible abutment;

Fig. 14 is a section taken along the line 14—14 of Fig. 2A;

Fig. 15 is a view in vertical section of the well unit casing taken along the line 15—15 of Fig. 3 and showing the various ports and passages;

Fig. 16 is a similar view taken along the line 16—16 of Fig. 3;

Fig. 17 is a similar view taken along the line 17—17 of Fig. 3;

Fig. 18 is a view in elevation of the booster impeller;

Fig. 19 is a sectional view taken along the line 19—19 of Fig. 18;

Fig. 20 is an isometric phantom view showing the motor port system of the pump of Figs. 2 and 2A;

Fig. 21 is a similar view showing the pump port system of this pump;

Fig. 22 is an isometric view with some parts broken away of a single stage pump and motor combination;

Fig. 23 is an isometric phantom view showing the motor port system of a modified pumping combination having interchangeable units; and

Fig. 24 is a similar view showing the pump port system of this pump.

In these showings, in which like reference numerals indicate like parts throughout, Fig. 1 is a diagram of a complete well pumping system to illustrate my method. As shown, I provide a plurality of motor driven pump units 1, each comprising a hydraulic motor 2 directly connected to a pump 3. For the sake of concreteness I have shown three such units, though the invention includes combinations having more or less than three units. The motors are connected in parallel as shown and are supplied with oil under pressure from a force pump 5 at the top of the well through conduit 4. The motors exhaust through conduit 6 which may be a separate pipe from the well casing or may be the casing itself. The pumps have inlet conduits 7 and outlet conduits 8 as shown, and are connected in series. The flow from the pumps is merged with the exhaust from the motors as at 9. The combined flow is forced upward through conduit 10, which may be the well casing. The bottom-most pump draws oil from the well at 11 and expels it at a certain pressure. The upper pumps increase this pressure to a degree sufficient to overcome the hydrostatic head of the well, causing the oil to flow out at the surface as at 12. A storage tank 13 is provided for the pumped oil. Sand, salt water and dirt are allowed to settle out from the oil in this tank. A certain portion of this oil is continuously withdrawn into a tank 14 and used as motive fluid. This oil may be strained or otherwise further cleaned if desired. The amount of oil in supply tank 14 may be controlled by an ordinary float valve 15 as shown. Clean oil is taken from the supply tank and forced down the motor conduit by means of a force pump 5 at the surface of the well, which pump is advantageously of the constant pressure type and may well be a ring gear and pinion pump of the types described in my prior Patent No. 1,990,750, dated Feb. 12, 1935.

In a specific example of my invention, oil is to be pumped from a well 4000 feet deep. The pressure due to the hydrostatic head is 1800 pounds per square inch at the bottom of this well. If a single well pump were used for forcing oil from the well, a full 1800 pound pressure would have to be supplied by the force pump at the surface. As stated, use of such high pressure is to be avoided when possible; leakage and strains on the surface force pump, and in conduits, occur. In this example of my method I use three pump and motor units down the well. The force pump is run to develop 600 pounds pressure. Thus the total pressure at the bottom of the motive fluid conduit 4 is 1800 plus 600, or 2400 pounds per square inch. The opposing pressure due to the column of oil in the well, is 1800 pounds, leaving a net 600 pounds to operate the motors. For the sake of simplicity the motors and pumps are shown the same in size; therefore in this case each pump develops 600 pounds pressure. The three pumps being in series, the total pressure developed is 1800 pounds per square inch, and just enough to overcome the hydrostatic pressure of the well and discharge oil at the top. In this example, it will be seen that I am able to develop the high pressure necessary to pump oil from the well, using only a moderate pressure in the force pump at the surface. Since the motors are connected in parallel and the pumps in series, theoretically three times as much oil must be pumped down as is forced upward by the well pumps. If motive fluid is forced down at the rate of 90 gallons per minute the flow of oil from the well, representing the exhaust from the motors and well oil being pumped, is 120 gallons per minute. The net flow of well oil is thus 30 gallons per minute.

In all embodiments of my system, the product of pressure times volume for the pumps equals the product of pressure times volume for the motors. In the above example, neglecting volumtric and frictional losses, the product of pressure times volume for the pumps is

$$P \times V = (600+600+600) \times 30 = 54000$$

and for the motors is

$$P \times V = 600 \times (30+30+30) = 54000$$

That is, the power oil pressure is one third the pressure exerted on the well oil, and the volume of power oil circulated is three times the volume of well oil pumped from the well.

The above examples represent ideal cases. In practice, volumetric losses and frictional losses are bound to occur, and accordingly motive fluid must be supplied at a greater pressure and in greater volume than in the above example. The slip of the well pumps reduces their delivery below the theoretical displacement; the slip of the well motors raises their throughput above the theoretical displacement. Therefore, for well pumps and well motors having equal displacements, the volume ratio between the motive fluid circulated by the force pump and the oil pumped by the well pumps equals $n/$ (volumetric efficiency)^2, where n is the number of pump and motor units. For three units this volume ratio equals 3.7 when the volumetric efficiency is 90 per cent; and 4.7 when the volumetric efficiency is 80 per cent.

The pressure ratio between the pressure required to be furnished by the force pump at the top of the well, and the hydrostatic pressure opposing the flow of liquid being pumped from the well, is affected by losses due to mechanical and fluid friction, as distinguished from losses due to slip or leakage. The fluid friction occurs principally in the long conduits 4 and 10, respectively conveying motive fluid to the motors, and mixed oil from the well. The pressure, P, required to be furnished by the force pump is given by the following expression, wherein n is the number of pump and motor units:

P=(hydrostatic pressure in well)=(equivalent head of fluid friction in conduit 10)$\times n/$ (mechanical efficiency)^2+(equivalent head of fluid friction in conduit 4).

In the case of a single force pump at the surface operating three well motors in series in a 4000 foot well I find the actual pressure to vary from 3.7:1 to 4.5:1, depending on the pumping rate and the size of the conduits.

My method is adapted for use with various other types of pumps and motors. Advantageously however, the pumps and motors are of the positive displacement type. The well pump and motor units may, for instance comprise pistons and cylinders with suitable valve connections, and the units may be driven by a reciprocating force pump at the surface. The method is particularly adapted for use in deep oil wells, but it may be applied to the pumping of water.

As stated, in deep wells I use a plurality of well motor and pump units. By thus having a separate motor drive for each pumping stage in the well, the motors being connected in parallel, I secure perfect balance of work among the stages. This is an important consideration in the case of positive displacement pumps.

In the specific example given, I have described the method as applied to a 4000 foot well, with 1800 pounds hydrostatic head. In this case the use of three well pump and motor units is advantageous, so that each well pump, and the supply force pump at the top of the well, need handle only 600 pounds pressure. In a 2700 foot well, having a 1200 pound head, I should need to use only two pump and motor units in the well, each developing a 600 pound pressure. In a shallow well of, for example, 1300 foot, the hydrostatic head is only 600 pounds, and only a single pump and motor unit need be used. In general it is convenient to have the pressure developed in each stage, and the pressure supplied by the surface force pump, somewhere between 500 and 900 pounds.

While I have described a system comprising pump and motor units in which the pumps and motors are of the same size, it is sometimes convenient to provide motors of different size from the pumps. For example, in the pumping system for the 4000 foot well described, I may provide a two stage well combination having two pumps each developing 900 pounds, and two motors each working at 600 pounds. In this case the motors would have 1½ times the volume of the pumps; in the case of rotary gear pumps and motors in which the corresponding rotors are of the same diameter, the motors would be provided with rotors 1½ times as long as the pump rotors. This combination would meet the requirement that the product of pressure times volume for the pumps be equal to the product of pressure times volume for the motors. In the pumps,

$$P \times V = (900+900) \times 30 = 54000$$

and in the motors,

$$P \times V = 600 \times 1.5(30+30) = 54000$$

My system may also be embodied in a single stage pump and motor unit, in which the motor has a larger volume and works at less pressure than the pump. For example, I may provide three pumps connected in series and adapted to be driven on one shaft and a single motor driving the pumps, the motor having three times the volume of the pumps. Here again, the volume of power oil pumped would be three times the volume of well oil discharged, and the motor would work at one third the pressure developed by the well pumps.

It is usually convenient in practice, however, to provide similar pump and motor units, and a motor for each pump. Separate pump and motor units allow perfect balance to be maintained among the pumps and motors; and this is highly desirable in high pressure pumping of liquids which may contain gas.

As stated, it is usually desirable in practice to provide in the pumping system that no pressures greater than about 900 pounds per square inch be applied to any one motor or be pumped by any one pump. With most pumps, excessive bearing strains and leakage losses begin to occur at higher pressures. However, the pump and motor combination which is to be described is especially suitable for high speed, high pressure operation, and the pumps and motors may be satisfactorily operated at pressures of 900 to 1000 pounds or even more.

Although, as stated, the method is applicable to use with various types of pumps and motors, I have developed a particularly useful well pumping apparatus, employing positive displacement pumps of the ring gear and pinion type. In my apparatus each well pump and motor unit comprises a pumping ring gear and pinion combination directly connected to a similar motor ring gear and pinion combination. The gears are enclosed in a casing having suitable ports and passages, to form a single, compact structure which may be lowered down the well on a string of pipe. The pump and motor units are adapted to be lubricated by clean oil, that is the motive fluid pumped down to the well motors, which consists of well oil from which sand and salt water have been removed.

I show two modifications of my pumping apparatus. In one, the combination comprises a plurality of pump and motor units assembled as a unitary whole, each unit being designed for its particular position in the assemblage, and not being primarily adapted for separate use. In the other modification, the combination is built up or assembled of similar pump and motor units: the pump and motor units are alike and are interchangeable so that the units to the desired number may be stacked and fastened together to function as a combination. In either modification, I usually find it advantageous to mount a booster pump on the first unit in the well, discharging into the inlet thereof, so as to raise the pressure of the well oil slightly before it is pumped by the first pump. The purpose of this will be explained later.

Figs. 2 to 22 illustrate the first modification. Figs. 2 and 2A are views of the upper and lower valves of a complete bottom hole well pump positioned in its normal position in the bottom of a well. The bottom hole well pump comprises three generally similar pump and motor units.

Each unit comprises a motor housing **20** in which run a motor pinion **21** and a ring gear **22** having a plurality of radial ports **22A** between the teeth **22B** (see Figs. 5, 6, 8, 9, 11 to 13) as shown. A sleeve **23** is fitted in the housing as shown. The sleeve **23** is held in place in the housing by means of lock rings **27**.

The motor pinion is mounted for rotation in the motor housing by means of discoid end plates **28** bolted to each end of the pinion by means of bolts **29** and nuts **30** as shown. The periphery of each end plate is adapted to receive needle bearings **24** which cooperate with an eccentric bearing race **31** and an eccentric race mounting **32** to mount the pinion for rotation in the motor housing. An eccentric spacing ring **33** is provided between the race mounting **32** and the end of the motor housing. Floating sealing rings **33A** are provided between the end of the ring gear and the end plates **28** as shown.

Adjacent each motor housing is a pump housing **34** similar in size and shape except for the interior ports. In the pump housing is mounted a pumping ring gear and pinion exactly alike the motor ring gear and pinion, mounted in the same way by means of similar needle bearings, and designated by the same reference numerals. The motor ring gear is mechanically connected to the pump ring gear by means of a plurality of pins **35** as shown. This pin coupling is in effect a flexible joint; small errors in alinement are compensated. Below the motor ring gear bearing sleeve **23**, the lower lock ring **27**, and the lower spacing ring **33**, is a center spacer ring **40**, grooved as shown. Corresponding elements are in the adjacent end of the pump, and the spacer ring **40** of the pump is spaced from the spacer ring **40** of the motor by means of a lock ring **41** in the grooves.

The various sleeves, spacing rings, etc. mounted in the motor and pump housings are kept from rotation in the housings by means of a key 42 running the length of the two housings and engaging appropriate seats in the various elements and the housing.

The motor pinion and the pump pinion are held in contact with each other, and are kept from end play, by means of a tie shaft 43, having nuts 44 at each end. At the upper end of the motor housing and fitted thereto is a ported, discoid crossover 45. A chamfered, beveled circular recess 46, eccentric to the axis of the ring gears, is provided in this crossover, for the reception of a bearing assembly for the tie shaft. The bearing assembly comprises two outer ball races 47 fitting snugly in the crossover, and retained by an outer ring 48 bolted to the crossover by bolts 49. Two corresponding inner ball races 50 are provided. The inner races are mounted on shaft 43 by means of spacer rings 51 fitting snugly on the shaft. A sleeve 53 spaces the lower ring from the end plate 28 of the motor, and the upper spacing ring is held by nut 44 on the shaft. Bearing balls 52 are provided as shown. Sleeves 52A, advantageously made of bronze or the like, are provided between the tie shaft and the pinions locating the pinions axially but allowing each pinion to follow its bearing without sensible restraint.

The crossover, the motor housing and the pump housing, comprise one pump and motor unit. These elements are much the same in each unit. The ports in the housing and the crossover are so arranged that two or more pump and motor units can be bolted together to form a pumping combination as shown. Each pump and motor unit is independent of the others, being connected only by fluid passages. This is a great advantage from an engineering point of view, for each motor and pump gear combination is aligned separately; no long shafts, with accompanying difficulties in alinement, are used. In a complete combination adapted for use at the bottom of a well as shown in Figures 2 and 2A, additional elements are required at the top and bottom. At the top is an upper adapter plate 54 and an adapter 55, both of the same outside dimensions as the housings and crossover. The plate carries appropriate ports, and the upper adapter is threaded to receive the lower end of a motive fluid pipe 56, as shown. The lower end may be similar. In Fig. 2A, however, I have illustrated a booster pump in combination with the lowermost motor and pump unit.

The periphery of the ring gear in the well pumping apparatus runs at a fairly high speed. For instance the periphery may run at 35 feet a second; the liquid entering the inlet of the first pump at about 6 feet a second. The acceleration of the liquid from 6 to 35 feet per second is equivalent to a drop in head of about 18 feet, or 6.5 pounds per square inch. Now if the well oil is gassy, this drop in pressure of 6 or 7 pounds, will result in escape of gas in the suction side of the lowermost pump. The presence of gas in the pump is deleterious; both the capacity and efficiency are reduced. In addition, vibration occurs. In order to prevent this objectionable evolution of gas I provide a centrifugal pump, drawing oil from the well bottom and discharging it to the inlet of the lowermost well pump, at a pressure of about 9 pounds. The eye of the pump is adapted to take the well oil at the speed it travels in the suction of the well pump, thus there is no pressure drop in the oil entering the booster.

The booster pump comprises a simple centrifugal impeller, shown best in Figs. 18 and 19 and comprising a discoid rotor 57 having impeller blades 58. The impeller is mounted on the lowermost pump pinion by means of an extension shaft 60 to which the impeller is keyed by a key 61. A cap 62 and pin 63 serve to hold the impeller from endwise displacement. The extension shaft is bolted to the pinion by means of the bolt 29 and nut 64. The pump housing for the impeller comprises a lower adapter plate 65 appropriately channeled to provide discharge chamber 66 for the impeller and an inlet to the first well pump; and a lower adapter 67 having a chamber 68 forming an inlet for the impeller and communicating with a threaded portion 69 adapted to receive a short conduit 70. The conduit 70 is adapted to extend into the oil 71 to be pumped, as shown, and may be provided with a screen or the like. A sealing sleeve is provided for the extension shaft as shown.

The several motor and pump units, the upper adapter, and the lower adapter, are all held together by means of a plurality of tie bolts 75 and nuts 76.

Fig. 2A illustrates a construction I use when gassy oils are being pumped, in order to allow "air lift effect" to assist in raising the oil from the well bottom. As shown, I provide a removable gas seal or "packer" 78 of rubber, canvas or the like, fitting in the casing 79 and closing off the oil in the well bottom from the upper part of the casing. With this arrangement, all the gas in the well oil goes through the pumps, and on being freed at the discharge of the well pumping apparatus and starting to rise, the gas expands, thus decreasing the weight of the return column and hence the pressure against which the pump operates.

It is sometimes desirable in pumping gassy oil to dispense with the packer, and provide a separate return conduit for the oil being pumped. In this case gas coming into the well bottom with the oil frees itself, passes up the well in the space between the casing, the motive fluid conduit and the well oil return, and is removed at the top. The gas completely bypasses the pump.

Figs. 15, 16, and 17 are vertical sections taken along the lines 15—15, 16—16, and 17—17 of Figs. 3 to 12 and 14, which are cross sectional views taken at various points along the length of the pumping combination of Figs. 2 and 24. Figs. 3 to 17 are for the purpose of showing the port arrangement, and various other constructional features of the apparatus.

Tracing out the port arrangement for the motive power fluid: power oil being pumped down the supply conduit 56 enters the upper adapter 55. The upper adapter plate 54 is provided with power oil inlets 85 (Figs. 15 and 17). Power oil passes through these ports and into the power oil conduit for the several units. This conduit comprises the power oil inlets 86 in each crossover, motor housing and pump housing, all of which inlets are alined so as to form a single bore, as shown in Fig. 15. In each motor shell is an entrance port 87, connecting the power conduit and the space around the motor ring gear. The ports 87 and conduits 86 serve to admit power oil to the motors in parallel connection.

Exhaust of oil from the motors is through a similar series of exit ports 95, and conduits 96 in the crossovers, motor housings and pump housings. Peripheral ports 97 in the upper adapter plate, and 98 in the upper adapter, lead the motor discharge to the well casing. At this point the motor exhaust mingles with the well oil being pumped upward. I may provide a separate conduit for the exhaust oil, if desired.

The course of the well oil being pumped is best seen in Figs. 16 and 17, 20 and 21. Well oil enters the pumping apparatus through the lower adapter and passes through conduit 99 and inlet 100 to the lowermost pump. Oil is discharged from the pump through outlet 101 and conduit 102 in the pump housing, and passes upwardly through a similar conduit 102 in the motor housing, through the crossover, and into the second stage pump through conduit 99 and inlet 100 as shown. The oil is forced upward through the third stage similarly, and is discharged through peripheral ports 102A in the upper adapter plate and 103 in the upper adapter, to the well casing, where the oil mingles with the exhaust from the motors.

Figs. 20 and 21 are isometric phantom or shadow views for the purpose of showing as clearly as possible the port arrangement of the pumping combination of Figs. 2 and 2A. For the sake of clarity the pump port system and the motor port system are shown in two separate views. The actual apparatus of course has both sets of ports, as shown in detail in Figs. 3 to 17. Fig. 20 shows only the motor port system, the pump ports being omitted from this view; while Fig. 21 shows only the pump port system, the motor ports being omitted. In each view (Figs. 20 and 21) the gears and other parts of the combination are omitted, for the sake of simplicity; Figs. 2 and 2A showing these elements in detail.

The course of liquids through the apparatus is indicated by arrows in Figs. 20 and 21. Referring to Fig. 20, power oil under pressure enters the apparatus through the three power oil inlets 85 (of Fig. 3). These deliver into the three power oil conduits 86. One of these conduits extends to the bottom-most motor, another only to the second stage motor, and the third reaches only to the uppermost motor. However, all the conduits 86 are in free liquid communication (cf. Figs. 5 and 8) and the pressure in all of them is hence substantially the same. The reason for providing three conduits rather than a single large conduit is a structural one. As is shown in Fig. 4, the tie bolts 75 cut down the available space in the casing, and the power oil conduits are run between tie bolts. This arrangement makes for compactness. While all three conduits 86 could extend clear to the bottom unit, in the embodiment of the pump under consideration this is not done. It is not necessary to so extend the conduits 86, insofar as hydraulic requirements are concerned, because one-third of the volume of entering power oil is taken by the uppermost motor and one-third by the second stage motor, leaving but one-third for the bottor-most motor.

Referring to Fig. 21, showing the pump port arrangement, oil from the well is supplied by the booster to the lowermost pump through inlet 99. Inlet 99 takes the form of a triple passage, the three passages being in communication (cf. Fig. 2). This arrangement is for the same reason as explained in connection with Fig. 20: to secure compactness, the liquid conduits are located in the space between the tie rods 75. Only one inlet passage is strictly necessary, but the three passages are provided to receive the output from the booster with maximum efficiency; to minimize frictional resistance. Referring to Fig. 21, oil is drawn through inlet 99 and inlet chamber 100, to the lowermost or first stage and is discharged at raised pressure through passage 102 to inlet passage 99 of the second stage pump. Oil is discharged from the second stage pump into the third stage pump in a similar manner. It is finally discharged from the upper end of the apparatus through passages 102A and 103, into the well casing, under a pressure at least equal to the hydrostatic head in the well, so as to cause oil to flow from the well at the surface.

Fig. 17 is a diagrammatic sectional view taken along line 17—17 of Fig. 3, for the purpose of showing only the lubrication system. It is desirable to use only clean oil for lubricating the pumps. The well oil being pumped often contains sand and salt water; these are removed by settling in the storage tank at the top of the well and the cleaned oil sent down again as power fluid for the motors. At the bottom of the well, this power fluid is at a greater pressure than exists anywhere else in the pumps or motors (2400 pounds in the specific example of a 4000 foot well). Hence this power oil may be used to supply clean lubricating oil to all the bearings and clearance spaces. The direction of flow of lubricating oil on the motors makes no difference as the lubricating fluid is all clean oil. In the case of the pumps, I provide ports so that the power fluid leaks inward through the bearings and clearances toward the dirty oil inside the pump. In this way I prevent sand and dirt from getting in the bearings; the only parts subjected to the action of sand and salt water are the gear teeth and the floating ring.

As shown in Fig. 17 power oil enters the apparatus through passage 85 and top-most conduit 86. A minor part of the flow is bled off through a port 104 to chamber 46 in the topmost crossover of the top unit. A port 105, common to the motor housing and pump housing as shown, allows oil to enter the space between the pump and motor and bleed into the motor and pump chambers. A lubrication port 105A (see Figs. 5 and 6) and a port 106 allow oil to reach the lower bearings of the first pump. In the first unit oil flows inwardly and to both pump and motor, and is bled into the pump similarly. Inlet port 104 in the two lower cross overs 28 does not show in the section shown in Fig. 17. In the central unit flow of oil is outward from the motor. The lowermost pump and the motor unit is similar to the second.

In the two lower units bleed ports 120 are provided, to allow bleeding off of lubricating oil from the bearing spaces into the well oil discharge conduits. Bleed orifice members 121 (fine-bored nipples) are provided in ports 120, for restricting the bleed of oil.

The sectional views 3 to 14 also show the port arrangement in detail. Fig. 3 shows three power oil inlets 86 which communicate with the upper adapter chamber, and three power oil outlets 97 which communicate with peripheral ports 98 in the upper adapter and hence open into the well casing. Fig. 3 shows also a well oil discharge 103 communicating with the well casing. Fig. 4 shows the power oil inlets and outlets continuing through the crossover 45, and the well oil discharge crossover. This figure also shows the upper part of ball bearing 47. Fig. 5 is a section through the upper motor and shows in addition to the power oil conduits and well oil discharge, the motor ring gear 22 and pinion 21. Fig. 6 is a section through adjacent pump and shows in addition to power oil conduits, a well oil suction passage 99 from the lower pumps and a well oil discharge 102 leading upwards. Figs. 7 to 12 and 14 are other sections along the length of the apparatus, and are believed self-explanatory.

Fig. 13 is a sectional view similar to Fig. 12 showing a modification which I sometimes use. In any pumping operations where gassy liquids are handled, loss of efficiency and other disadvantages occur to a greater or less degree, due to wasteful compression and expansion of the gas. In a copending application Serial No. 626,420 I have disclosed a gear pump or compressor of the ring gear and pinion type, having a flexible abutment for the purpose of adapting the pump to work with gases. For an explanation of the principles involved reference is made to the said copending application. As shown in Fig. 13 I provide a flexible abutment comprising an arcuate flexible member 107 of spring steel, bronze or the like engaging the discharge side of the pump ring gear and retained in the sleeve 23 by screws 108, as shown. For pumping gassy wells, I ordinarily use a flexible abutment on each well pump.

Fig. 22 is an isometric view, with parts broken away, of a single stage pump and motor combination, which is made up of the lowermost pump, motor and crossover of Fig. 2A enclosed between two similar adapters 55 and adapter plates 54 as shown. No booster pump is shown. This showing is for the purpose of making clear the general arrangement and location of the pump and motor gears and associated elements in the casing. The descriptions which have been given in connection with the other showings apply to this figure.

As stated, I sometimes embody the invention in a pumping combination in which the several pump and motor units are interchangeable. This construction, while it presents some additional complication in manufacturing, is advantageous in certain relations in that it allows pumping combinations to be assembled from separate pump and motor units in any practical number. Combinations comprising one to four units may be built up simply by bolting the units together and providing appropriate upper and lower adapters, and appropriate crossovers. In the modification already described, the pump and motor housings, gears and other parts are generally similar, and were it not that the port and channel arrangements differ in each housing, the units could be interchangeably stacked. In the interchangeable type the difference from the first described modification resides in the port arrangement in the pump and motor housings. Accordingly this modification is illustrated by phantom views in Figs. 23 and 24, showing the pump port arrangement and motor port arrangement respectively. The gears, bearings, housings and other parts are like those described ante in connection with Figs. 1 to 22.

Figs. 23 and 24 show a three unit combination, comprising three exactly similar pump and motor units each comprising a pump housing 34, a motor housing 20 and a crossover 45. The combination is topped by an adapter plate 54 and adapter 55, and the bottom is provided with a booster pump adapter fitting 69. The casings are provided with power oil discharge conduits 96, well oil discharge conduits 102 and power oil inlet conduits 86. In this modification, however, the three power oil inlet conduits and the three power oil outlet conduits extend through each unit of the combination. In the first-described combination there are three power oil inlet conduits and three outlet conduits in the uppermost unit; two in the intermediate unit; and one in the lowermost unit. In the apparatus of Figs. 23 and 24 well oil enters the lowermost pump through a single channel 99 instead of three channels 99 as in the first-described modification. Also, oil for lubrication is forced directly from the power oil inlet, through inlets 105 and 106. Well oil is forced upwardly through the three pumps in series as described in connection with Fig. 21, being finally discharged into the well casing through discharge outlet 103. The course of power oil to the motors is similar to that in Fig. 20. Oil is delivered to the inlet side of the three motors in parallel, through inlet conduits 86 and inlets 87, and is discharged from the motors through outlets 95 and discharge conduits 96. Each crossover 45 contains six passages 86 extending therethrough: three passages for incoming power oil and three passages for discharged oil. The port arrangement in each crossover is similar, allowing interchangeability. The lower adapter plate blocks off the lower ends of all three passages 86 and of all three passageways 95. It is seen that each unit comprising motor, pump and crossover, is exactly like the others.

The three power oil conduits 86 are all in free fluid communication, and pressure is substantially the same in each. A single large conduit could be used in place of the three separate ones, but as described in connection with Figs. 20 and 21 it is convenient to provide the liquid passages in the spaces in the casing between the tie bolts 75. The reason for having all three power oil conduits extending to the bottom-most (first stage) motors is to make each casing unit exactly alike, and thereby secure interchangeability. Insofar as hydraulic requirements are concerned, the power oil conduits could be arranged as shown in Figs. 20 and 21—only a single conduit extending to the bottom—but in such case the pump-motor unit casings have different passage arrangements and are not interchangeable.

These units are interchangeable. For example, if it is desired to make up a two-stage combination for a well of moderate depth, the central pump, motor and crossover can be removed from the combination of Figs. 23 and 24, and the remaining two units bolted together with shorter tie-bolts, whereupon a complete two-stage pumping modification is formed. There is no problem of lining up the component units; the connections between units are only fluid connections.

The present apparatus is found in practice to have many advantages over other pumping apparatus for deep wells. The well pump works smoothly and without interruption, and the flow that can be pumped from a deep well is remarkably high. A three-stage pumping combination installed in a deep well, the pump and motor pinions having a pitch diameter of 2 inches and the outside diameter of the housings being 5.75 inches, pumped 1000 barrels per day when run by a surface force pump developing 850 pounds pressure. The pumping apparatus is much better adapted for handling gas than any other well pumps known to me.

What I claim is:

1. The method of pumping oil from deep wells hydraulically which comprises forcing oil in a conduit down the well under pressure, passing such oil at substantially the same pressure in

parallel through and to drive a plurality of hydraulic motors located far down the well, operating the motors to drive a like plurality of pumps arranged hydraulically in series, causing oil to be drawn from the well bottom into and through the pumps in series, each pump raising the pressure in the well oil, the volume of oil passing through the motors being a plurality of times greater than that passing through the pumps, whereby the motors and each pump work at a fraction of the pressure necessary to force oil from the well, and the pressure given the well oil by the pumps being sufficient to cause oil to flow from the top of the well.

2. The method of pumping oil from deep wells hydraulically which comprises forcing cleaned oil in a conduit down the well under pressure, passing such oil at substantially the same pressure in parallel through and to drive a plurality of hydraulic motors located far down the well, utilizing the motors to drive a like plurality of pumps arranged hydraulically in series, lubricating the motors and the pumps by said cleaned oil, causing oil to be drawn from the well bottom into and through the pumps in series, each pump raising the pressure in the well oil, the final pressure developed by the pumps being sufficient to cause oil to flow from the top of the well, the volume of oil passing through the motors being a plurality of times greater than that passing through the pumps, whereby the motors and each pump work at a fraction of the pressure necessary to force oil from the well, and the oil issuing from the well is cleaned and a part of it continuously returned through the motors in cyclical operation.

3. The method of pumping gassy oil from deep wells hydraulically which comprises forcing oil in a conduit down the well under pressure, passing such oil at substantially the same pressure in parallel through and to drive a plurality of hydraulic motors located far down the well, operating the motors to drive a like plurality of pumps arranged in hydraulic series, the pumps being adapted to function as gas compressors, causing gassy oil to be drawn from the well bottom into and through the pumps in series, each pump raising the pressure in the well oil, the final pressure developed by the pumps being sufficient to cause oil to flow from the top of the well, the volume of oil passed through the motors being a plurality of times greater than that passing through the pumps, whereby the motors and each pump work at a fraction of the pressure necessary to force oil from the well, the pumps being separated from the gassy oil supply in the bottom of the well so that gases are constrained to enter the pumps and aid in lifting the oil by air lift effect.

4. The method of claim 1 wherein the well oil is subjected to slight pressure just before entering the first of the pumps, so as to prevent escape of gas in the inlet of the first of the pumps.

5. A hydraulically operated deep well pumping apparatus comprising in combination a plurality of positive displacement pumps hydraulically connected in series, each pump having an inlet and an outlet, the inlet of the first pump in the series being in communication with the oil in the bottom of the well, the pumps being located far down the well and being adapted to draw oil from the bottom of the well and force it upwards, a plurality of positive displacement hydraulic motors, each coupled and driving one of the pumps, a supply force pump at the top of the well for actuating the motors, a conduit connection leading from the force pump to the motors and supplying oil to all the motors at substantially the same pressure, and means for furnishing the supply pump with clean oil.

6. The apparatus of claim 5 wherein means are provided to adapt the well pumps to be lubricated by clean oil forced down the well, this oil being under greater pressure than the well pump pressure and passing inwardly, to prevent seepage of the well oil outward into the bearings.

7. A hydraulically operated deep well pumping apparatus comprising in combination a plurality of positive displacement pumps hydraulically connected in series, each pump having an inlet and an outlet, the inlet of the first pump in the series being in communication with the oil in the bottom of the well, the pumps being located far down the well and adapted to draw oil from the bottom of the well and force it upwards, a plurality of positive displacement hydraulic motors, each coupled with and driving one of the pumps, a supply force pump at the top of the well for actuating the motors, a conduit connection leading from the force pump to the motors and supplying oil to all the motors at substantially the same pressure, means for furnishing the supply pump with clean oil, the pumps positioned down the well being provided with flexible abutment means so as to adapt them to act efficiently as gas compressors, a packer separating the pumps from the oil supply in the bottom of the well, and an outlet for the pumps above the packer, so that any gases contained in the well oil aid in lifting the oil in the well, by air lift effect.

8. The apparatus of claim 5 wherein a pump adapted to produce a slight pressure is positioned below the well pumps, between them and the oil in the well bottom and adapted to deliver into the inlet of the first of the well pumps, so as to prevent escape of gas in the first of the well pumps with consequent vibration and loss of efficiency.

9. A hydraulically operated deep well pumping apparatus comprising in combination a plurality of rotary positive displacement pumps hydraulically connected in series, located near the bottom of the well and adapted to draw oil from the bottom of the well and force it upwards, a plurality of rotary positive displacement hydraulic motors, each being mechanically connected to and adapted to run one of the pumps, the pumps and motors being combined in a unitary structure with ports and passages enclosed in the structure for delivering well oil to the pumps and for delivering power oil to the motors and for discharging exhaust power oil and well oil from the pumps and motors, a constant pressure supply pump at the top of the well for actuating the motors, conduit connections in parallel from the supply pump to the motors so that the supply pump supplies oil to each motor at substantially the same pressure, and means for supplying the supply pump with oil.

10. The apparatus of claim 9 in combination with a rotary impeller pump adapted to deliver well oil into the inlet at a slight pressure and driven through one of the well pump motors.

11. A hydraulically operated deep well pumping apparatus comprising in combination a plurality of positive displacement pumps of the ring gear and pinion type hydraulically connected in series, substantially coaxially arranged one above the other, the pumps being located near the bottom of the well and being adapted to draw oil from the bottom of the well and force it upwards, a like plurality of positive displacement motors of ring gear and pinion type each being mechanically

connected to and adapted to drive one of the pumps, the motors being substantially coaxial with the pumps, the pumps and motors being mounted in a compact, elongated, substantially cylindrical housing with ports and passages enclosed therein for delivering well oil to the pumps and for delivering power oil to the motors and for discharging exhaust power oil and well oil from the pumps and motors, a constant pressure supply pump at the top of the well for actuating the motors, conduit connections in parallel from the supply pump to the motors so that the supply pump supplies oil to each motor at substantially the same pressure, and means for furnishing the supply pump with oil.

12. In a system for pumping oil from deep wells by hydraulic power, fluid driving means near the top of the well, a plurality of pumping units near the bottom of the well, each unit comprising a positive displacement hydraulic motor and a positive displacement hydraulic pump, the motor being operatively connected to and adapted to drive said pump, a power fluid conduit connecting said fluid driving means and the motors of each unit, said motors being connected to said conduit in parallel so that each motor receives power oil at substantially the same pressure, fluid conducting means connecting well oil in the well bottom with the inlet of one of said pumps, the remaining pumps being arranged in series with the outlet of said first named pump to form a multi-stage pumping device, tile outlet of the final stage in said device being connected by a return conduit with a suitable reservoir at the top of the well, means connecting each motor exhaust with said return conduit, and conduit means connecting the reservoir with the inlet of said fluid driving means.

13. A pumping apparatus, comprising in combination a plurality of separable self-contained pumping units in contact, each comprising a hydraulic motor and a hydraulic pump driven thereby, a substantially cylindrical casing surrounding the motor and pump and having peripheral communicating ports and passages therein for supplying motive fluid to the motor and fluid being pumped by the pump, the ports and passages in each unit casing ending in open ports in the ends of the cylindrical casing and being so disposed that the several units in contact act as a complete pumping combination, fluid being pumped through the combination and motive fluid being passed through all the motors of the combination.

14. A pumping apparatus comprising a plurality of individual hydraulic pump and motor units stacked together, each pump and motor unit having communicating passages and ports so that motive fluid is delivered to all the motors at substantially the same pressure and is passed through all the motors in parallel and fluid is pumped through all the pumps in series.

15. A pumping apparatus comprising in combination a plurality of hydraulic motor and pump combinations and casings for motors and pumps having ports and passages for fluids, the motor and pump combinations being stacked together, ported crossovers being interposed between the combinations, the ports in each crossover making communicating fluid connections between combinations above and below the crossover.

16. A compact pumping unit comprising a hydraulic motor and a hydraulic pump and a cylindrical housing therefor, the motor and the pump each comprising a ring gear, a coacting pinion and bearings for the ring gear and for the pinion, a mechanical coupling operatively connecting the motor and the pump, the housing being provided with inlet and outlet chambers adjacent the inlet and outlet of the pump and the motor, ports and passages peripherally disposed in the cylindrical casing along the direction of the axis thereof for delivering fluid to the inlet of the pump and from the outlet thereof and for supplying power oil to the motor, and abutments adjacent the peripheries of the ring gears separating the inlet and outlet sides of the pumps and motors.

17. A pumping combination comprising a plurality of units as defined in claim 16 stacked together vertically, means being provided adjacent the topmost unit for connection with a supply conduit for power oil, and booster pump means adjacent the lowermost unit and driven thereby and adapted to supply the lowermost pump with oil from the well under a slight pressure.

18. A compact pumping unit comprising a plurality of hydraulic motor driven pump units stacked together vertically, each unit comprising a ring gear and coacting pinion motor, a housing and bearings therein for the ring gear and pinion, and a similar pump, each unit further comprising a mechanical coupling operatively connecting the motor and pump, the housing being provided with inlet and outlet chambers adjacent the inlet and outlet of the pump and motor gears and with peripherally disposed ports and passages in the housing extending along the direction of the axis, for delivering fluid to the inlet of the pump and from the outlet thereof and for supplying power oil to the motor, and abutments adjacent the peripheries of the ring gears separating the inlet and outlet sides of each pump and each motor, the combination having means adjacent the topmost unit for connection with a supply conduit for power oil and means adjacent the lowermost unit adapted to communicate with liquid to be pumped.

19. A pumping apparatus comprising in combination an elongated, substantially cylindrical casing, and a plurality of mechanically independent pumping units disposed one above the other in the casing, each unit comprising a hydraulic motor and a hydraulic pump mechanically coupled therewith and driven thereby, the casing having passages disposed peripherally therein and extending in an axial direction, some of the passages communicating with the motors for supplying motive fluid thereto, and other of the passages communicating with the pumps and carrying fluid being pumped from one pump to another in series, and an end piece on each end of the casing, one end piece having an inlet passage for delivering fluid to the lowermost pump and the other end piece having an inlet passage for delivering fluid to all the motors.

20. A pumping apparatus comprising in combination an elongated, substantially cylindrical casing and a plurality of mechanically independent pumping units in the casing, each unit comprising a hydraulic motor having a coacting ring gear and pinion and a similar hydraulic pump mechanically coupled therewith and driven thereby, the axis of the gears being parallel to the axis of the casing, the casing having peripheral passages disposed therein and extending longitudinally, some of the passages communicating with the motor gears for supplying motive fluid thereto and exhausting motive fluid therefrom

and other of the passages communicating with the pumps and carrying fluid being pumped from one pump to another, and an end piece on each end of the casing, one end piece having an inlet passage for delivering fluid to the lowermost pump and the other end piece having an inlet passage for delivering fluid to all the motors.

21. In a hydraulically operated pumping apparatus, a pumping unit comprising a hydraulic pump, a hydraulic motor driving the pump, a substantially cylindrical casing for the pump and motor, the casing being provided with peripheral ports and passages extending in an axial direction for flows of power fluid for the motor and for flows of fluid being pumped by the pump, said ports and passages opening at each end of the cylindrical casing, a crossover member at one end of the casing having ports and passages cooperating with certain of the ports and passages in the unit casing to direct a flow of power fluid to the motor, means for supplying power fluid to the crossover member, and means for supplying fluid to be pumped, to the said ports and passages in the casing for fluid to be pumped.

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