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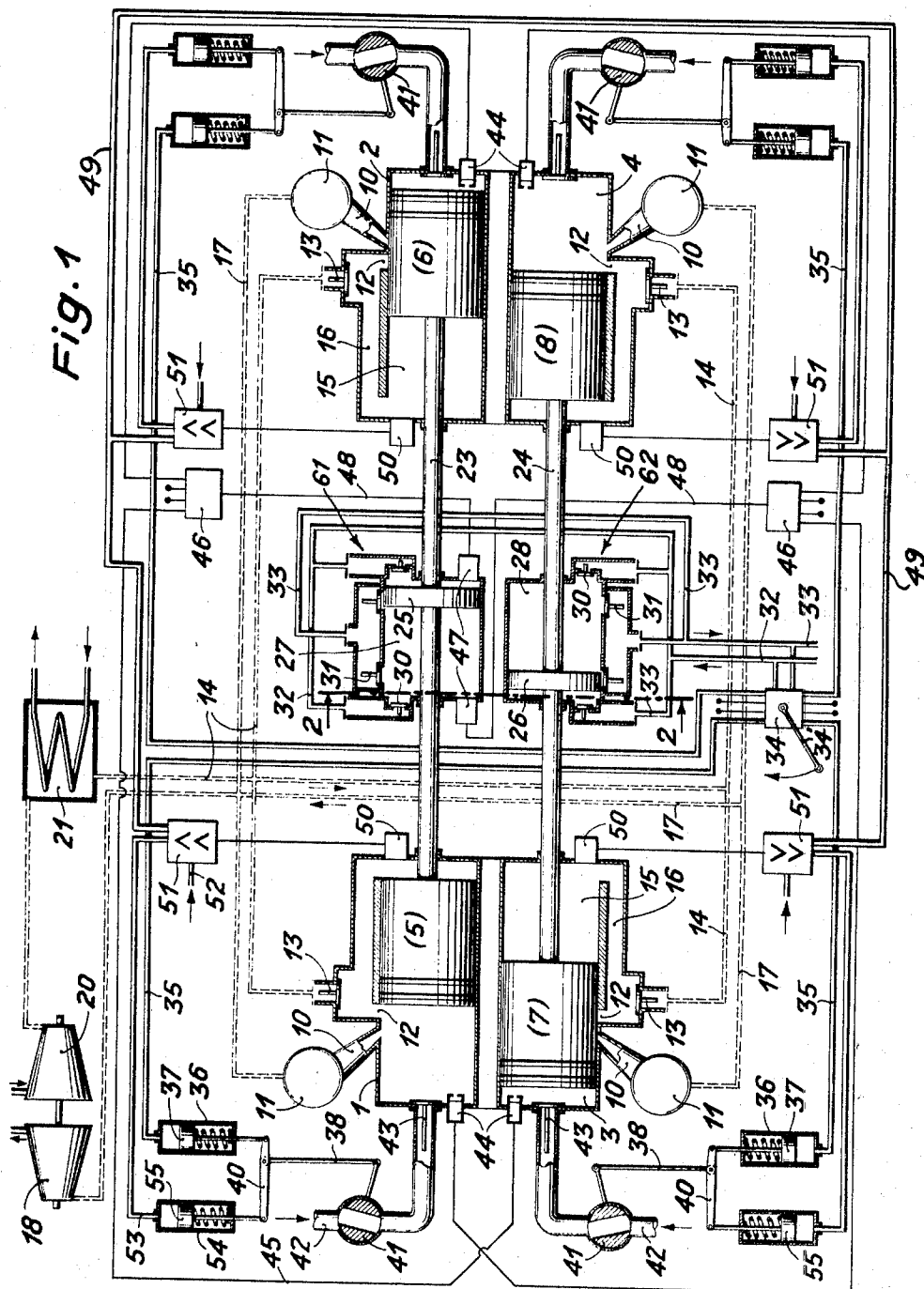
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FREE PISTON-TYPE INTERNAL COMBUSTION PUMPING ENGINE

Filed May 24, 1967

Sheet 1 of 2



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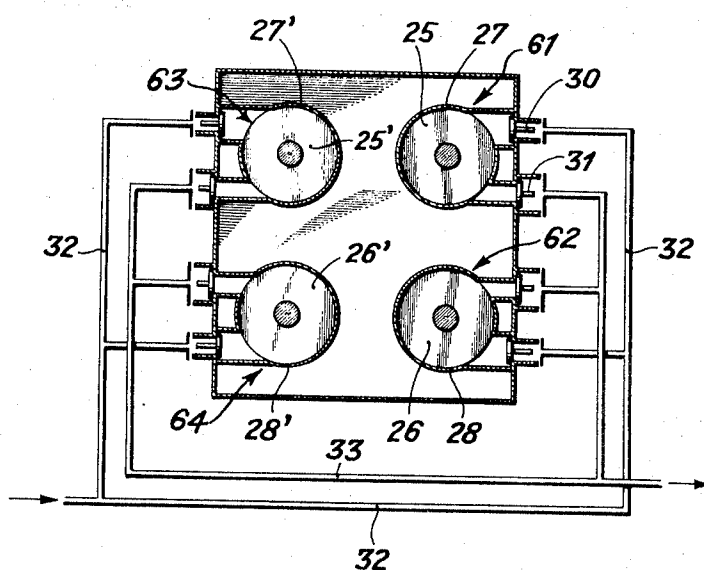
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Sheet 2 of 2

Fig. 2



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FREE PISTON-TYPE INTERNAL COMBUSTION PUMPING ENGINE

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5 Claims

ABSTRACT OF THE DISCLOSURE

There is disclosed a pump or compressor comprising four pumping units each having a double-acting pumping piston disposed in a pumping cylinder, this piston being connected by a piston rod to two pistons each disposed in an internal combustion engine cylinder having spark ignition, the three coupled pistons constituting a free piston unit. The four pumping units are disposed in a rectangular array and are connected together by ignition control so that successive units peripherally around the array are in successively opposite phases while diagonally opposite units in the array are in the same phases. The ignition system operates on pressure-sensitive devices disposed one at each end of one of the pumping cylinders and operates to fire the eight engine cylinders in the sequence required to operate the pumping units in the phase relation above described. In addition, each engine cylinder includes a device for sensing the approach of the piston in that cylinder to the end of its stroke. Signals generated by these approach detectors are applied to interconnected control devices which differentially adjust the fuel supply to their respective engine cylinders so as to correct for departures thereof from correct phase relative to a master engine cylinder.

Background of the invention

The present invention relates to pumps of the free piston-type in which a pumping cylinder contains a double-acting pumping piston coupled by a piston rod to one or more internal combustion engine driving pistons.

Summary of the invention

According to the present invention, a free piston internal combustion engine and coupled pumping or compressor machine comprises a bank of four piston units each of which has a double-acting compressor piston connected by a piston rod to one or more engine pistons arranged to drive the piston unit in both directions, and a control system which controls the movements of the piston units so that two units are in phase and the other two are in antiphase, the piston units being located in space so that linear and moment inertia forces arising from movements of the piston units are substantially balanced out. Each of these piston units, together with the pumping cylinder surrounding the pumping piston thereof, the engine cylinders surrounding the engine pistons thereof, and the inlet and outlet valves to the pumping cylinder and the valving, fuel supply, control and exhaust devices associated with those engine cylinders, constitutes a pumping unit of which four (or a multiple of four) are included in the pumping engine of the invention.

The engine piston drives for the compressor pistons may be constructed in various ways. For example each double-acting compressor piston can be connected to one double-acting engine piston. However, in the preferred construction the compressor piston is connected to two single-acting engine pistons, one on each side of the compressor piston.

A machine constructed in accordance with the invention is particularly suitable for pumping natural gas along

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natural gas pipelines, the natural gas being at the same time employed as fuel for driving the internal combustion engine part of the machine.

The piston units may be arranged in various ways. In a preferred arrangement, the longitudinal axes of the piston units are parallel and, when viewed along these axes, are at the corners of a parallelogram such as a square, the control system being arranged so that diagonally opposite piston units move in phase with each other.

Brief description of the drawing

The invention will now be described in further detail in terms of a non-limitative exemplary embodiment and by reference to the accompanying drawings in which:

FIG. 1 is a diagrammatic longitudinal sectional view through two of the four pumping units of one form of pumping machine according to the invention, shown together with the elements necessary for control thereof and for delivery thereto and withdrawal therefrom of the gas to be pumped; and

FIG. 2 is a sectional view taken on the line 2—2 of FIG. 1, the valving of the pumping cylinders and the associated piping diagrammatically shown in FIG. 1 appearing in a different diagrammatic arrangement in FIG. 2.

Description of the preferred embodiment

The machine of which half is shown in FIG. 1 is provided with engine cylinders 1, 2, 3 and 4, which contain pistons 5, 6, 7 and 8 respectively. The cylinders 1 to 4 have exhaust ports 10 which lead into exhaust manifolds 11. The cylinders also have inlet ports 12 which are connected to a combustion air line 14 via non-return valves 13. To assist in scavenging the cylinders of the engine, which operates on a two-stroke cycle, a scavenging chamber 15 is provided on the side of each piston opposite the combustion chamber, the scavenging chamber being in communication with the inlet port 12 via a passage 16. The exhaust manifolds 11 are connected to a common exhaust gas line 17 which leads to an exhaust gas turbine 18. The exhaust gas turbine is coupled to a turbo-blower 20, the turbo-blower drawing in and compressing air and delivering it via an air cooler 21 to the air line 14. The air line 14 is connected via the non-return valves 13 previously mentioned to the air inlet ports 12 of the engine cylinders.

The pistons 5 and 6 are connected to each other by a piston rod 23 and the pistons 7 and 8 are likewise connected by a piston rod 24. Fixed to the piston rods between the engine pistons are compressor or pumping pistons 25 and 26, movable in compressor or pumping cylinders 27 and 28. FIG. 1 thus shows two piston units, one for each of the two compressor or pumping units there shown. The first piston unit comprises pistons 5, 25 and 6 and piston rod 23. The second comprises pistons 7, 26 and 8 and piston rod 24.

The pumping cylinders 27 and 28 are double-acting. Each has two pumping chambers, one on either side of the piston therein, each of these chambers being provided with at least one inlet valve 30 and one delivery valve 31. The inlet valves 30 are connected to a supply line 32 for the gas to be pumped or compressed, for example natural gas. The delivery valves 31 lead to a delivery line 33 through which the compressed gas is discharged.

The machine includes a regulator 34 to which are applied the pump inlet and delivery pressures prevailing in the lines 32 and 33 respectively. Depending on these pressures, for example depending on their difference or on a deviation of the delivery pressure in line 33 from a set value established in regulator 34, for example at

control lever 34, the regulator delivers to its output signal lines 35 a control signal in the form of a pressure. This pressure is applied to a separate control cylinder 36 for each engine cylinder. Each cylinder 36 contains a spring-loaded piston 37 which is coupled to a control valve 41 via a linkage 38 including a two-armed lever 40, the control valve 41 adjusting the supply of gaseous fuel flowing through a line 42 to the corresponding engine cylinder. The gas lines 42 of the individual engine cylinders have gas valves 43 which are positively controlled by a mechanism not shown.

To ignite the combustible mixture, the engine cylinders are provided with electric spark plugs 44 which are connected by wiring 45 to electric ignition devices 46. The ignition is caused to occur in the engine cylinders by sensing elements 47 which are mounted in the end walls of one of the compressor cylinders, i.e., the cylinder 27 in the embodiment illustrated. The elements 47 provide signals when the piston 25 approaches the ends of the cylinder 27. The elements 47 may take the form of pressure-sensitive devices such as quartz crystals which, when a certain pressure thereon is exceeded, transmit electric signals to the ignition devices 46 by wiring 48 so as to trigger an igniting spark. Alternatively, the elements 47 may be constructed to respond to approach of the piston 25 (i.e. irrespective of pressure ahead of the piston 25), and may then contain mechanical contacts which release the spark on being touched by the piston.

The engine cylinders 1 to 4 shown in FIG. 1 are provided with proximity detectors 50 which transmit electric pneumatic or hydraulic signals to governors 51 in response to the approach of the engine pistons to those detectors. The governors control the flow of a hydraulic pressure medium from lines 52 to lines 53 which are connected to cylinders 54 containing each a spring-loaded piston 55. The piston rods of the pistons 55 act on the ends of the levers 40 opposite those on which the pistons 37 act, and in this manner the governors also influence the supply of fuel to the individual engine cylinders by providing a superimposed, individual correction signal for each engine cylinder.

The governors 51 may be constructed to respond to the signals generated by their detectors 50 and thereby, on each power stroke of their associated ones of the engine pistons 5, 6, 7 or 8, to adjust the fuel valve 41 of the corresponding engine cylinder by an amount proportional to the overtravel executed by that piston toward its detector 50, beyond a specified point of approach of the piston to the detector. This specified point of approach may be referred to as a threshold point, being that at which the detector 50 first responds to the approach of its piston.

However by means of integrating elements it is possible for the governors 51 to form mean values over a number of engine cycles, each governor then controlling its valve 41 in accordance with this mean value developed by it. The governors 51 of the individual engine cylinders may, moreover, be connected to each other by means of signal lines 49, which may be of hydraulic, electric or other nature. With the governors thus interconnected, one governor may function as a master governor, the others then operating on their valves 41 to close or open them according as their respective engine pistons lead or lag the piston associated with the master governor.

The pumping engine of FIG. 1 comprises four pumping units of the kind of which two are visible in FIG. 1, each unit including a piston unit as hereinabove described, a double-acting compressor cylinder enclosing the pumping piston and two engine cylinders each enclosing one of the engine pistons of that piston unit. The two pumping units visible in FIG. 1 are generally identified at reference characters 61 and 62 respectively.

FIG. 2 is a cross-sectional view of the embodiment of the invention shown in FIG. 1, the pumping cylinder

valves being however differently shown. Thus in FIG. 2 reference characters 27 and 28 identify the two pumping cylinders visible in FIG. 1, within which move pumping pistons 25 and 26, while reference characters 27' and 28' identify two similar pumping cylinders beneath and behind the plane of FIG. 1 and within which move pumping pistons 25' and 26'. In the embodiment of FIGS. 1 and 2 there are thus provided four pumping units disposed in a rectangular array. Identifying these four units by the reference characters 61, 62, 63 and 64, the units 61 and 62 are in opposite phase as indicated in FIG. 1. The units 63 and 64 are in opposite phase with respect to each other and, moreover the units 63 and 61 are in opposite phase, as are the units 62 and 64. That is, when in FIG. 2 the piston 25 of unit 61 is at the end of its travel farthest from the reader, the piston 26 of unit 62 is at the end of its travel nearest to the rear. Moreover when the piston 25 is thus farthest from the reader, the piston 25' of unit 63 is nearest to the reader and the piston 26' of unit 64 is farthest from the reader. The plane of FIG. 2, to which the directions of motion of all of the pistons are perpendicular, is therefore that of a parallelogram at whose corners are disposed the four pumping units of the engine shown.

Further, in the embodiment diagrammatically illustrated in FIGS. 1 and 2, pressure-sensitive elements 47 for control of the ignition are provided on only one of the four pumping cylinders, namely cylinder 27, which may be referred to as the main or master pumping cylinder.

FIG. 2 also shows the manner in which the gas to be compressed or pumped is obtained from a supply line 32 and passes via inlet valves 30 to the pumping cylinders. From the pumping cylinders the compressed gas passes through the delivery valves 31 into the delivery line 33. FIG. 2 is to be understood as illustrating on each pumping cylinder two inlet valves 30, one behind the other, and two delivery valves 31, also one behind the other. The showing of the inlet valves 30 in the end walls of the cylinders in FIG. 1 is for clarity of the drawing only.

As may be seen from FIG. 1, when a pumping piston, such as the piston 25 of FIG. 1, approaches the end of its stroke (whether moving to the right or to the left), it travels past the delivery valve 31 through which it has effected delivery of compressed gas during part or all of that stroke, and the space ahead of the piston on that stroke is closed off from the delivery valve by the piston itself. The gas thus trapped ahead of the piston cannot escape and forms a gas cushion which effectively limits the motion of the piston unit comprising pistons 5, 25 and 26 and piston rod 23, and thus performs a stroke stabilization function. At the same time, the pressure rise occurring in the trapped gas may trigger the ignition of the combustible mixture in the engine cylinders. Triggering is obtained by the elements 47 in the main pumping cylinder 27 which controls the spark plugs 44. Primary synchronization of the movements of the four piston units is obtained by the fact that the ignition in all eight engine cylinders of the machine is controlled by a single pumping cylinder. The piston unit movements resulting from the firing sequence are such that two diagonally disposed piston units move in phase with each other and the two other piston units move in phase with each other but in phase opposition to the first two. With perfect synchronization, this type of movement balances not only all free linear inertia forces but all free moments.

Thus when the right-hand pressure-sensitive element 47 in FIG. 1 responds to the rise in pressure at the right end of cylinder 27 as piston 25 moves to the right, the upper ignition device 46 in FIG. 1 fires the cylinder 2 and simultaneously the cylinder 3 and also the cylinder of the pumping unit 63 (FIG. 2) which is disposed behind the cylinder 1 of pumping unit 61 as seen in FIG. 1 and the cylinder of pumping unit 64 which is behind the cylinder 4 of pumping unit 62 as seen in FIG. 1.

In similar fashion, when the piston 25 of the master

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pumping unit 61 approaches the left-hand end of its travel in FIG. 1, the pressure-sensitive element 47 at the left end of the cylinder 27 will trigger the ignition device 46 at the bottom of FIG. 1 thus firing simultaneously the cylinder 1 of the pumping unit 61, the cylinder 4 of the pumping unit 62, the engine cylinder of the pumping unit 63 behind the cylinder 2 in FIG. 1 and the cylinder of the pumping unit 64 behind the cylinder 3 of the pumping unit 62.

Unavoidable inequalities in the supply of fuel and of combustion air to the various engine cylinders and in frictional resistances existing in the pumping units may introduce departures of the piston motions from the synchronous movement established therefor by the ignition process. It is for this reason that there is provided for each engine cylinder a correction device comprising an approach detector 50, a governor 51 and a compensating cylinder 54 with its piston 55. These elements together constitute for each of the combustion cylinders a correction device for adjustment of fuel supply to that cylinder in the sense required to compensate for these irregularities. Thus, if in one of the pumping units, the piston of a combustion cylinder approaches its detector 50 too closely or in advance of proper phase, by reference to the motions of the master piston unit including the pistons 5 and 6, then the correction piston 55 of the combustion cylinder in question will be so shifted in position as to reduce the opening of the associated fuel valve 41. Since the action here contemplated is a correction only, the piston 55 is coupled to the longer arm of its lever 40, longer than that which connects the piston 37 thereto, the piston 37 being under control of the main throttle control 34. The controller 34, consequently, exerts the preponderant influence on the fuel valve settings, whereas the approach detectors 50 and governors 51 operate only to effect corrections thereon.

The machine of the invention represents a substantial simplification over crankshaft-type piston-driven internal combustion engines with coupled compressors. Since control of the scavenging phase in the internal combustion engine is not dependent on synchronization of piston motion, the machine of the invention is relatively insensitive to small departures in synchronization among the several piston units. Consequently, these plural piston units may be assembled together in the compact manner which has been described without mechanical elements interconnecting them.

The invention is not limited to the construction shown in the drawings and hereinabove described. Thus for example the cylinders need not be disposed at the corners of a rectangle as indicated in FIG. 2. Their axes of motion, i.e. the piston rods 23 and 24, and 23' and 24' (FIG. 2), may for example be disposed at the angles of a parallelogram. Or they may be disposed collinearly. In such an embodiment the two inner piston units may move together in one direction, while the two outer ones move in the opposite direction. The machine of the invention may, moreover, include more than four piston units, for example a multiple of four. Lastly, the invention may also be constructed to have a double-acting compressor piston coupled with a single double-acting cylinder of a piston-type internal combustion engine.

More generally, while the invention has been described hereinabove in terms of a number of presently preferred embodiments thereof, the invention itself is not limited thereto but rather comprehends all modifications on and departures from those embodiments properly falling within the spirit and scope of the appended claims.

I claim:

1. A free piston internal combustion pumping engine comprising:

- (a) four pumping units each including:
 - (1) a double-acting pumping piston,
 - (2) a pumping cylinder surrounding the pumping piston,

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- (3) at least one engine piston,
- (4) means coupling the engine piston to the pumping piston for reciprocating motion therewith, and
- (5) an engine cylinder surrounding each of said engine pistons,
- (6) said pumping units being disposed for parallel motion of the pistons therein,

said engine further comprising:

- (b) means to control the times of combustion in the engine cylinders of said pumping units for cophasal reciprocating motion of the pistons of said pumping units in pairs with the pistons of one pair of pumping units being in anti-phase to the pistons of the other pair,
- (c) said pumping units being disposed at the corners of a quadrilateral parallelogram with the directions of motion of the pistons thereof perpendicular to the plane of that parallelogram,
- (d) each of said pairs including pumping units at diagonally opposite corners of the parallelogram.

2. A free piston internal combustion pumping engine comprising:

- (a) four pumping units each including:
 - (1) a double-acting pumping piston,
 - (2) a pumping cylinder surrounding the pumping piston,
 - (3) at least one engine piston,
 - (4) means coupling the engine piston to the pumping piston for reciprocating motion therewith, and
 - (5) an engine cylinder surrounding each of said engine pistons,
 - (6) said pumping units being disposed for parallel motion of the pistons therein,

said engine further comprising:

- (b) means disposed in one of said pumping units and responsive to approach of the pumping piston therein to the ends of its pumping cylinder to control the times of combustion in all of said engine cylinders for cophasal reciprocating motion of the pistons of said pumping units in pairs with the pistons of one pair of pumping units being in anti-phase to the pistons of the other pair,
- (c) said pumping units being disposed relatively to each other for substantial balance of the linear and moment inertia forces of said pistons and coupling means.

3. A free piston internal combustion pumping engine comprising:

- (a) four pumping units each including:
 - (1) a double-acting pumping piston,
 - (2) a pumping cylinder surrounding the pumping piston,
 - (3) at least one engine piston,
 - (4) means coupling the engine piston to the pumping piston for reciprocating motion therewith, and
 - (5) an engine cylinder surrounding each of said engine piston,
 - (6) said pumping units being disposed for parallel motion of the pistons therein,

said engine further comprising:

- (b) means to control the times of combustion in the engine cylinders of said pumping units for cophasal reciprocating motion of the pistons of said pumping units in pairs with the pistons of one pair of pumping units being in anti-phase to the pistons of the other pair,
- (c) said pumping units being disposed relatively to each other for substantial balance of the linear and moment inertia forces of said pistons and coupling means,

said engine further comprising for each of a plurality of said pumping units means to detect approach of an engine

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piston therein to the end of its respective stroke, said engine further comprising means responsive to said detecting means upon overtravel of the engine pistons in the pumping units of said plurality to adjust the supply of fuel to the combustion cylinders of said last-named engine pistons inversely with said overtravel.

4. A pumping engine according to claim 2 wherein said approach responsive means comprise pressure-responsive means disposed in the ends of the pumping cylinder of said one pumping unit.

5. A pumping engine according to claim 3 including signal means interconnecting said detecting means to vary the fuel supply to the engine cylinders of all but a master pumping unit of said plurality inversely with the times of arrival of the engine pistons at the ends of their strokes

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in said last-named engine cylinders by reference to the time of arrival at the end of its stroke of an engine piston in said master pumping unit.

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