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(54) Hydraulic pump or motor.

(57) An hydraulic machine which can operate either as a motor or a pump, the machine having a rotor and a stator, one of which is provided with lobed cam track means (16, 17, 18, 107, 108, 109, 400, 500, 604, 605) on which operate a plurality of phased series of piston and cylinder modules (105, 205, 306, 610) to impart relative motion between the rotor and stator. Modular valve means (13, 35, 102, 300, 606) control the supply of hydraulic fluid to each series of pistons.

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IMPROVEMENTS IN OR RELATING TO HYDRAULIC MACHINES.

This invention relates to hydraulic machines. Hydraulic machines have previously been proposed, as for example in our British Patent No. 633,733, in which a multi-cylinder hydraulic motor is formed by a plurality of hydraulic cylinders with pistons working therein radially arranged around a driven shaft. The shaft has fixed thereto a single primary undulating cam track and each piston carries a pair of rollers which ride on the cam track. Each cylinder has an associated valve which controls inlet and exhaust of pressure liquid to and from the cylinders, the valves being controlled through the intermediary of a valve-operating cam track which is mounted for rotation with the first cam track. The valve-operating cam track causes the valves to admit pressure liquid to a number of the hydraulic cylinders and the pistons, through their rollers and co-operating cam track, impart a rotary motion to the driven shaft. As the shaft rotates, the reciprocating movement to the valves in operation results in the pressure liquid being intermittently admitted and exhausted to and from each of the corresponding hydraulic cylinders.

The contour or undulation of the primary cam track is such that an harmonic or substantially harmonic motion is imparted to the pistons during their radially inward (power) stroke and their outward (exhaust) stroke. The number of pistons and number of undulations on the cam track is selected such that a continuous smooth rotation of the driven shaft is effected so that the unit functions as a motor. For example, it has been found convenient to have thirteen pistons and five undulations.

The above-described previously proposed arrangement has been found to be satisfactory in use but does have a number of disadvantages. For example, it is a relatively expensive machine to produce and the cam track in particular has a relatively short working life. If one of the piston and cylinder units or the valve units fails then the machine has to be effectively dismantled so that the faulty part can be serviced. Furthermore, the prior arrangement has limitations in its range of speed variations with which it can operate as a motor or the range of displacement variations if operating as a pump.

An object of the present invention is to provide an hydraulic machine in which the aforesaid disadvantages are obviated or mitigated.

According to the present invention, there is provided an hydraulic machine comprising a first member; a second member arranged for movement relative to said first member; cam track means carried by said first member; a plurality of independently mounted hydraulically-operated piston and cylinder modules carried by said second member, said modules forming at least one interconnected bank of such modules in operative relationship with the cam track means; and modular valve means associated with at least each bank of modules for controlling the supply and exhaust of hydraulic liquid to each of the modules in the bank.

The valve means can be embodied in a module separate from the piston and cylinder modules or, alternatively, the valve means can be incorporated in the piston and cylinder modules.

Embodiments of the present invention will now be described, by way of example, with reference to the accompanying drawings in which:-

Fig. 1 is a part sectional view of a first embodiment of hydraulic machine.

Fig. 2 is a part sectional view on the line II-II of Fig. 1.

Fig. 3 is an alternative form of valve module which can be substituted for the valve module illustrated in Fig. 2 when the machine is to be used as an hydraulic pump.

Fig. 4 is a perspective view of a second embodiment of hydraulic machine.

Fig. 5 is a diagrammatic fragmentary cross-sectional view illustrating part of one row of module units of the machine of Fig. 4.

Fig. 6 is a diagrammatic fragmentary cross-sectional view illustrating part of one bank of module units of the machine of Fig. 4.

Fig. 7 is an enlarged sectional view of a module unit as disposed in a bank of such units.

Fig. 8 is an enlarged sectional view of a module unit as disposed in a row of such units, and

Fig. 9 is a plan view of module unit used in the machine of Fig. 4.

Fig. 10 is a sectional view of an alternative form of piston and cylinder module as compared to that shown in Figs. 2 and 3.

Fig. 11 is a sectional view of an alternative form to that shown in Figs. 7 and 8, of a piston and cylinder module incorporating a valve assembly.

Fig. 12 is a diagrammatic representation of one embodiment of a motor having one pair of cam tracks.

Fig. 13 is a development of part of the cam of Fig. 12.

Fig. 14 is a diagrammatic representation of a further embodiment of a motor having a single pair of cam tracks and

Fig. 15 is a development of part of the cam of Fig. 14.

Fig. 16 is a sectional view of the upper half of a further embodiment of hydraulic motor incorporating two banks of module units, each of said banks itself constituting a hydraulic motor. The piston and valve sleeves have been omitted from the right hand bank in order to illustrate the hydraulic cavities of the cylinder and

Fig. 17 is a diagrammatic representation of the motor of Fig. 16 illustrating the two cams and the hydraulic interconnections between the module units.

Fig. 18 is a part-sectional side view of a motor similar to that shown in Fig. 16 but incorporating an auxiliary bank of slave modules.

Fig. 19 is a part-sectional front view of the motor of Fig. 18.

Referring to Figs. 1 and 2 of the drawings, an hydraulic machine suitable for use as a constant torque hydraulic motor comprises a stator 10 incorporating a 3" thick ring of mild steel into which flats are machined with apertures therein to receive a plurality of separately detachable module units indicated generally by the reference numeral 12. The modules 12 comprise modular valve units 13 and modular piston and cylinder units 14.

As can be seen best from Fig. 1 the modules 12 are disposed in rows extending parallel to the longitudinal axis of the motor. Furthermore, as can be seen best from the upper half of Fig. 2, the modules are also disposed in banks annularly around the longitudinal axis of the motor. Hereinafter therefore, the term "row" will be used to describe a series of modules extending lengthwise of the motor and the term "bank" will be used to describe a series of modules extending annularly or transversely of the motor.

The piston and cylinder units 14 extend into the interior of the stator 10 and each co-operates with a pair of rollers 15 which run on one of three primary undulating or lobed pairs of cam tracks 16, 17, 18 (Fig. 1). The cam tracks 16, 17, and 18 are fixedly mounted on a hollow driven shaft 19 so that reciprocation of the pistons within the piston and cylinder units causes the driven shaft 19 to be rotated in known manner.

Each modular piston and cylinder unit 14 as shown in Fig. 2 comprises a cylinder 20 within which a piston 21 can reciprocate, the rollers 15 being carried on a crosshead 15a at a radially inward end of the pistons 21.

Each valve module 13 comprises a piston 22 spring-loaded by means of a spring 23, the piston 22 operating within a bore or chamber of a cylinder 24. The piston 22 bears on a crosshead 25a which carries rollers 25 at its radially inward end, which rollers run on separate undulating valve-operating cam tracks 26, 27, 28 located between each pair of cam tracks 16, 17 and 18. Fluid cavities 24a, 24b and 24c are provided in the cylinder 24 and an annular groove 22a is formed on the external surface of the piston 22.

Fig. 2 of the drawings shows a motor in which only a single valve module 13 is incorporated in each bank, the other locations in the bank which could receive additional valve modules being provided with blank modules 29.

Pressure oil passages 30, 31, 32 and 33 in the valve modules 13, piston and cylinder modules 14, blank modules 29 and stator 10 respectively interconnect each of the modules in each of the three banks of the motor. Each of the primary cam tracks 16, 17 and 18 co-operate with one of the three banks of modules. As illustrated in Fig. 2 each primary cam track has eight lobes and the lobes of each cam track are arranged 120° out of phase with its adjacent cam track. Each bank incorporates eight piston and cylinder modules 14, all operating in the same phase.

The lobes on the separate valve-operating cam tracks 26, 27 and 28 associated with each bank of modules are arranged 90° out of phase with its related primary cam track. The cam followers or rollers 25 of each bank are all in the same phase.

From the foregoing description, it will be appreciated that each bank of modules is not a motor in itself as all of the piston and cylinder modules are operating in the same phase. At least three banks are required for the machine to function as a motor. In other words, the work done on each primary cam track is one third of that done by a normal multi-cam motor having a single cam track.

In operation of the above-described embodiment, pressure oil is supplied to each bank of modules by its valve module 13, the pressure oil being supplied to and exhausted from the eight piston and cylinder modules 14 through the passages30, 31, 32 and 33 so as to effect rotation of the hollow driven shaft 19.

If a greater power output is required from the motor, one or more of the blank modules 20 in each bank can be substituted by an additional valve module or modules 13. In this way, the power output of the motor can be increased in up to eight steps as desired. It will also be apparent that such modifications or other repairs can easily be effected from the outside of the machine merely by removing one module and substituting another so that the whole machine does not require to be dismantled and be out of operation over an extended period.

If desired, the hollow driven shaft 19 can be provided with additional means whereby additional banks can be added to the hollow shaft to provide greater power output or torque. The motor is provided with a brake 34 of known form.

Fig. 3 is a view similar to Fig. 2 wherein the valve module 13 of the motor shown in Fig. 2 is replaced by a valve module indicated generally by the reference numeral 35. The valve module 35 allows the machine to be employed as an hydraulic pump. The valve 35 allows liquid being pumped to be drawn from a sump through suction inlet valves 36 and discharged through delivery valve 37. One or more of the inlet valves can be provided with means for lifting it off its seat to allow variable stepped displacement.

Mostly, the machine will be used as a high displacement pump utilising all available piston and cylinder modules. The pump can be modified, however, to a variable displacement pump, for use e.g. with windmills where variable wind speeds require a variable displacement, high torque, low speed pump, merely by cutting out an appropriate number of piston and cylinder modules. When used as a pump, the valve-operating cam tracks 16, 17 and 18 of Fig. 1 are not required.

Figs 4 to 9 illustrate a second embodiment of the present invention in which, as in the first embodiment, a stator 100 having flats 101 machined thereon receives a plurality of modules 102. The modules 102 perform the joint function of the valve modules 13 and piston and cylinder modules 14 of the first embodiment and are similarly arranged in banks and rows as hereinbefore defined.

Each module has a cylinder 103 defined by a separate valve sleeve 104 and a piston 105 is provided with a pair of rollers 106 at its radially inward end through the intermediary of a crosshead 106*a*. The rollers of one of the three banks of modules 102 run on a respective one of three pairs of undulating or lobed cam tracks 107, 108 and 109 (Fig. 5). The cam tracks 107, 108 and 109 are fixed to a hollow driven shaft 110 so that reciprocation of the pistons 105 causes the driven shaft 110 to be rotated through the intermediary of the cam tracks 107, 108 and 109.

As can be seen from Fig. 4, each module 102 in each of the three banks of the motor is interconnected by telescopic or flexible pressure fluid conduits 111 which connect the piston at the upper portion of one module with the lower portion of the adjacent module. Telescopic or flexible fluid pressure supply conduits 112 and exhaust conduits 113 also interconnect each of the eight rows of modules (Figs. 4 and 5).

The three cam tracks 107, 108 and 109 each have six lobes and the lobes of each track are disposed 120° out of phase relative to the lobes of the adjacent track.

For one module 102 to act as a valve for the piston of the next adjacent module, the modules must be phased relative to each cam track lobe at $\frac{\pi}{2}$ (where $\pi = 180^{\circ}$) or multiples of $\frac{\pi}{2} + \pi$. For a multi-lobe cam track $\frac{\pi}{2}$ is generally not practical since the module spacing is too close.

Conveniently therefore, the modules 102 in each bank can be phased at $\frac{3\pi}{2N}$ or $\frac{5\pi}{2N}$ where N = the number of lobes. From this, it can be calculated that if N is a multiple of 3 i.e. the number of lobes is 3 or 6 or 9 etc. the number of modules required per bank is 4, 8 or 12 etc. respectively. If N is a multiple of 5 i.e. the number of lobes is 5 or 10 or 15 etc., the number of modules required per bank is 4 or 8 or 12 etc. respectively.

Referring to Figs. 7 and 8 of the drawings, these Figs. show a valve module 102 in which its hydraulic connections within a bank and a row are respectively illustrated. The module 102 comprises a cylinder 103 defined by a separate valve sleeve 104 and piston 105 previously referred to. The inner portion of the cylinder 103 constituted by the valve sleeve 104 is of annular form and is slidably located within the outer portion of cylinder 103 and is provided with seals 114. The valve sleeve 104 has three external grooves formed therein each of which defines upper, centre and lower cavities 115a, 115b and 115c respectively, each cavity 115 being connected by a passage 116 which extends through the valve sleeve 104 to the radially inner surface thereof. The piston 105, which is spring loaded by means of a spring 117, is slidable within the valve sleeve 104 and has a groove 118 formed in its external surface so that it can be connected with the upper two or the lower two of the cavities 115 through the passages 116 depending upon the position of the valve sleeve 104 and piston 105 within the cylinder 103. A seal 119 is located between the piston 105 and valve sleeve 104. Referring to Fig. 7, the upper end of the chamber of the cylinder 103 is connected through passage 120 in the cylinder wall to the upper end of a conduit 111 which connects the module to the centre cavity 115b of the adjacent module in the bank at one side thereof. A passage 121 connects centre cavity 115b to the lower end of another conduit 111 which connects the module to the chamber of the cylinder of the adjacent module in the bank on the other side thereof.

Fig. 8 shows the module connections within a row i.e. at 90° to the view shown in Fig. 7. Fig. 8 shows a pressure supply port 122 which is connected by passage 123 to the lower cavity 115c. The pressure port receives pressure oil from a pressure conduit 112 connected to the adjacent module in the row on one side thereof and transmits it through passage 124 to pressure conduit 112 connected to the adjacent module in the row on the other side thereof. Similarly exhaust conduits 113 interconnect upper cavity 115a with adjacent modules in the row through passages 125 and 126. Each row of modules has an independent supply and exhaust for the pressure oil.

In operation of the embodiment shown in Figs. 4 to 9, pressure oil is supplied to the cylinder 103 of each module 102 through conduit 111 to cause the piston 105 to be urged radially inwardly against its associated cam track via a crosshead and bearing assembly to assist in rotating the driven shaft 110. The conduit 111 receives the oil through lower cavity 115c, groove 118, and centre cavity 115b in the adjacent module. On the cam track rotating further, the piston is forced radially outwardly and the oil is exhausted from the cylinder 103 through the conduit 111 at the upper end thereof and from where the oil passes to exhaust through passages 121, centre cavity 115b, groove 118, and cavity 115a in the adjacent module.

As in the first embodiment, each module 102 can be readily removed or substituted after suitable telescoping or flexing of its conduits 111, 112 and 113.

Fig. 10 is a sectional view illustrating a modified form of piston and cylinder module as compared to that illustrated in the embodiments described with reference to Figs. 2 and 3. The piston and cylinder module of Fig. 10 is particularly for use in the embodiment described with reference to Figs. 4 to 9. The module of Fig. 10 comprises a body 200 which can be releasably mounted in a stator 201. Secured to the body 200 by means of bolts 202 extending therethrough is a cylinder 203. A cylinder chamber 204 is defined within the interior of the cylinder and a piston 205 is reciprocable within the cylinder 203 under the influence of a spring 206. At its radially inward end, the piston bears on a crosshead 207a which is provided with a pair or rollers 207 which co-operate as before with a pair of lobed cam tracks (not shown). Pressure fluid supply or exhaust bores 208 extend through the cylinder 203 from the exterior thereof into the upper end of the chamber 204.

Fig. 11 illustrates an alternative form of valve module to that shown in Figs. 7 and 8. The module 300 shown in Fig. 11 comprises a cylinder body 301 releasably mounted in a stator 302. The body 301 has mounted thereon, by means of bolts 303, a cylinder 304 defining therein a chamber 305. Within the cylinder 304 is a combined piston and valve member 306 (hereinafter referred to merely as a piston). The piston 306 carries through a crosshead 307a, a pair of rollers 307 at its radially inward end which co-operates with a pair of lobed cam tracks (not shown).

The interior surface of the cylinder 304 has three grooves formed therein which define upper, centre and lower cavities 308a, 308b and 308c respectively.

A passage 309 extends into the upper end of the cylinder chamber 305 from the exterior of the cylinder 304. A similar passage 310 extends into the centre cavity 308b from the exterior of the cylinder 304. The passages 309 and 310 are for connection to telescopic or flexible pressure fluid conduits (corresponding to the conduits 111 in Fig. 7) for the transmission of pressure fluid between adjacent modules in a bank.

Pressure fluid exhaust and supply ports 311 and 312 extend into the upper and lower cavities 308a and 308c respectively and by means of telescopic or flexible pressure fluid conduits (corresponding to conduits 112 and 113 of Fig. 8), pressure fluid can be transmitted between adjacentmodules in a row.

The exterior surface of the piston 306 is profiled to define a groove 313 therein. Depending on the position of the piston 306 within the cylinder 304, the groove 313 can interconnect either the upper and centre cavities 308a and 308b or the centre and lower cavities 308b and 308c.

Seals 314 are provided between the cylinder 304 and its piston 306 which allow the possibility of using a hydraulic fluid through ports 309, 310 which is separate to a lubricating fluid for the rollers, cam tracks and associated components.

The module illustrated in Fig. 11 operates in a manner analogous to that of the module 102 of Figs. 7 and 8 in that pressure oil is supplied through port 309 to cause the piston 306 and associated crosshead and bearings to be urged inwardly against its associated cam track to assist in rotating a driven shaft. On the cam track rotating further, the piston is forced radially outwardly and the oil is exhausted from the cylinder 304 through the passage 309 and from where the oil passes to exhaust through passage 310, centre cavity 308b, groove 313 and cavity 308a in the adjacent module.

It will be appreciated that the above described embodiments described with reference to Figs. 1 to 11 involve, when used as a motor, the use of at least three cams, the lobes of each cam being arranged 120° out of phase with each other. Consequently, each bank of modules operatively mounted on each of the three cams does not constitute a motor in its own right. Important alternative embodiments of the invention are illustrated diagrammatically in Figs. 12 to 15 which show examples of arrangements of modules on a single cam which will permit the modules on said single cam to function as a constant torque motor. It will be appreciated that the valve modules and piston modules can be in the form of any of the embodiments described above.

Fig. 12 shows a single cam 400 having eleven lobes 401. Three valve modules a, b and c can be positioned adjacent each other on a single lobe displaced angularly relative to each other at $\frac{2\pi}{3}$ so as to act on the lobe at different angular locations. Each valve module a, b or c controls through a pressure fluid conduit, a series of five piston modules A, B and C respectively spaced at predetermined angular intervals around the remaining ten lobes of the cam.

Considering the valve module a and its associated five piston modules A, it will be noted that the valve module a operates 90° out of phase with the piston modules A and the piston modules A all operate in the same phase as each other. The same is similarly true of valve modules b and c and their respective piston modules B and C.

Fig. 13 is a diagram showing a development of part of the cam of the single cam arrangement of Fig. 12. As the angular measurement of total circumference of the cam is equivalent to 2π ($\pi = 180^{\circ}$), the angle subtended by a single lobe of the elven lobe cam is $\frac{2\pi}{11}$. The valve modules a, b and c are spaced equidistant from each other on a single lobe so that there is an angle between each valve module of $\frac{2\pi}{33}$ or 10.90909°. Similarly the equal angle between each adjacent piston module, i.e. the angle between each piston module A and adjacent piston module B, between each piston module B and adjacent piston module C, and between each piston module C and adjacent piston module A is $\frac{4\pi}{33}$ or 21.81818°. The approximate outside diameter of the cam is 46".

In an alternative embodiment utilising the same single cam principle as in Figs. 12 and 13, Figs. 14 and 15 relate to a single cam machine incorporating a cam 500 having twelve lobes 502. Arranged to operate over two lobes are two groups of three valve modules, each group comprising three valve modules a, b and c and a_1, b_1 and c_1. The valve modules a, b and c are positioned adjacent each other to act at different angular locations and the valve modules a and a_1, b and b_1 and c and c_1, are in the same phase as each other. Each valve module a, b and c controls, through suitable pressure fluid conduits, a series of three piston modules A, B and C respectively spaced at predetermined angular intervals over six lobes of the cam and each of the valve modules a_1 b_1 and c_1 similarly controls a series of two piston modules A_1, B_1 and C_1 respectively spaced at predetermined angular intervals over the remaining four lobes.

As in the preceding embodiment, each valve module operates 90° out of phase with its associated piston modules. The piston modules of each set operate in the same phase as each other and the pistons modules A and A_1, B and B_1 and C and C_1 also correspond in phase.

Fig. 15 is a diagram showing a development of part of the cam of the single cam arrangement of Fig. 14. As before, the angular measurement of the total circumference of the cam is equivalent to 2π and the cam has twelve lobes. Consequently the angle subtended by a single lobe is $\frac{2\pi}{12}$. The valve modules a, b, c, a_1 b_1 and c_1 are equally spaced over two lobes and therefore their angular spacing is $\frac{4\pi}{6x12} = \frac{2\pi}{36}$ or 10°. Similarly the equal angle between each adjacent piston module is $\frac{4\pi}{36}$ or $\frac{2\pi}{18}$.

The embodiment illustrated in Figs. 16 and 17 is an hydraulic motor comprising an annular outer casing 600 constituting a stator and carried on bearings 601, 602 for rotation about a hollow driven shaft 603. In the manner shown in previous embodiments, the driven shaft 603 has two pairs of undulating, lobed cam tracks 604 and 605 each having six lobes and fixedly mounted about the driven shaft for rotation therewith. The two cams are out of phase with each other by $\frac{\pi}{2}$ radiants.

The stator 600 is provided with two banks A and B of valve modules 606 each incorporating a valve assembly. The modules 606 are angularly spaced around the motor in a manner analogous to that shown in Figs. 12 and 14. In the present embodiment, however, each cam track has 6 lobes and the number of modules 606 is 10. Each module 606 is similar to that shown in Figs. 7 and 8 and comprises a cylinder body 607 releasably mounted in the stator by bolts (not shown). The cylinder defines therein a chamber 608 defined by a portion of the cylinder in the form of a valve sleeve 609. A combined piston and valve 610 (hereinafter referred to as a piston) is slidable within the valve sleeve 609. Each piston 610 is provided with a crosshead and an associated pair of rollers at its radially inward end to run on its associated cam track 604 or 605. Seals 611 and 612 are provided between the valve sleeve 609 and cylinder 607 and between the valve sleeve 609 and piston 610. The seals 612 act to separate hydraulic fluid from a lubricating fluid contained in the central portion of the machine in order to lubricate the cam tracks and bearings, including crossheads and associated rollers.

The valve sleeve 609 has three external grooves formed therein each of which defines upper, centre and lower cavities 613<u>a</u>, 613<u>b</u>, and 613<u>c</u>, each cavity being connected by a passage 614 which extends through the valve sleeve 609 to the radially inner surface thereof. The piston 610 which is spring-loaded by means of a spring 615, is slidable within the valve sleeve 609 and has a groove 616 formed in its external surface so that it can be connected with the upper two or lower two of the cavities 613.

A cover plate 617 secured by bolts 617a retains the modules 606 within the stator.

Pressure fluid is supplied to each module in a bank by pressure fluid supply conduits (not shown) in the module body connecting the upper or lower cavities 613a, 613c of each adjacent module in the bank. Similarly, pressure fluid return conduits interconnect the lower or upper cavities of each adjacent module in the bank. The central cavity 613b of a module in bank A is connected through conduit 618 to the top of the chamber 608 in the adjacent module in bank B. Similarly a conduit 619 connects the central cavity 613b of the module in bank B with the top of the chamber 608 in the adjacent module in bank A. In this way, the valve sleeves 609 in the modules in one bank act to control the flow of pressure fluid to the piston of a module in the adjacent bank.

As can be seen in Fig. 16, the radially inward end of each piston is recessed to retain therein a bearing member 620 of hardened material. By means of shims 621, the position of the piston 610 relative to its valve sleeve 609 can be adjusted.

It will be appreciated that the pressure fluid supply and return conduits can be connected to either the upper or lower cavities 613a or 613c.

In operation of the motor as illustrated diagrammatically in Fig. 17, a pressure fluid supply conduit 622 supplies the upper cavity 613a of each module of bank B and the lower cavity 613c of each module of bank A. Fluid exhaust conduit 623 interconnects the lower cavities 613c of each module of bank B and the upper cavity 613a of bank A. Conduits 618 interconnect the central cavity 613b of each module in bank A with the top of the chamber 608 of an adjacent module in bank B and conduits 619 interconnect the central cavity 613b of each module in bank B with the top of the chamber of its associated module in bank A.

Pressure fluid is supplied to each module 606. When the piston 610 of a module in bank A (as shown in Fig. 16) is in an extended position, its groove 616 interconnects the lower cavity 613*c* and the central cavity 613*b* and allows pressure fluid to pass through conduit 618 to the chamber 608 of the associated module of bank B to urge its piston downwardly to effect rotation of the hollow shaft 603 by action of the bearings of the crosshead and associated rollers against the cam track 605 which is associated with bank B. On the said piston of bank B being forced radially outwardly on further rotation of its cam track 605, the upper and central cavities 613*a* and 613*b* of the associated piston in bank A are interconnected due to its groove 616 being moved radially outwardly. The fluid is thus passed to exhaust from the chamber 608 of the module of bank B through conduit 618, central cavity 613*b* and upper cavity 613*a*.

It will be appreciated that the above embodiment incorporates two cam tracks 604 and 605 out of phase with each other. If desired, other cam tracks in the same phase as cam track 604 or 605 can be fitted as shown in Figs. 18 and 19. The motor shown in Figs. 18 and 19 consists of a twin cam track master unit similar to that described in Figs. 16 and 17 but incorporating seven cam track lobes and fifteen modules per bank, the motor of Figs. 18 and 19 bearing the same reference numerals as Figs. 16 and 17 where applicable. To the twin cam track master unit incorporating module banks A and B is added an auxiliary bank C of slave modules 700. Each slave module consists of a piston 701 and cylinder 702 without any valve mechanism. It will be noted that cam track 703 of bank C is in phase with the cam track 604 of bank A. The addition of the slave modules 700 enables an increased torque and for power output to be achieved.

The above-described embodiment in Figs. 16 and 17 relates to six lobed cam tracks each surrounded by 10 modules. It will be appreciated that the number of lobes per cam track and associated modules can be selected according to the desired output torque. The following table sets out certain properties of hydraulic motors incorporating a variety of numbers of lobes and modules:-

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Design. Lobes/ Pistons	Strokes/ Rev. 2xLobesx Pistons	Capty./ Rev. "L"	Torque output at 3000 lb Tons."	Torque Ratio:- where 7/15= 1	No. of Piston/ valve mods & X Head Assys.	Stator Dia (Ins.).	Shaft R.P.M. for 7/15 = 30	Power Ratio where 7/15=1	Shaft HP for 7/15 = 395
5/11	110	15.715	193.8	.5238	22	39	42	0.733	290
6/13	156	22.286	274.9	.7429	26	43	35	0.867	342
7/15	210	30.0	370	1.0	30	46½	30	1.0	395
8/17	272	38.858	479.2	1.295	34	50½	26.25	1.133	448
9/19	342	48.858	602.6	1.629	38	54	23.33	1.267	500
10/21	420	60.0	740	2.0	42	58	21	1.40	553
11/28	506	72.287	891.5	2.410	46	61½	19	1.533	606
12/25	600	85.716	1057.2	2.86	50	65½	17.5	1.667	658
13/27	702	100.29	1236.9	3.34	54	69	16.15	1.80	711

The modules used in each of the embodiments described above are easily removable individually. Consequently repair can be easily effected by removing a module from the machine and substituting it by another module.

Furthermore, it is possible to utilise a different displacement between banks A and B and associated slave units if fitted to effect a wide range of motor or pump displacements. Also, one or more banks can be arranged to operate in a by-pass mode.

Although in the above embodiments, machines have been described which function as hydraulic motors, it will be readily apparent to those skilled in the art that the machines can equally well be utilised in reverse as hydraulic pumps. This may require some modifications e.g. use of valve modules of the type shown in Fig. 3.

It is also possible by valve means to have a variable displacement machine by making modules act in a by-pass capacity thereby not producing or absorbing positive torque.

The embodiments described above involve arrangements wherein the modules are directed radially inwards. It will be understood that the modules can have other dispositions. For example, they can be directed radially outwards or axially of the machine, the co-operating cam tracks being correspondingly re-located.

Furthermore, the modules have been described as forming part of the stator with the cam tracks forming part of the rotor. This situation can be reversed with the cam tracks being held stationary and the modules forming part of the rotor.

The principles of the present invention can also be applied to linear motors as well as to rotary hydraulic motors.

From the above described embodiments, it will be readily appreciated that a hydraulic machine can be provided which is capable of being easily modified to produce a wide range of torque if the machine is being used as a motor or a wide range of displacement if operating as a pump. The possible modifications can include (a) variation in the number of valve modules or groups of modules (b) the utilisation of a single cam or groups of three cams to constitute a motor and (c) the feasability of mounting a plurality of such motors on a member to be driven.

CLAIMS:-

1. An hydraulic machine comprising a first member; a second member arranged for movement relative to said first member; cam track means (16, 17, 18, 107, 108, 109, 604, 605) carried by said first member characterised in that there is provided a plurality of independently mounted hydraulically-operated piston and cylinder modules (105, 205, 306, 610) carried by said second member, said modules forming at least one interconnected bank of such modules in operative relationship with the cam track means; and modular valve means (13, 35, 102, 300, 606) associated with at least each bank of modules for controlling the supply and exhaust of hydraulic fluid to each of the modules in the bank whereby substantially constant torque or displacement can be produced by the machine.

2. A machine as claimed in claim 1, in which the first and second members are annular and said cam track means (16, 17, 18, 107, 108, 109, 400, 500, 604, 605) is fixedly mounted on a driven shaft (19, 110, 603).

3. A machine as claimed in claim 2, in which said driven shaft (19, 110, 603) is hollow.

4. A machine as claimed in any of claims 1 to 3, in which the valve means (102, 300, 606) is incorporated in one or more of the piston and cylinder modules.

5. A machine as claimed in any preceding claim comprising a unit having a rotor in the form of a driven shaft (603); a first lobed cam track (604) and a second lobed cam track (605) mounted on said driven shaft (603) for rotation therewith; a first bank (A) of hydraulically controlled piston and cylinder modules (606) in operative relationship with said first cam track (604) to effect rotation thereof; a second bank (B) of hydraulically controlled piston and cylinder modules in operative relationship with said second cam track (605) to effect

rotation thereof; valve means (613, 614, 616) in the piston and cylinder modules; each module (606) in one bank being hydraulically connected in a phased relationship with an associated module (606) in the other bank whereby the valve means (613, 614, 616) in each module of the pair controls actuation of the piston (610) of the other module of the pair and the modules of each bank being angularly disposed around the lobes of its cam track such that a motor is constituted which produces substantially constant torque.

6. A machine as claimed in claim 5, in which each module comprises a cylinder (607); a piston (610) reciprocable within said cylinder (607); first, second and third annular cavities (613a, 613b and 613c) defined in the cylinder (607) and communicating with the internal surface of the cylinder (607); passage means (616) in said piston (610) for placing in communication said first and second cavities (613a and 613b) or said second and third cavities (613b and 613c) on displacement of the piston; a conduit (622) for supplying pressure fluid to said first cavity (613a); a conduit (623) for exhausting pressure fluid from said third cavity (613c); and a conduit (618, 619) connecting the second cavity (613b) with the effective surface of the piston (610) of the associated module in the other bank.

7. A machine as claimed in claim 6 in which the first, second and third cavities (613a, 613b and 613c) are defined in the cylinder (607) by a separate cylinder valve sleeve (609) disposed between the internal wall of the outer portion of the cylinder (607) and the external wall of the piston (610).

8. A machine as claimed in any of claims 5 to 7, in which one or more auxiliary lobed cam tracks in phase with said first or second cam tracks (703) are provided on said driven shaft (603), each auxiliary cam track or tracks having a bank (C) of valve-free slave piston and cylinder modules (700) in operative relationship with said auxiliary cam track

or tracks (703) and each slave module (700) being hydraulically connected with a module in a bank operating in a different phase.

9. A machine as claimed in any of claims 5 to 8, in which the displacement of one bank (A, B or C) differs from that of the other bank or banks.

10. A machine as claimed in any of claims 5 to 9, in which one or more banks operate on a by-pass mode.

11. A machine as claimed in any preceding claim wherein the hydraulic fluid is effectively separated from the lubricating fluid for cam tracks and bearings.

12. A machine as claimed in any of claims 1 to 3, in which the valve means comprises a plurality of separate valve modules (13) disposed in phased operative relationship with lobed cam track means (26, 27, 28), and a series of piston and cylinder modules (14) is hydraulically connected to each of the valve modules (13) and disposed in a phased relationship to its associated valve module and in operative relationship with said cam track means.

13. A machine as claimed in claim 12, in which each valve module comprises a cylinder (24); a piston (22) reciprocable within said cylinder (24) and communicating with the internal surface of the cylinder (24); passage means (22a) in said piston for placing in communication said first and second or said second and third cavities on displacement of the piston (22); a conduit for supplying pressure fluid to said first cavity; a conduit for exhausting pressure fluid from said third cavity; and a conduit (30, 31, 32, 33) connecting the second cavity with the effective surface of an associated piston of a module in the same series.

14. A machine as claimed in claim 13, in which the first, second and third cavities (24a, 24b, 24c) are defined in the cylinder (24) by a separate cylinder valve sleeve disposed between the internal wall of the outer portion of the cylinder (24) and the external wall of the piston (22).

15. A machine as claimed in claim 4, in which each valve module (102, 300) comprises a cylinder (103, 304); a piston (105, 306) reciprocable within said cylinder (103, 304); first, second and third cavities (115a, 115b, 115c, 308a, 308b, 308c) defined in the cylinder (103, 304) and communicating with the internal surface of the cylinder (103, 304); passage means (118, 313) for placing in communication said first and second or said second and third cavities on displacement of the piston (105, 306); a conduit (112,312) for supplying pressure fluid to said first cavity; a conduit (113, 311) for exhausting pressure fluid from said third cavity; and a conduit (111, 310) connecting the second cavity with the effective surface of an associated piston.

16. A machine as claimed in claim 15, in which the first second and third cavities (115a, 115b, 115c, 308a, 308b, 308c) are defined in the cylinder (103) by a separate cylinder valve sleeve (104) disposed between the internal wall of the outer portion of the cylinder (103) and the external wall of the piston (105).

17. A machine as claimed in any of claims 12 to 16, in which there are at least three valve modules each having a series of piston and cylinder modules associated therewith.

18. A machine as claimed in any of claims 12 to 17, in which the plurality of valve modules and their associated series of piston and cylinder modules are disposed in operative relationship about a single cam track (400,500).

19. A machine as claimed in any of claims 12 to 17, in which each valve module and its associated series of piston and cylinder modules is disposed in operative relationship on one of at least three cam tracks phased relative to each other.

20. A machine as claimed in claim 1 in which each valve module incorporates a valve or valves (36,37) which permit the machine to be utilised as a pump.

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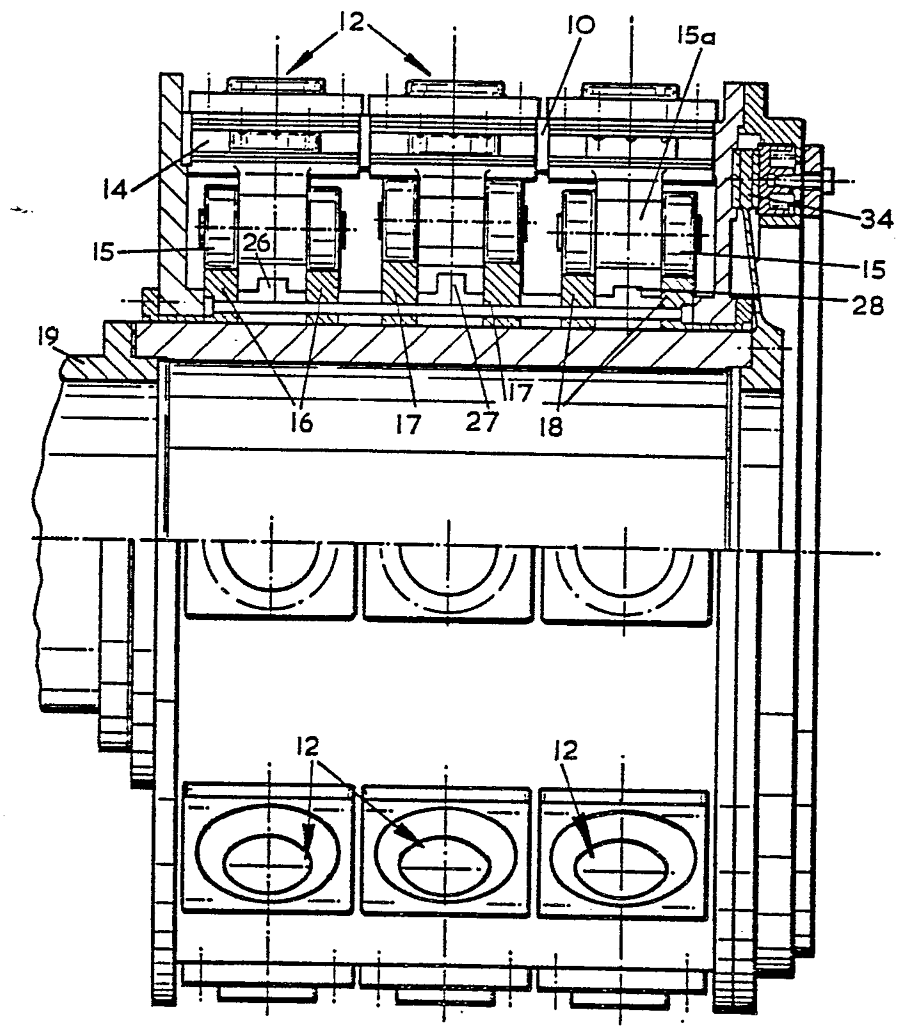

FIG. 1

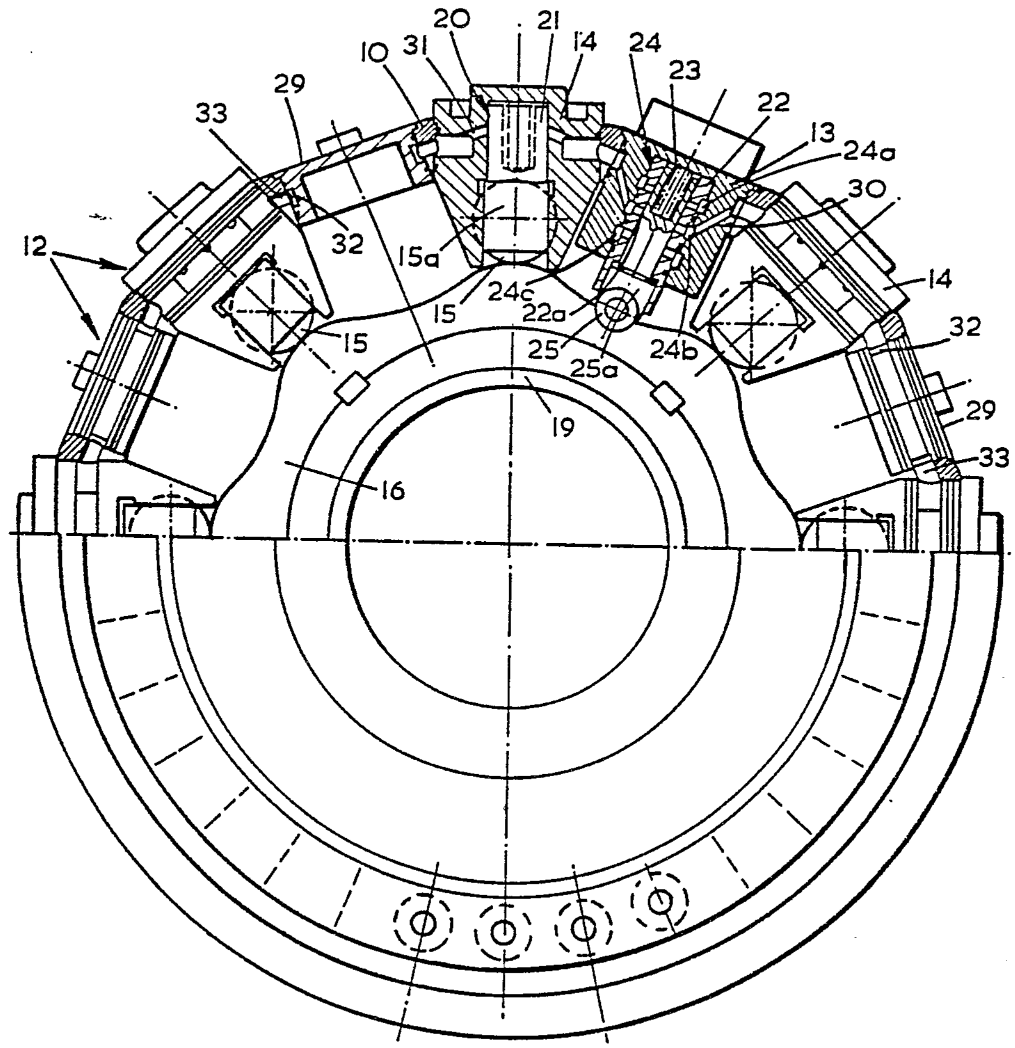
20
21
14
24
23
22
10
31
29
33
13
24a
30
12
32
15a
14
24c
15
22a
15
32
25
25a
24b
29
19
33
16

FIG. 2

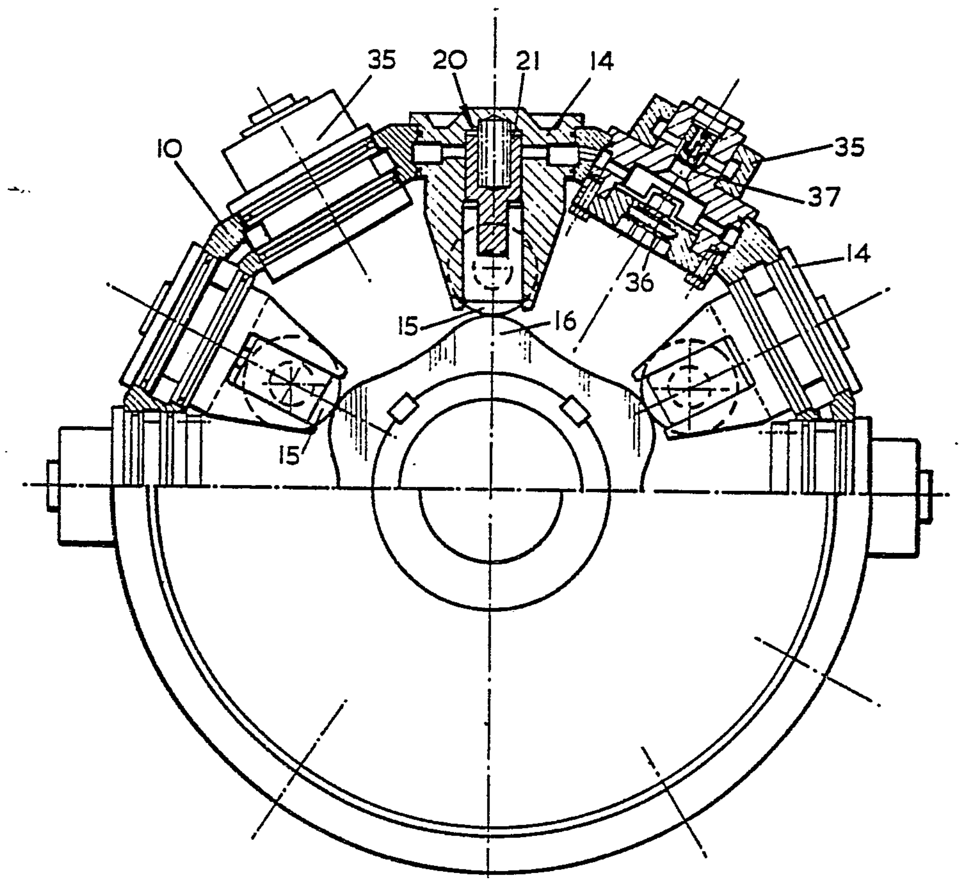

FIG. 3

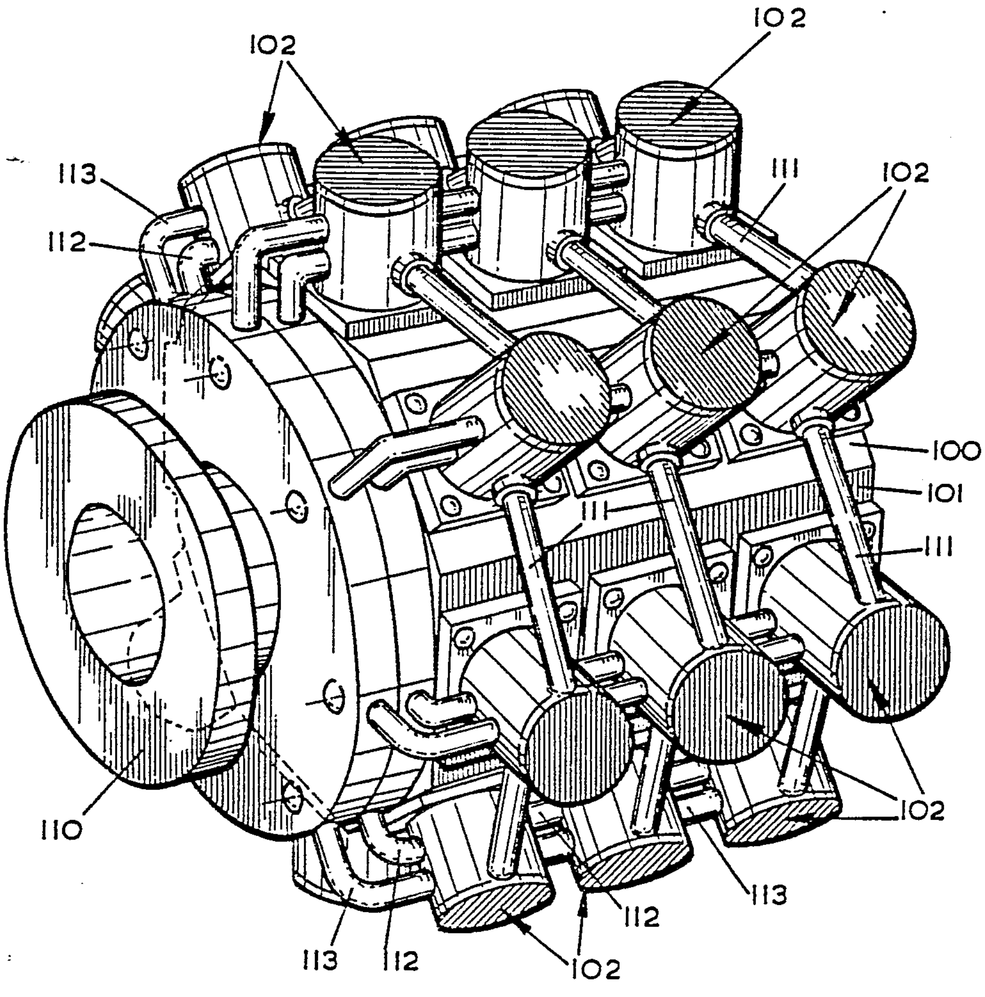
102
102
113
111
102
112
100
101
111
111
110
102
113
112
113
112
102

FIG. 4

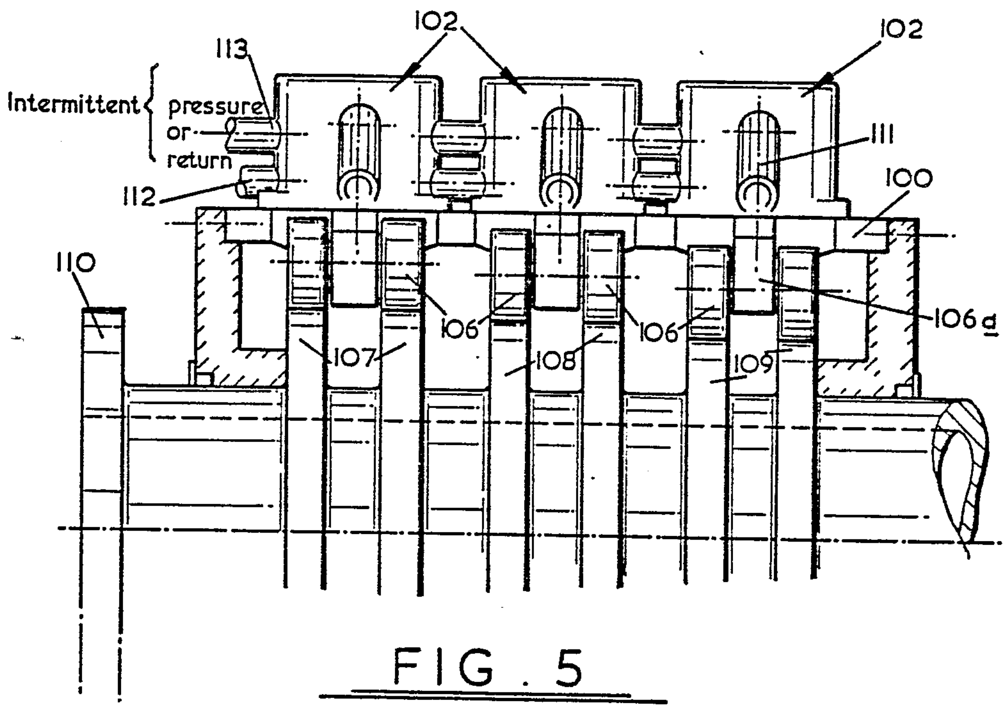
113
102
102
Intermittent
pressure
or
return
111
112
100
110
106
106
106d
107
108
109

FIG. 5

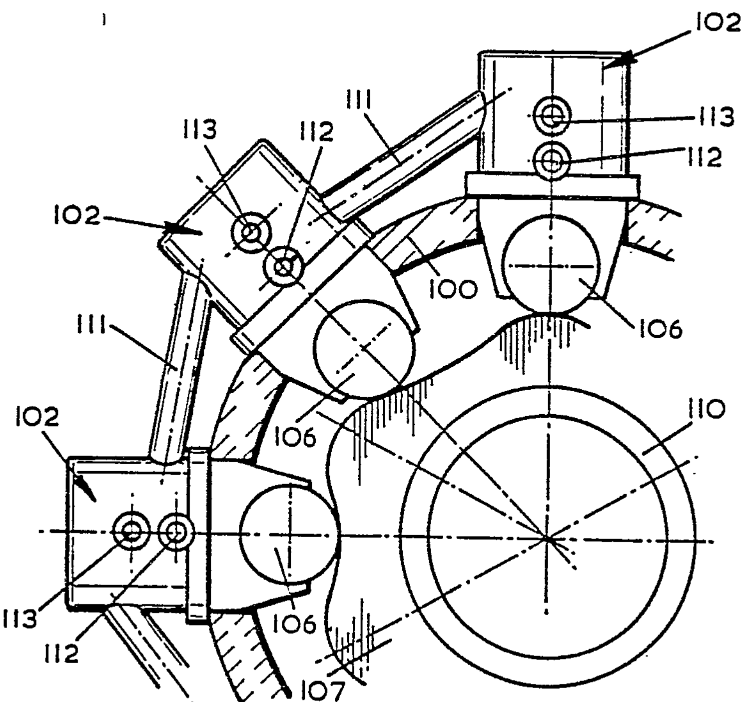
102
111
113
112
113
112
102
100
106
111
110
102
106
106
113
112
107

FIG. 6

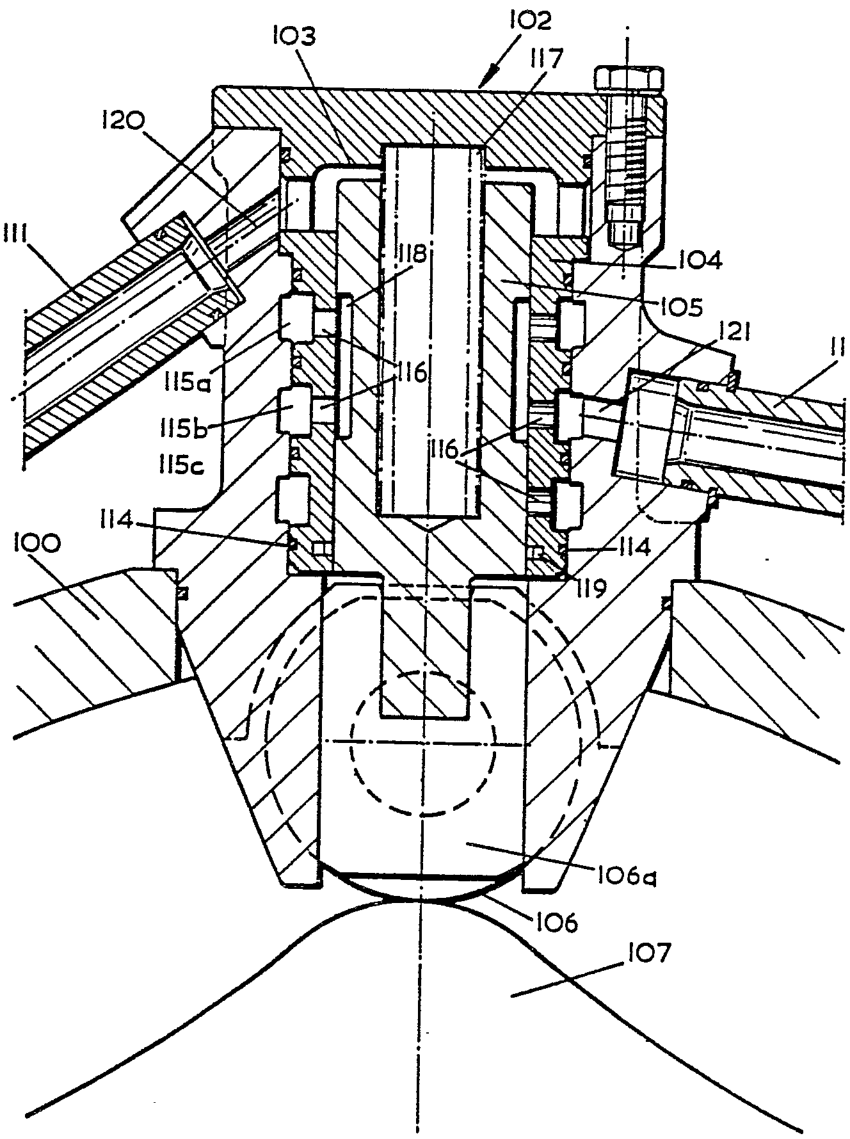
102
103
117
120
111
104
118
105
121
111
116
115a
115b
115c
116
114
100
114
119
106a
106
107

FIG. 7

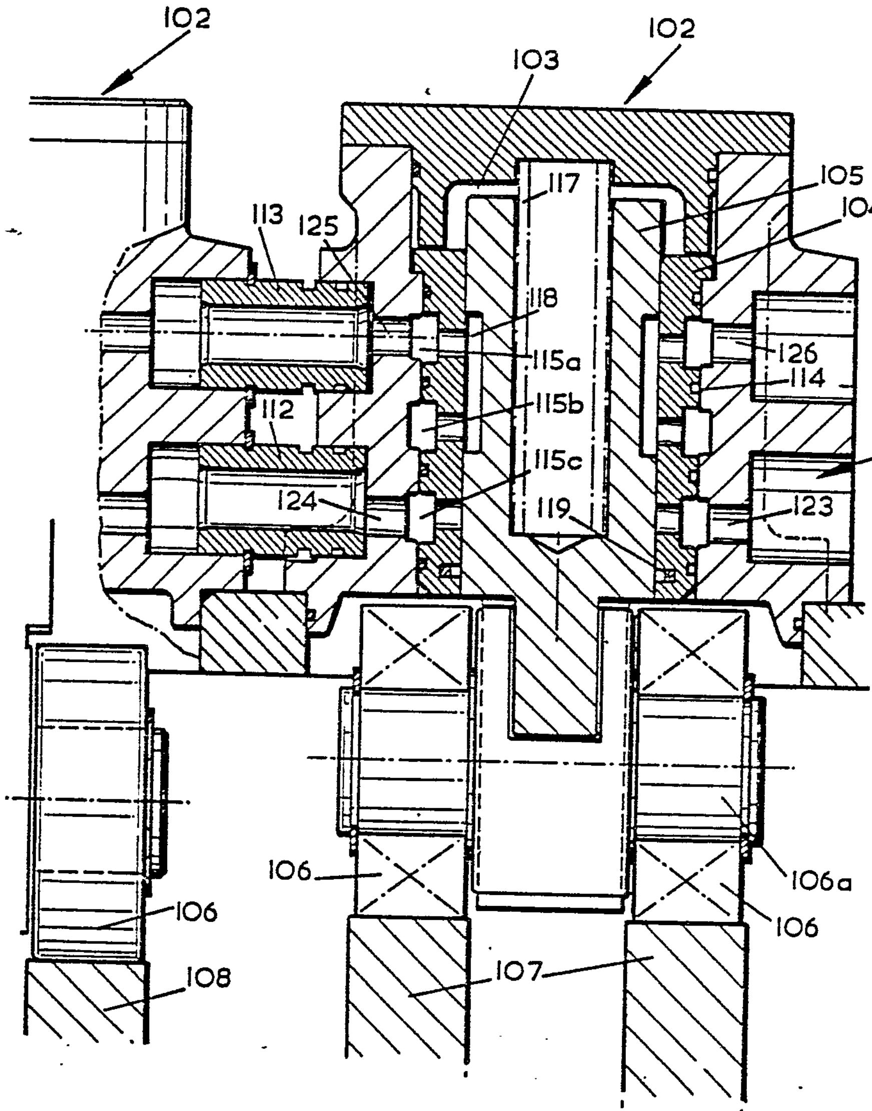
102
102
103
117
105
104
113
125
118
126
115a
114
112
115b
122
115c
124
119
123
106
106a
106
106
108
107

FIG. 8

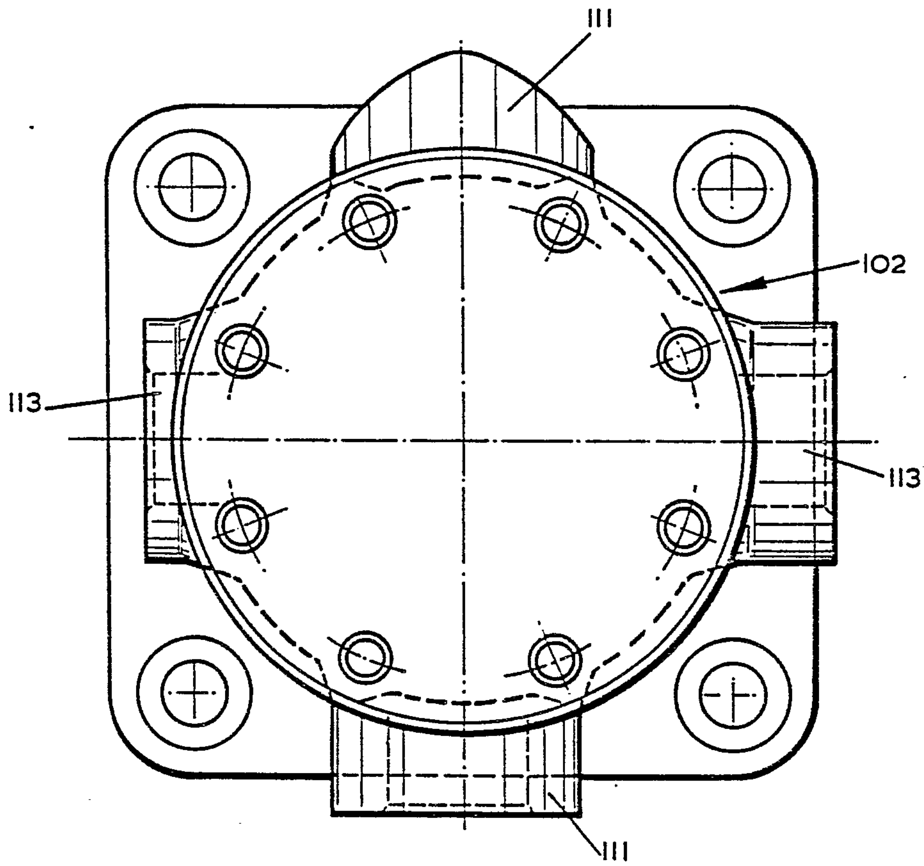

FIG. 9

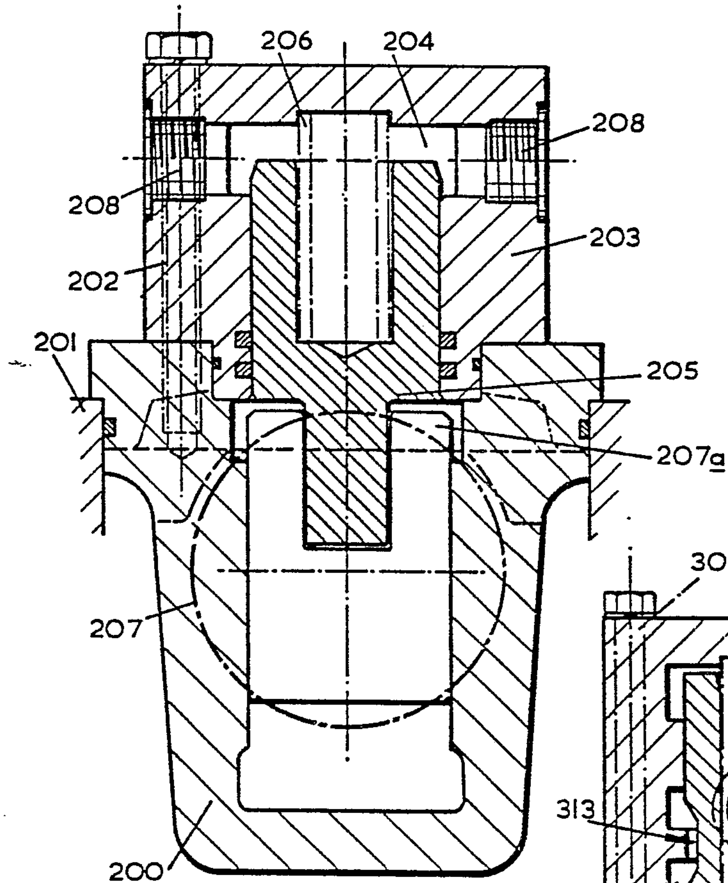
206
204
208
208
203
202
201
205
207a
207
200

FIG. 10

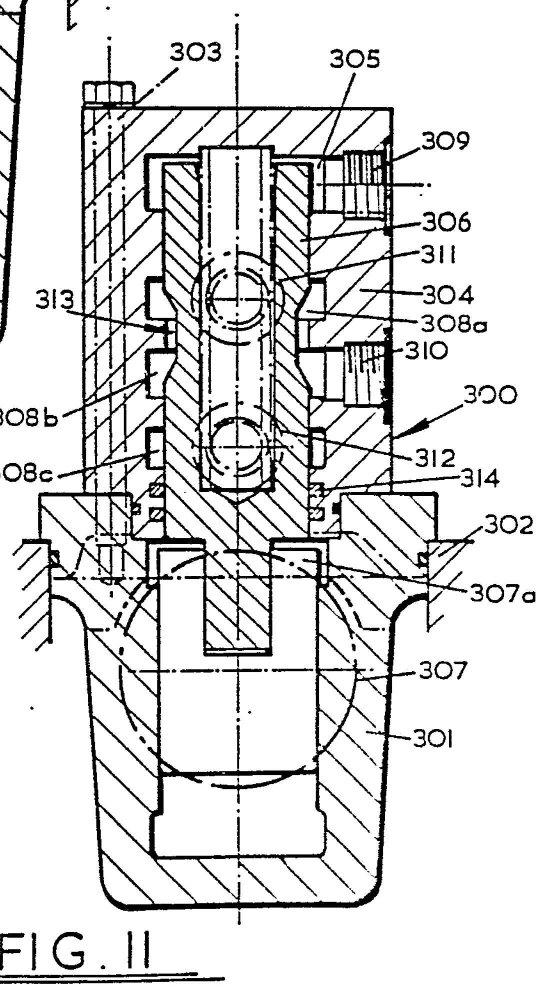
303
305
309
306
311
304
313
308a
310
300
308b
312
308c
314
302
307a
307
301

FIG. 11

30·06·

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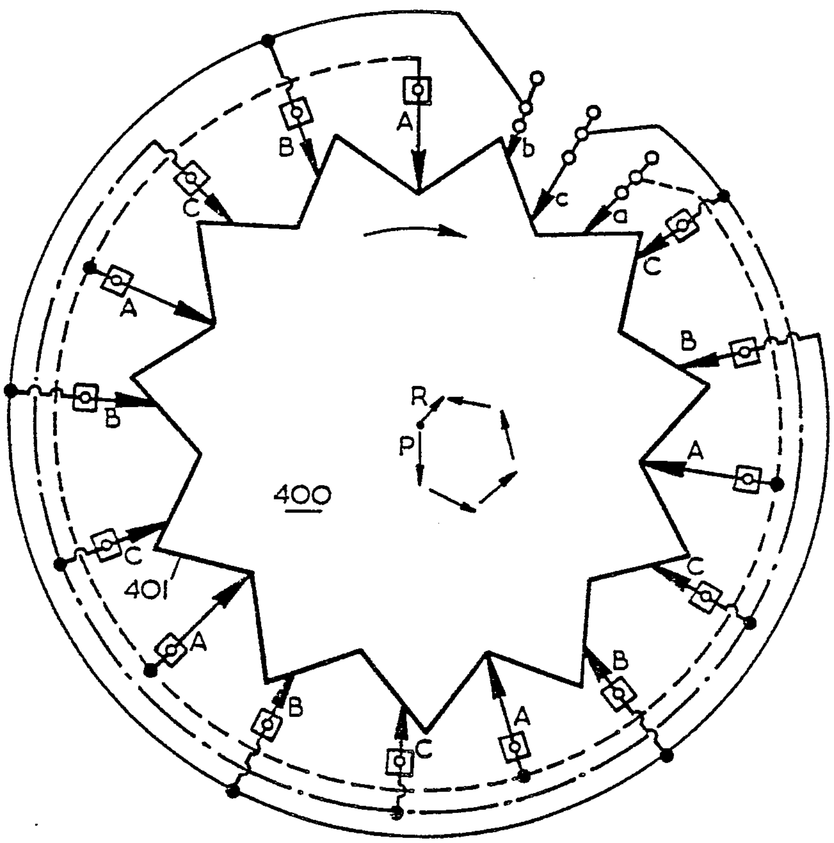


FIG.12

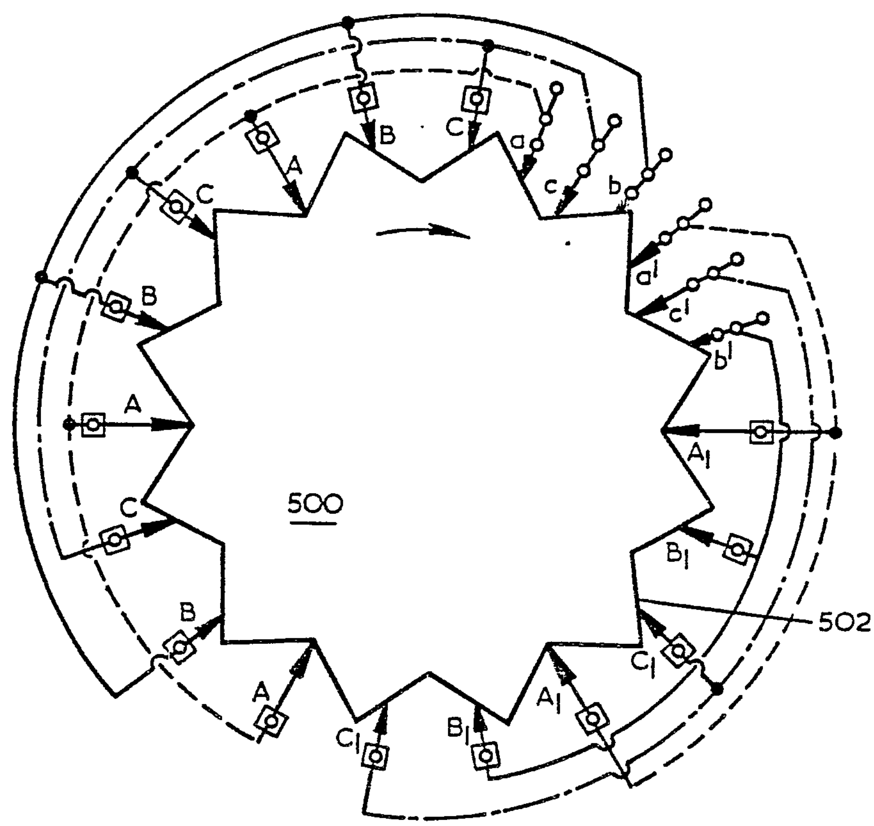


FIG. 14

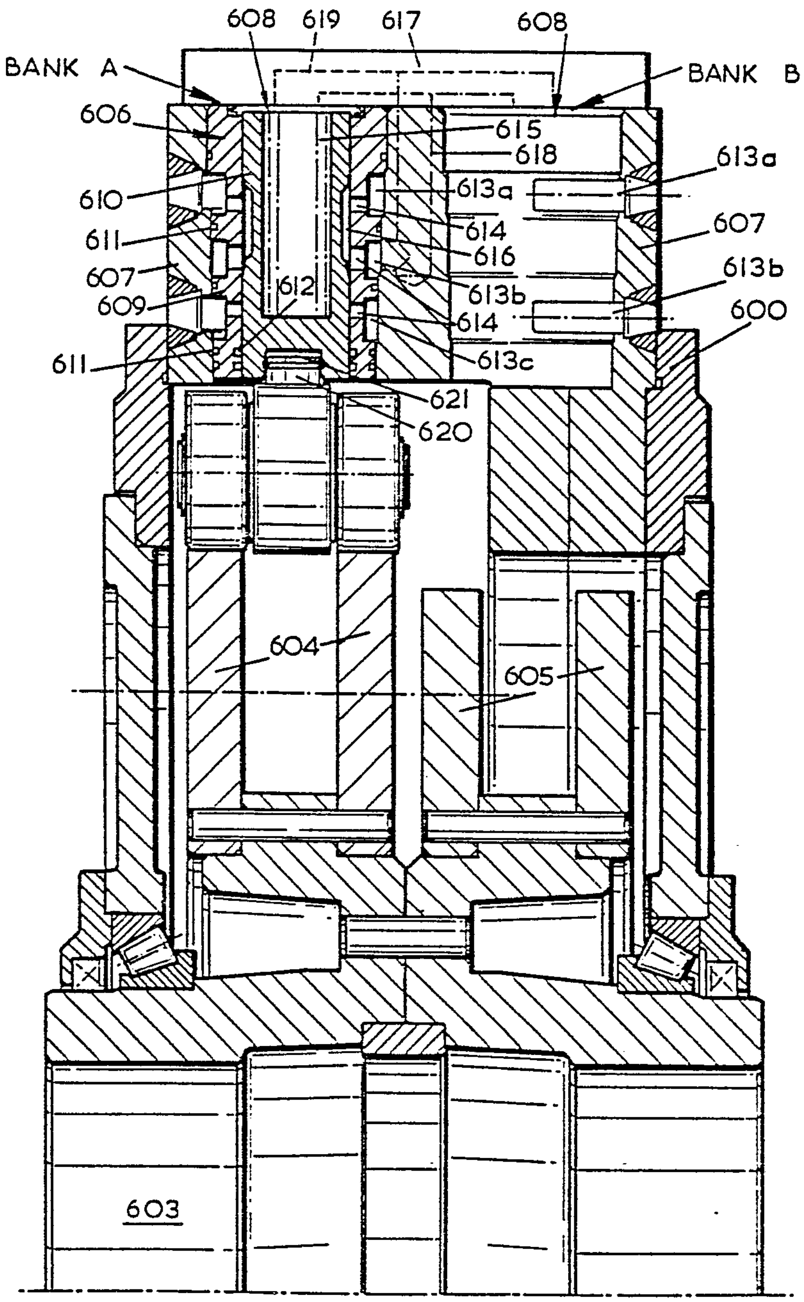

608
619
617
608
BANK A
BANK B
606
615
618
613a
610
613a
611
614
607
616
607
613b
612
613b
609
614
600
611
613c
621
620
604
605
603

FIG. 16

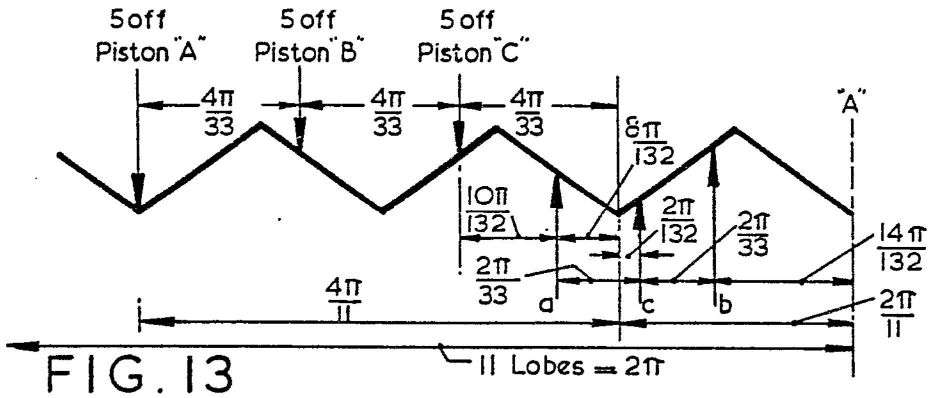


FIG. 13

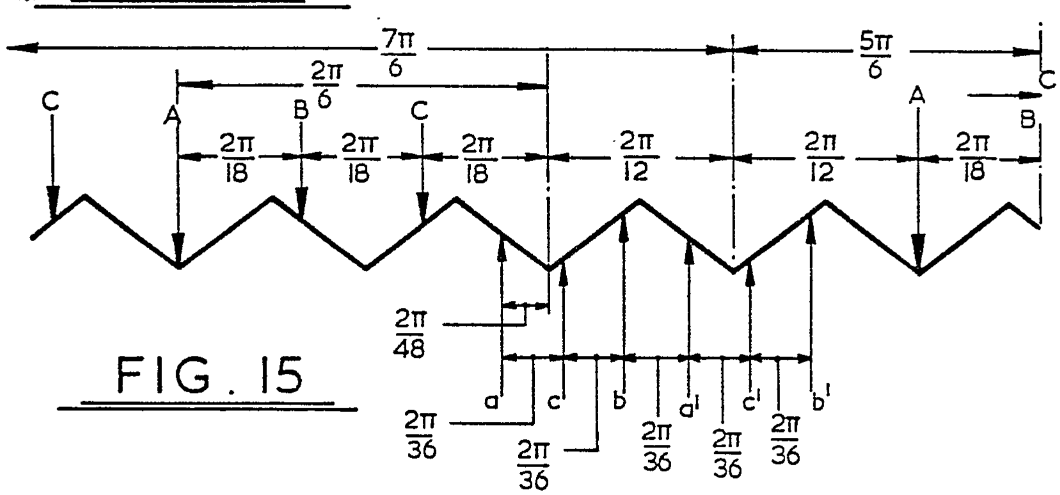
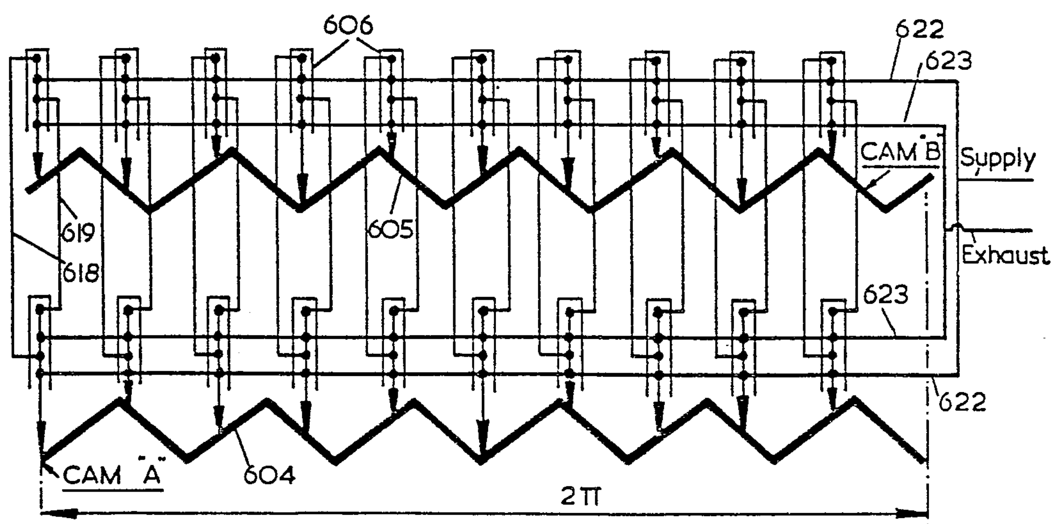


FIG. 15



Cams phased at $\frac{\pi}{2N}$
ie $(\frac{2\pi}{N} \times \frac{1}{4})$

FIG. 17

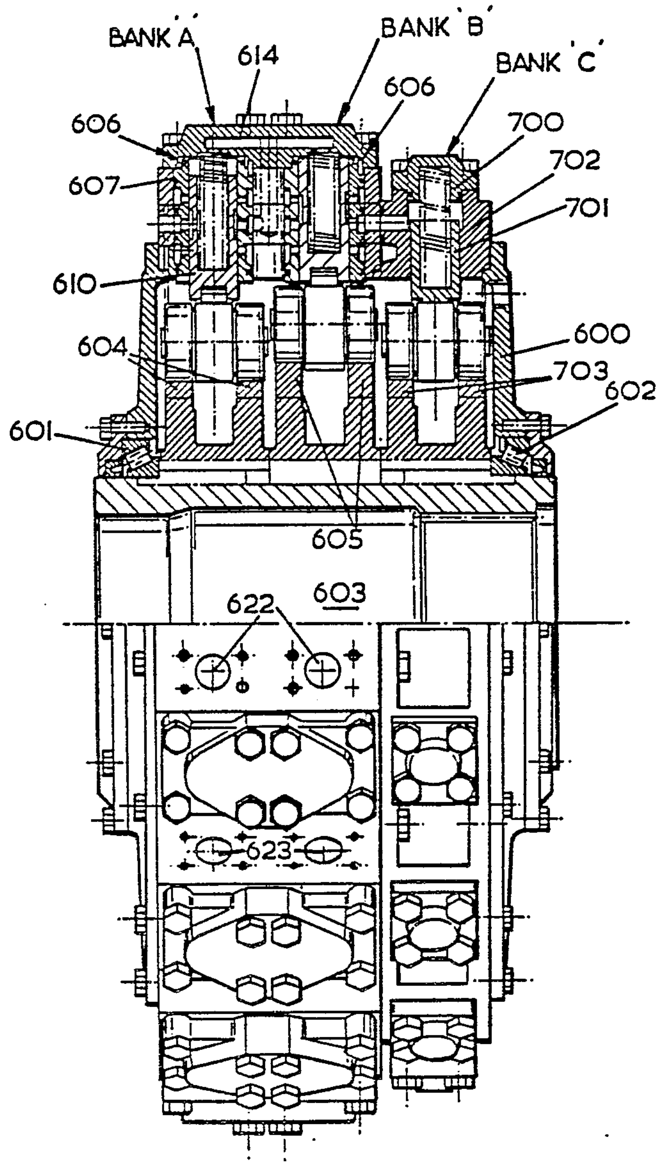

BANK 'A'
614
BANK 'B'
606
BANK 'C'
606
700
607
702
701
610
600
604
703
602
601
605
622
603
623

FIG. 18

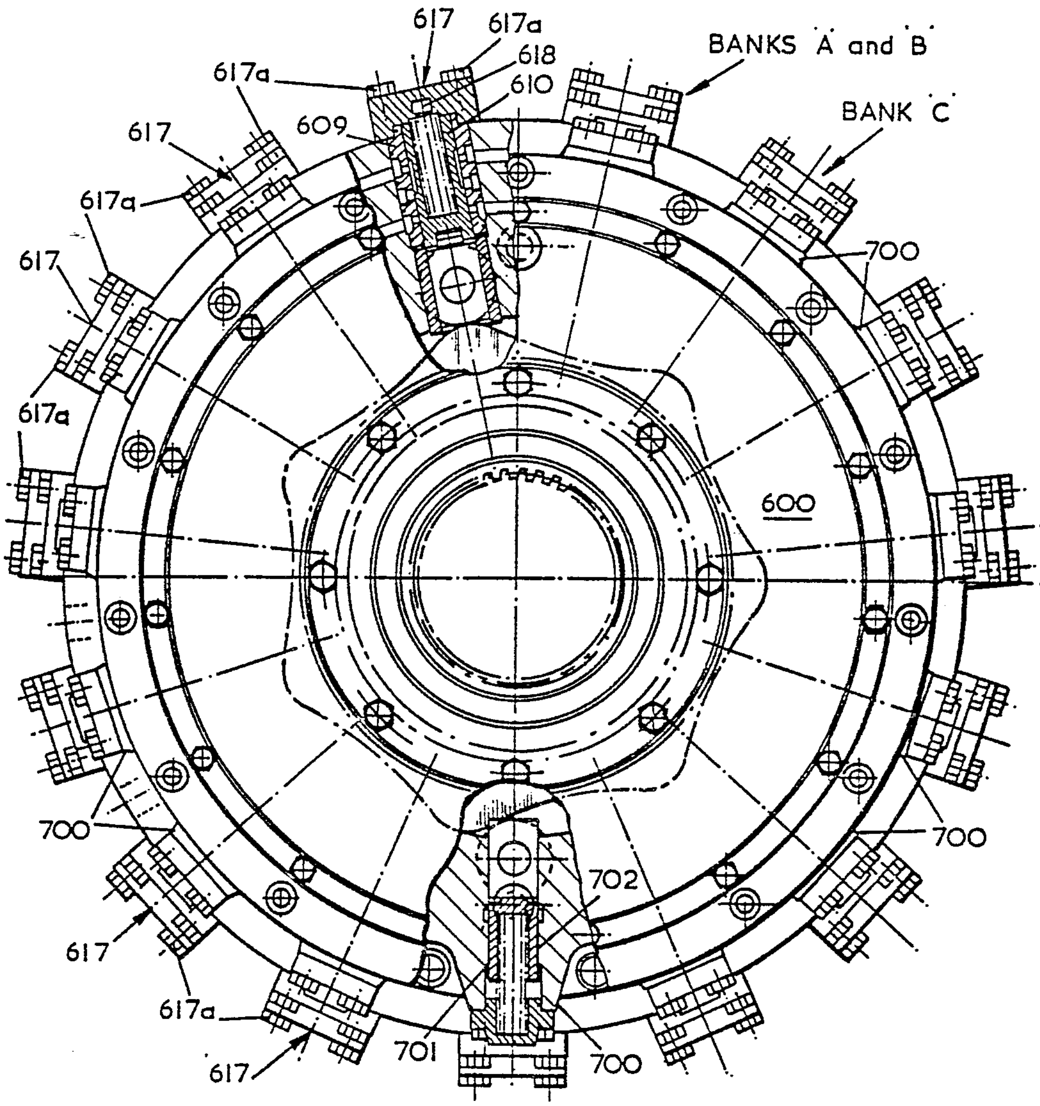

617
617a
618
610
617a
609
617
617a
617
617a
BANKS A and B
BANK C
700
600
700
700
702
617
617a
617
701
700

FIG. 19