This invention relates to pumps and particularly to reciprocating piston pumps which are capable of delivering varying volumes of fluid while the piston or pistons of the pump reciprocate at a substantially constant rate.

Other so-called "variable volume" pumps have been known for many years for specific uses, but for one reason or another these pumps are not well adapted for use in mobile service, such as oil and gas well or other earth well treating service, for example. Such service requires maximum utilization of available horsepower to thereby deliver the maximum volume of pumped fluid at the highest possible pressure without exceeding the strength limits of the equipment. Such requirements necessitate minimum weight and bulk consistent with the achieving of other requirements, and ease and reliability in controlling the "variable volume" feature of the pump while under load. Exceptional reliability is necessary because the pump will be used in remote areas where facilities are not available for making major repairs and because in well treating service equipment breakdown can result in great damage to the well under treatment. For example, a pump breakdown during a well cementing job could result in the cement setting up in the well casing before displacement can be effected between the casing and well bore wall.

In conventional well treating units, a power source or prime mover, usually an internal combustion engine, transmission (which may include a torque converter) and the pump are disposed on a truck, barge, or trailer.

Any reduction in weight which can be achieved in the coupling of power to the pump of the treating unit would obviously permit the construction of a lighter treating unit or would permit the construction of a treating unit having an increased pumping capacity (either in volume or pressure, or both) without exceeding the gross weight requirements of the unit.

Accordingly, a principal object of this invention is to provide an improved variable-volume pumping apparatus which is suitable for use in treating earth wells. Another object of this invention is to provide an improved mobile fluid pumping system for well treating service or the like.

In accordance with this invention a piston type position displacement pump achieves an infinitely variable stroke between maximum and minimum limits through a controlled variable phase relationship between two mechanically interlocked crankshafts. These crankshafts operate through connecting rods to an equal-legged walking beam pinned at its centerline to a plunger crosshead. Similar planetary gears, with the ring gears interconnected by means of a common drive mechanism, are used to drive the crankshafts and also to establish and maintain the desired phase relationship between the crankshafts during operation. By rotating the ring gears and thus changing the phase of the gears coupled to each crankshaft, the phase relationship between crankshafts and hence the piston stroke may be changed inversely with the discharge pressure to provide a hydraulic horsepower output desirably matched to the available horsepower of the prime mover.

The invention, as well as additional objects and advantages thereof, will best be understood when the following detailed description is read in connection with the accompanying drawing, in which FIG. 1 is a simplified plan view, partly broken away and in section, of apparatus in accordance with this invention; FIG. 2 is a sectional view taken along the line 2-2 of FIG. 1, and FIG. 3 is a sectional view taken along the line 3-3 of FIG. 1.

Referring to the drawing, there is shown variable volume pumping apparatus, indicated generally by the numeral 10 mounted on a common frame (not shown). The apparatus includes a single-action reciprocating piston-type pump 12 (see FIG. 3 especially) whose piston 14 is coupled to a crosshead plunger 15, adapted to reciprocate in the guide 15a, and to the center of an equal-legged walking beam 16 which in turn is coupled at its ends by connecting rods 18, 20 to crankshafts 22, 24, respectively, which are journalied in bearings 17, 19, 21 and 17a, 19a, 21a, for example.

Each of the crankshafts 22, 24 is rigidly mechanically coupled at one end to the sun gear (34 in FIG. 2) of a planetary gear assembly 30, 32, respectively. The planetary gear assembly 30, shown in section in FIG. 2, is the same as the assembly 32 which is shown in plan in FIG. 1.

The crankshafts 22, 24 are disposed parallel to each other. The sun gears of each of the assemblies 30, 32 are coupled to their respective ring gears 26, 28 by means of planet gears, the planet gears 46, 48 being shown in FIG. 2.

The planet gears of each planetary gear assembly 30, 32 are journaled on to shaft 50, 52 (and 54, 56 in FIG. 1) which are parallel to the crankshafts 22, 24 and which are fixedly connected by means of brackets 55, 61, respectively, to a hollow shaft 36 or 38, each of which is concentric to and surrounds one of the respective crankshafts 22, 24, as shown. Each of the hollow shafts 36, 38 is supported in position by two bearings 62 and 64 and 62a and 64a, respectively.

Spur gear wheels 78, 80 are rigidly coupled in a fixed rotational relationship with respect to the hollow shafts 36, 38, respectively, near the end of the shafts 36, 38 which are remote from the planetary gear assemblies 30, 32. The gears 78, 80 are of equal diameter and have an equal number of teeth, the teeth of one wheel engaging those of the other. Means, such as the gear 84 are coupled to the end of the shaft 87 whereby power from a prime mover may be coupled to the shaft 36 and thence through the spur wheels 78, 80 to the shaft 38.

The power source 86, which may be an internal combustion engine or gas turbine, for example, is diagrammatically indicated by the block 86 and is coupled, as indicated by the shaft 87, to the gear 84.

The ring gears 26, 28 each have teeth 66, 68 on their outer surface as well as on their inner peripheral surface (see FIG. 2). The teeth 66, 68 are the same size and type in each of the planetary gear assemblies 30, 32.

A rack gear 70, having teeth along its length is coupled to the teeth 66, 68 on the outer periphery of the ring gears 26, 28. A prime mover or power source 72 having braking means (which may be conventional brakes or the natural braking inherent in a worm gear drive to the output shaft 76) is coupled by a gear on shaft 76 to the teeth of the rack gear 70. The ring gears 26, 28 are coupled to shafts 58, 59 by means of brackets 63, 65. The shafts
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$38, 60$ are concentric with respect to the ring gears 26, 28 and are journaled on bearings 40, 40a.

The gear bearings 19, 19c, 21, 21a, 40, 40a, 62a, 64, 64a, the pump 12, guide 15a, rack gears 70, and rack gear driving power source 72 are mounted on common framework for the apparatus, which framework also carries the prime mover power source 86 for operating the pump, the framework being attached to or supported by the mobile unit, e.g. a truck, which carries the apparatus.

In operation, the apparatus, as shown, has the rack gear 70 arbitrarily positioned so that the angle $A$ is equal to the angle $A'$ as shown, for example, in FIG. 3. In this position, the throws of the crankshafts 22, 24 are connected in an in-phase driving relationship, so that the movement of the piston 14 of the pump 12 backwards and forward in the pump cylinder 88 at maximum stroke length as power from the source 86 is coupled by means of the gears 84 and 78 to the shaft 36 and, by means of the spur gears 78, 80, to the shaft 38.

The shafts 36, 38 drive the planet gears (46, 48 in FIG. 2) of each planetary gear assembly 30, 32, respectively. The planet gears of each assembly are coupled to the ring gear (26 or 28) of its assembly 30, 32 and to the sun gear (34 in FIG. 2) which drives the crankshafts 22, 24 of the apparatus. The planet gears of each planetary gear assembly are freely coupled to their shafts 50, 52 and 54, 56, but these pairs of shafts are fixedly coupled to the shafts 36 or 38 and are, therefore, rotated as the shafts 36, 38 rotate on being driven by the prime mover 86. The ring gears 26, 28 are held in a fixed position by the rack gear 70 except when the pumping rate of the apparatus is varied, under the control of the equipment operator, for example.

When the stroke length of the piston 14 is to be changed, the rack gear 70 is moved forward or backward (as by rotating the gear on the shaft 76, for example), the amount of movement depending upon the degree of phase change which is desired between the two crankshafts 22, 24. The movement of the rack gear 70 is usually at a slow rate as compared with the rate of rotation of the planet gears (46, 48 in FIG. 2). The shafts 50, 52 and 54, 56 on which the planet gears (46, 48 in FIG. 2) are rotated, are mounted, as mentioned above, as the driven spur wheels 78 and 80 rotate (as are the hollow shafts 36, 38 rotate), since spur gear wheels 78 and 80 are coupled to these shafts. Moving the rack gear 70 causes the ring gears 26, 28 to also rotate, adding their motion to that of the planet gears which are driven by the sun gears (34 in FIG. 2) and which drive the crankshafts 22, 24. With the crankshafts 22, 24 rotating in opposite directions (one clockwise, one counter-clockwise), the relative phasing between the crankshafts 22, 24 is changed as the ring gears 28, 30 are rotated. By "in phase" is meant that the crank throws viewed from the ends of the crankshafts occupy mirror image positions as in FIG. 3 where angles $A$ and $A'$ are equal; when angles $A$ and $A'$ differ the crankshafts are "out of phase." The angular difference between the angles $A$ and $A'$ can be varied by suitably advancing or retracting the rack gear 70, thereby providing for a variation in the piston stroke length from a maximum to a minimum. The length of the piston stroke is at a maximum when the crankshafts 22, 24 are in phase as shown. Piston stroke length decreases as the crankshafts become out of phase with respect to each other, that is, when angles $A$ and $A'$ (FIG. 3) differ from each other by $180^\circ$. When the length of the piston stroke is at a minimum one of the connecting rods 18, 20 will be at its most forward position with respect to the piston 14 and the other connecting rod will be at its most rearward position with respect to the piston. Since both connecting rods 18, 20 are connected to the walking beam 16 which is coupled at its center to the crosshead 15, the movement of the piston 14 is a resultant of the movement of the two connecting rods 18, 20, and at minimum piston stroke, is practically zero as to the walking beam pivots around its point of attachment to the crosshead.

When the phase relationship of the crankshafts is at an intermediate point between the in-phase relationship and the maximum out-of-phase relationship there will be some rocking of the walking beam about its point of attachment to the crosshead, and also some forward and backward motion of the piston 14.

It should be noted that in the apparatus thus far described, the rotation of the drive shafts 36, 38 has been in opposite radial direction because of the coupling together of the spur gears 78, 80. Thus, even though the rotatable shafts 58, 60 are rotated in the same direction, the phase relationship of the crankshaft throws is changed when the ring gears are rotated in the same direction.

The apparatus described above provides means whereby constant horsepower may be applied to the pump 12 even though the pressure head against which the pump works may vary over a wide range. When the pressure head is low enough to permit such operation, keeping the two crankshafts operating on an in-phase relationship results in maximum volume being displaced through the pump 12. As the pressure head increases the rack gear 70 is moved to cause rotation of the ring gears 26, 28 to cause the crankshafts to move out of phase with each other so that the available driving horsepower may be used to drive the piston 14 in increasingly shorter strokes and thus deliver less volume at a higher pressure.

Also, since the pump output can be continuously varied between practically no output and maximum output, there is no need for a torque converter or an additional speed varying transmission to be interposed between the power source and the pump apparatus providing the coupling between the power source 86 and the gear 78 does not cause the crankshafts 22, 24 to be rotated at excessive speeds.

While the apparatus has been illustrated as driving a single barrel single action reciprocating piston pump, a triplex pump, either single or double acting, or other multiple cylinder pump may be coupled to suitable crankshafts which are coupled so that the crankshafts are driven by the sun gears 78, 80 and which are driven by the sun gears of the gear assemblies 30, 32.

The apparatus of the invention permits the power source to operate at a substantially constant r.p.m. rate even though the pumping rate varies widely. Thus, this apparatus is well adapted to be driven by turbines or by an internal combustion piston-type engine operating at an optimum r.p.m. rate.

Because the pump is driven by two crankshafts the bearing loading on the individual connecting rods is reduced. A single pump may deliver either a large volume at moderate pressures or smaller volume at high pressures. In fixed stroke reciprocating piston-type pumps a so-called "high volume" pump has a relatively low maximum pumping pressure in order to prevent overloading of the connecting rod bearings or to prevent the stalling of the prime mover. Conversely, a so-called "high pressure" fixed stroke piston pump is limited in the volume it can pump at lower pressures because of the maximum safe r.p.m. rate of the crankshaft even though the connecting rod bearings may not be overloaded and the horsepower capabilities of the prime mover are not exceeded.

Pumping apparatus in accordance with this invention is most versatile than conventional apparatus in that it is good both as a high pressure-low volume pump and as a low pressure-high volume pump and it admits of continuous variation of the relationship between pressure or volume during operation. Also, if a torque converter or speed varying transmission is used, the apparatus is more compact and lighter than a conventional unit of similar work capabilities.
What is claimed is:
1. A mobile pumping unit comprising, in combination, a prime mover and a variable displacement pump, said pump comprising a cylinder and piston reciprocally therein, a crosshead, means for mechanically coupling the piston to the crosshead to reciprocate the piston with reciprocation of the crosshead, a walking beam having a central part and two end parts, said walking beam being pivotally coupled at its central part to the crosshead, a pair of crankshafts, each of said crankshafts having at least one throw, a pair of connecting rods, one of said connecting rods being pivotally coupled to one end part of said walking beam and to a throw on one of said pair of crankshafts, the other connecting rod being pivotally coupled to the other end of the walking beam and to a throw on said other crankshaft, a pair of planetary gear assemblies each comprising a sun gear, at least one planet gear and a ring gear, said ring gear having teeth on both its inner and outer peripheral surfaces, one of said crankshafts being operatively coupled to the sun gear of one of said planetary gear assemblies, the other of said pair of crankshafts being operatively coupled to the sun gear of the other of the planetary assemblies, a pair of drive shafts, means for coupling said prime mover to said drive shafts and for rotating each of said drive shafts at the same rate, one of said drive shafts being operatively coupled to one of said planet gears, the other of said drive shafts being operatively coupled to the other of said planet gears, positioning means coupled to the teeth on the outer peripheral surface of each ring gear whereby the radial position of the sun gear in one planetary assembly may be varied with respect to its planet gear to cause the throw of one crankshaft to change its radial position with respect to the radial position of the corresponding throw of the other crankshaft.

2. A pumping unit in accordance with claim 1, wherein said crankshafts are disposed parallel to one another.

3. A pumping unit in accordance with claim 1, wherein said drive shafts are disposed parallel with one another.

4. A pumping unit in accordance with claim 1, wherein the means for coupling the prime mover to the drive shafts includes means for rotating the drive shafts in opposite radial direction to one another.

5. A pumping unit in accordance with claim 1, drive shafts are hollow and each surrounds a crankshaft along a part of the length of said crankshaft.

6. A pumping unit in accordance with claim 1, wherein said positioning means comprises an elongated gear element which is operatively coupled to the teeth on the outer peripheral surfaces of said ring gears and apparatus coupled to said elongated gear element for actuating said element.

7. A pumping unit in accordance with claim 1, wherein said prime mover is coupled to said drive shaft through fixed-ratio gear means.

8. A pumping unit in accordance with claim 1, wherein said prime mover is a gas turbine.

9. A pumping unit in accordance with claim 1, wherein said prime mover is a reciprocating piston-type internal combustion engine.

10. A pumping unit in accordance with claim 6, said elongated gear element is a rack-type gear.

11. A pumping unit in accordance with claim 1, wherein the sun gear, planetary gear and ring gear in one planetary gear assembly are the same as the corresponding part in the other planetary gear assembly.

12. A pumping unit in accordance with claim 1, wherein the longitudinal axis of the crank throw of each crankshaft is offset from the longitudinal axis of its crankshaft by an equal amount.

13. A pumping unit in accordance with claim 1, wherein the point of coupling of the crosshead to the walking beam is along a line perpendicular to and bisecting a line drawn between the points of coupling of the connecting rods to the walking beam.

No references cited