July 19, 1955 M. E. CHANDLER 2,713,244

COMPOUND GEAR AND CENTRIFUGAL PUMP

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FIG. 1

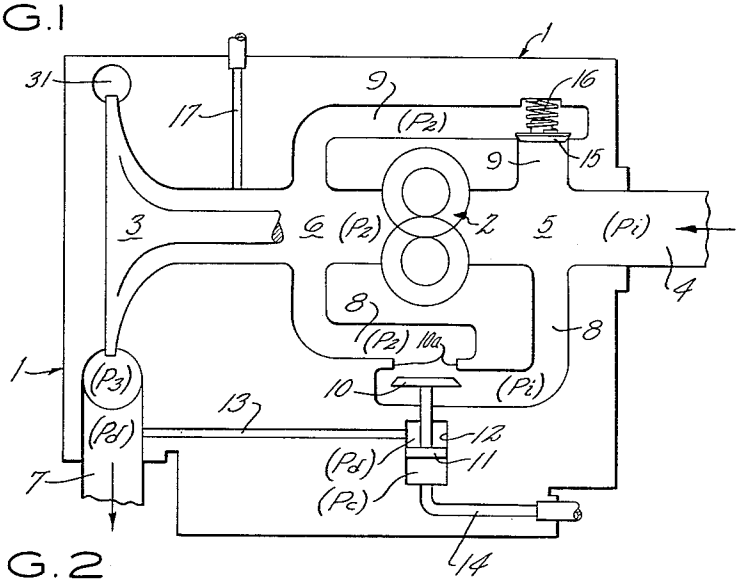
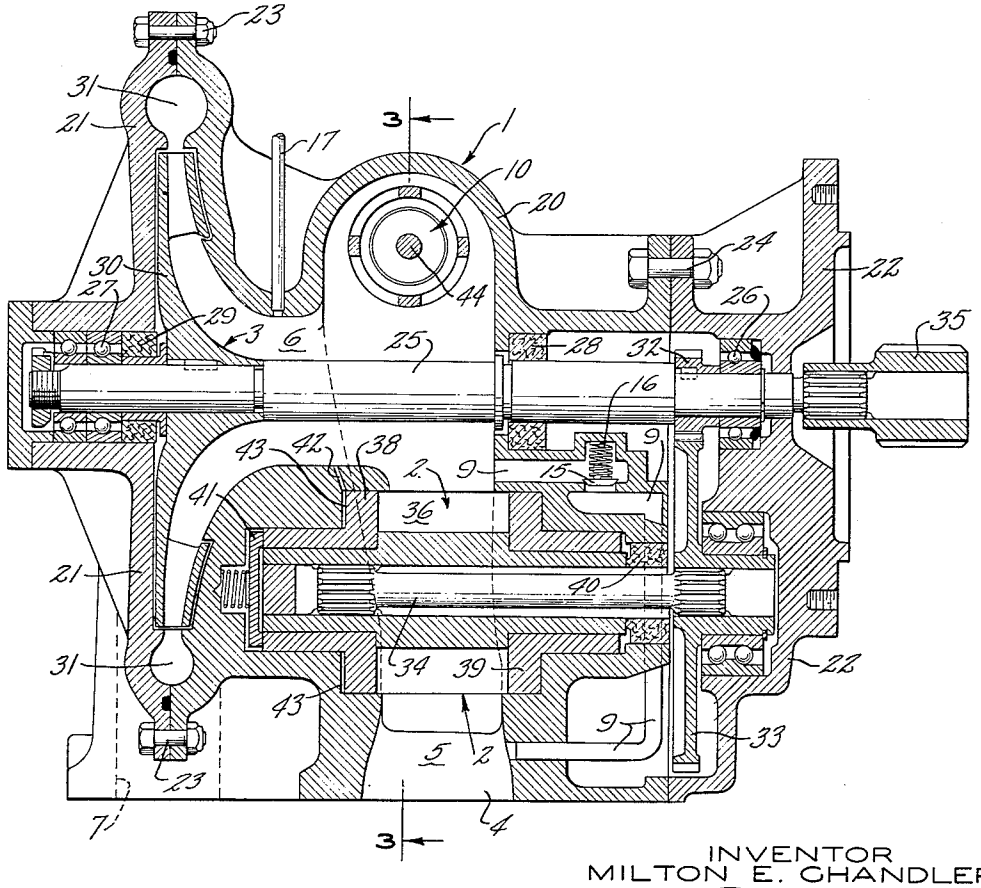


FIG. 2



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FIG. 4

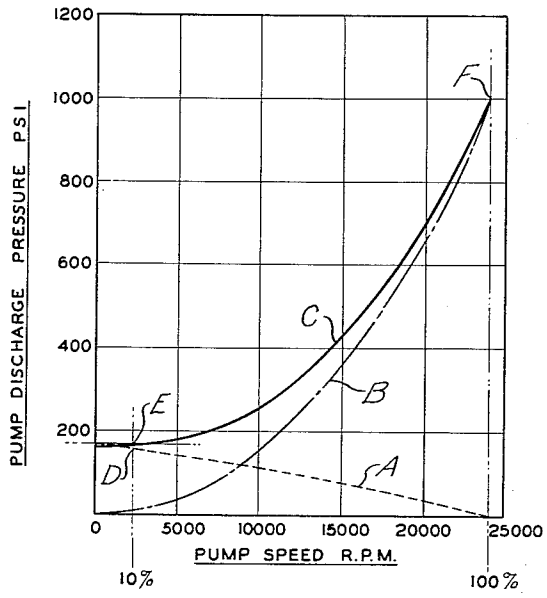
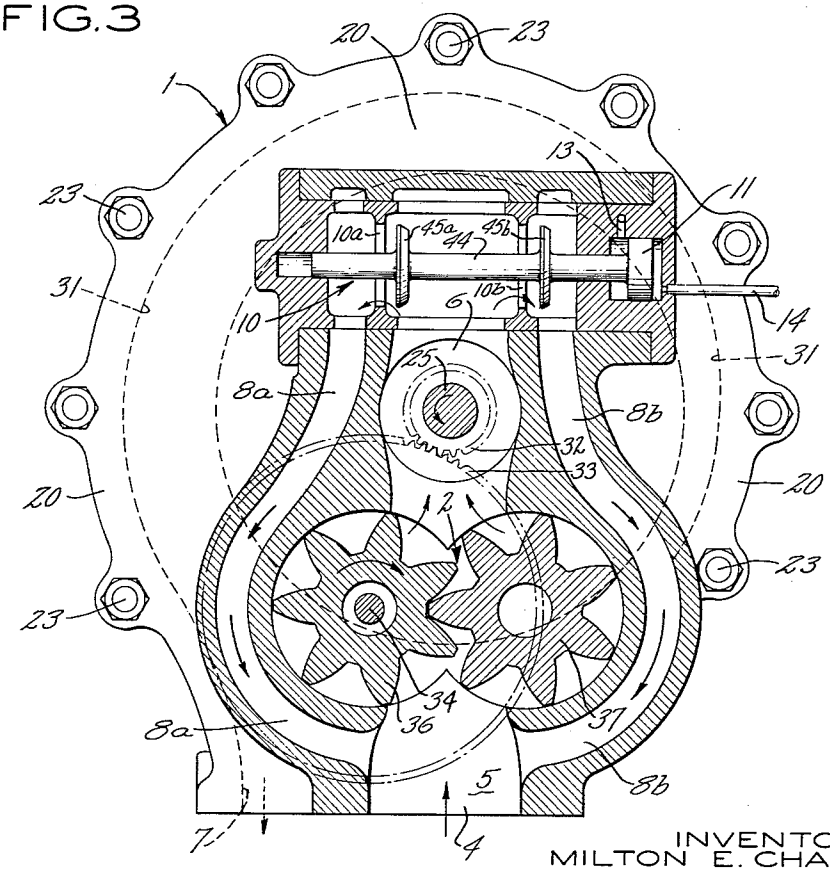


FIG. 3



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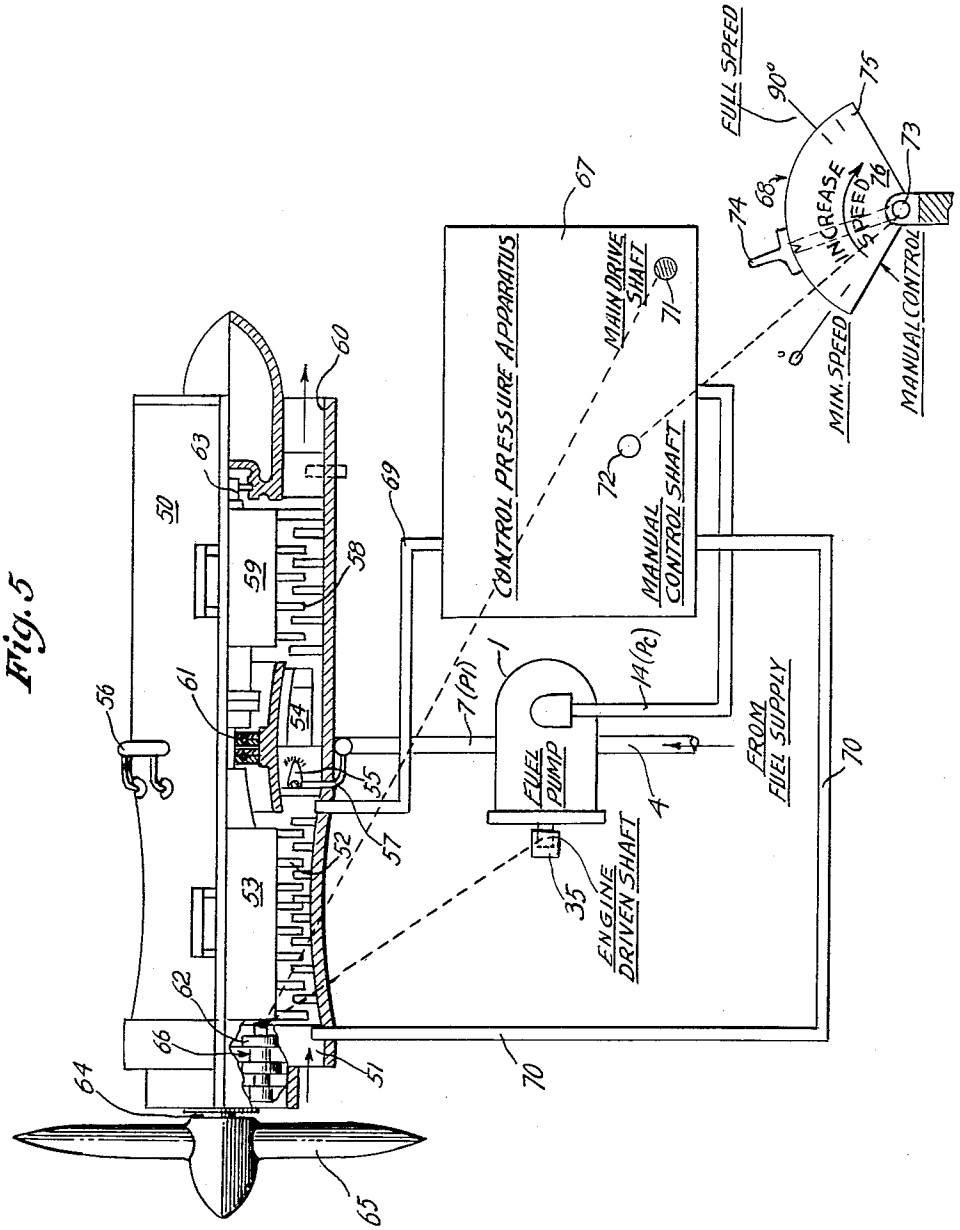


Fig. 5

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COMPOUND GEAR AND CENTRIFUGAL PUMP

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Application December 20, 1951, Serial No. 262,530

11 Claims. (Cl. 60—39.28)

This invention pertains to improvements in rotary pumps and more particularly has reference to high speed, high pressure pumps of the centrifugal type, especially adapted to meet the requirements of fuel pumps for aircraft internal combustion engines and gas turbines of the turbo-jet type. Such pumps should have the following general characteristics:

(1) Ability to handle considerable quantities of liquid fuel at moderate or high discharge pressures.

(2) Ability to develop sufficient discharge pressures at low speeds, without developing excessive discharge pressures at high speeds.

(3) High head in a single stage, with small diameter impeller wheel.

(4) Fairly large capacity, with small over-all size and weight.

(5) Simplicity of construction.

Experience with aircraft engine fuel pumps heretofore in use has shown that a single-stage, direct-engine-driven, positive displacement type of pump, such as a gear or vane pump, will develop sufficient discharge pressures at low speeds (e. g. 10 per cent of maximum rated speed), but also develops, at full (100 per cent) rated speed, such high discharge pressures as to cause excessive strain and wear on the pump. On the other hand, a centrifugal type of pump develops proper discharge pressures at high speeds, but insufficient discharge pressures at low speeds. Accordingly, in order to meet the above mentioned requirements, some form of compound pump, or a variable capacity dynamic pumping arrangement is necessary.

With the primary objective of achieving a solution of this problem, without resorting to the use of multiple stage pumps with their attendant complicated control valve mechanisms, I propose to devise, in a single unit, a compound gear and centrifugal pump, having certain auxiliary control features, which enables it to meet the required performance characteristics.

The basic philosophy of my invention is to provide a compound pump comprising a gear pump in series with a centrifugal pump, with the capacity of the former in excess of the capacity the latter pump is called upon to deliver. On the discharge side of the gear pump leading back to inlet, there is a relief valve which is loaded by a variable control pressure from the engine fuel control apparatus. This relief valve is unloaded by the discharge pressure of the centrifugal pump, but the unloading area of the relief valve exposed to the discharge pressure is less than the loading area subject to the engine control pressure. At low engine and pump speeds, the gear pump will produce substantially all the pressure, but as said speed increases the centrifugal pump will take on more and more of the load, until at high speeds the gear pump produces very little pressure and the centrifugal pump most of the pressure. I also provide a bypass check valve around the gear pump, so that in case this pump fails, the centrifugal pump may still suck fuel through the bypass. Connected to the discharge outlet of the gear pump there is a "no pressure" signal to indicate a drop in pressure if the gear pump fails.

With the foregoing and other objects in view, which may be incident to my improvements, my invention consists in the combination and arrangement of elements hereinafter described and illustrated in the accompanying drawings, in which:

Fig. 1 is a schematic view of the principal elements of my invention;

Fig. 2 is a central, longitudinal section through a compound pump constructed in accordance with my invention;

Fig. 3 is a cross section on the line 3—3, of the pump shown in Fig. 2;

Fig. 4 is a diagram showing the performance characteristics of my improved pump; and

Figure 5 shows, somewhat diagrammatically, my improved pump, as applied to an aircraft turbo-prop engine having an operatively associated manual (pilot's) control and an apparatus for generating a control pressure which regulates the operation of said pump.

Referring first to Figure 5, there are shown the principal elements of an aircraft turbo-prop engine, comprising a supporting casing **50**, an air inlet **51**, a multistage air compressor **52**, a compressor rotor shaft **53**; one each of a number of combustion chambers **54**, one of a corresponding number of fuel discharge nozzles **55** connected to a generally circular manifold **56** by means of a conduit **57**; a multistage gas turbine **58**, a turbine rotor shaft **59** connected to the compressor rotor shaft **53**; a tail pipe **60** for discharging combustion gases from turbine **59**; a center bearing **61** and end bearings **62** and **63** supported by casing **10**, a propeller shaft **64** to which is fixed a propeller **65**, and a gear train **66** connecting shafts **53** and **64** for rotating propeller **65**, and for operating fuel pump **1** and other engine accessories, at a speed proportional to engine speed.

Fuel pump **1**, which is the subject of my invention, is of the variable capacity type, and its delivery of fuel (through a conduit **7** to combustion nozzles **55**) is regulated by an engine control pressure (p_c) which is generated by a control pressure apparatus **67**, operatively associated with engine **50** and a manual (pilot's) control **68**. Apparatus **67** is connected by a conduit **69** to a source of compressor discharge pressure in the engine, and to a corresponding source of compressor inlet pressure by a conduit **70**. The control apparatus **67** is responsive to the pressure differential across the compressor **52**, which is an indication of air flow through the engine **50**.

A main drive shaft **71** in apparatus **57** is driven by the engine at a speed proportional to engine speed, and a manual control shaft **72** is rotatable in response to movement of a shaft **73**, to which is fixed an engine control lever **74** of the pilot's manual control **68**. Lever **74** is operable in reference to a scale **75** on a fixed quadrant **76**, said scale being calibrated in terms of angular degrees in relation to engine speed (R. P. M.).

From the foregoing description, it will be appreciated that the delivery of fuel to the engine by pump **1** is regulated in accordance with the engine control pressure (p_c), generated by apparatus **67**, in response to the pressure differential across the compressor **52** and other engine operating characteristics, and also in response to movement of manual control lever **74**.

Referring now to Fig. 1, the reference numeral **1** denotes a fluid-tight casing containing all the elements of my compound pump which comprises an engine-driven gear pump **2**, operatively connected in series with a centrifugal pump **3**. The fluid to be pumped enters the pump through an inlet **4**, traverses a passage **5**, gear pump **2**, a passage **6**, and centrifugal pump **3**, and is discharged through an outlet **7**. Connecting inlet pas-

sage 5 with gear pump discharge passage 6, are two bypass passages 8 and 9, in the former of which is mounted a control valve 10 that cooperates with a port 10*a* to control fluid flow through bypass 8 from passage 6 to passage 5. Valve 10 is actuated by a piston 11, slidably mounted in a cylinder 12, of which the upper end is connected through a conduit 13 to discharge passage 7.

The lower end of cylinder 12 is connected by a conduit 14 with a source of variable control pressure (p_c) from fuel control apparatus 67 (Figure 5). As thus arranged, valve 10 is responsive to the differential between the inlet pressure (p_1), and the gear pump discharge pressure (p_2), acting on valve 10, and the differential between the centrifugal pump discharge pressure (p_d) and the variable control pressure (p_c), which act on the opposite sides of piston 12. Mounted in bypass 9 is a check valve 15 which is biased toward closed position by a spring 16 and is adapted to open whenever the gear pump discharge pressure (p_2) in bypass passage 9 is less than the pressure (p_1) in inlet passage 5. This occurs only in the event of failure of the gear pump 2, in which case the centrifugal pump draws fluid through bypass 9 and continues to deliver said fluid to the engine. Gear gump discharge passage 6 is connected by a conduit 17 with a warning signal (not shown) in the cockpit which indicates to the pilot when gear pump 2 has failed.

Referring now to Figs. 2 and 3, it will be seen that the outer casing 1 of the compound pump comprises: (1) a central body member 20, which encloses inlet passage 5, gear pump 2, the greater part of impeller 30 of centrifugal pump 3, bypass control valve 10, and check valve 15; (2) a left-end closure member 21, which houses the outer portion of impeller 30 and, together with body member 20, forms discharge passage 7; and (3) a right-end closure member 22, which houses the gear pump driving gears 32 and 33. Left-end member 21 is secured to central body member 20 by a plurality of bolts 23 and right-end member is similarly secured to member 20 by a plurality of bolts 24, so that the three members 20, 21 and 22 form a single unitary fluid-tight casing 1.

Rotatably mounted in casing 1 is a drive shaft 25 which is journalled in ball bearings 26 and 27 and is sealed against escape of fluid from casing 1 by seals 28 and 29. Keyed to the left end of shaft 25 is an impeller 30 of centrifugal pump 3 which communicates with passage 6 from gear pump 2 and discharges into a volute passage 31 opening into discharge outlet passage 7. A spur gear 32, keyed to the right end of shaft 25, engages a reduction gear 33 which is keyed to a drive shaft 34 of gear pump 2, so that the latter shaft is driven at one-fourth of the speed of the former. The right end of shaft 25 is splined to a gear 35 which is driven by the engine at engine speed.

Gear pump 2 comprises two intermeshing shallow-angle, helical gears 36 and 37 which are journalled in floating, pressure-loaded sleeve bearings 38 and 39, mounted in the lower part of body member 20. Gear 36 is splined to shaft 34 and drives idle gear 37. A seal 40 prevents escape of fluid from the end of bearing sleeve 39. Bearing 38 is loaded by a spring pressed end bearing 41 and the discharge pressure (p_d) of gear pump 2 which is transmitted from passage 6 by a duct 42 to an annular space 43 between the radial flange of sleeve 38 and body member 20.

Slidably mounted transversely in the upper part of body member 20 is a stem 44 to which are integrally attached piston 11 and two valve heads, 45–*a* and 45–*b*, that together constitute the control valve 10 shown in Fig. 1. Valves 45–*a* and 45–*b*, respectively cooperate with ports 10*a* and 10*b* which respectively connect gear pump discharge passage 6 to bypass passages 8–*a* and 8–*b* that together constitute bypass passage 8 of Fig. 1. As shown in Fig. 3, valve 45–*b* is larger than 45–*a* so that the gear pump discharge pressure (p_2) in passage 6

biases valve 10 toward open position (i. e., to the right), in opposition to the difference between the compound pump discharge pressure (p_d) (from passage 13), and the variable control pressure (p_c) (from passage 14), that act on piston 11. But the difference in area between valves 45–*b* and 45–*a* is less than the area of piston 11, so that the unit pressure differential (p_2—p_1) between passages 6 and 5 must exceed the unit pressure differential (p_d—p_c) acting on piston 11, in order to open valve 10. Valve 10 is thus loaded by the variable control pressure (p_c) in conduit 14 from control apparatus 67, and said valve is unloaded by the centrifugal pump discharge pressure (p_d) in conduit 13 from discharge passage 7.

Referring now to the chart in Fig. 4, in which the ordinates denote the pump discharge pressures in pounds per square inch (p. s. i.), and the abscissas denote the speed of the engine and centrifugal pump 3, in revolutions per minute (R. P. M.), it will be noted that the dotted curve A indicates the speed-pressure characteristic of gear pump 2, as modulated by the operation of bypass control valve 10; the dotted curve B indicates the speed-pressure characteristic of centrifugal pump 3; and the full line curve C, indicates the speed-pressure characteristic of the compound pump; all in the range from zero speed to maximum rated engine speed (e. g. 24,000 R. P. M.). At low engine and pump speeds (circa 10 per cent of maximum rated speed), the gear pump 2 produces substantially all of the compound pump pressure (p_d), but as the engine and pump speed increases, the centrifugal pump 3 takes on more and more of the pumping load, so that at high speeds the gear pump 2 produces very little pumping pressure, while the centrifugal pump 3 produces most of said pressure. The gear pump 2 and centrifugal pump 3 are so arranged that the former, which runs at one-fourth of the speed of the latter, has sufficient capacity to deliver the required fuel at low speeds (circa 10 per cent of maximum rated engine speed). Thus for example, the gear pump 2 may be designed to deliver a fuel flow of 4,000 pounds per hour, (P. P. H.) at a pressure (p_2) of 165 p. s. i. at 2,400 R. P. M. (10 per cent speed).

As the speed of the engine and drive shaft 25 increases, the pressure rise created by the compound gear and centrifugal pump increases and eventually reaches a magnitude equal to or greater than that called for by the engine fuel feed regulator. When this point is reached, the fuel control valve 10 starts to open and that portion of the gear pump output which is not required by the engine is by-passed around the gear pump through passage 8 by the control valve 10. At 100 per cent of the maximum rated engine speed (e. g. 24,000 R. P. M.), the gear pump flow capacity is greater than the fuel required by the engine at that time (e. g. 40,000 P. P. H.), so that the whole engine fuel requirement is fed to the centrifugal pump 3 through the gear pump 2, with a portion being by-passed through control valve 10.

As a result of the above described arrangement, the discharge pressure (p_2) of gear pump 2, which is set at say 165 p. s. i. at 2,400 R. P. M., progressively decreases with increasing engine speed, as shown by curve A in Fig. 4, until said discharge pressure (p_2) is reduced to zero at maximum rated engine speed (24,000 R. P. M.). On the other hand, the discharge pressure (p_3) of the centrifugal pump 3, which is approximately 10 p. s. i. at 10 per cent engine speed (2400 R. P. M.), progressively increases with increasing engine speed, as shown by curve B in Fig. 4, until it reaches a predetermined value of 1,000 p. s. i. at maximum rated engine speed (24,000 R. P. M.). As gear pump 2 and centrifugal pump 3 operate in series, their respective discharge pressures (p_2) and (p_3) are additive, so that the ordinate of any speed point in the compound pump curve C in Fig. 4 is the sum of the ordinates of points in curves A and B at the same speed point. Since control valve 10 is

responsive to the pressure differential $(p_2-p_1)-(p_a-p_c)$, by a proper choice of areas of valves **45**–*a* and **45**–*b*, and the area of piston **11**, the speed-pressure characteristic of gear pump **2**, may be modulated, as indicated in curve A of Fig. 4, and a desired speed-pressure characteristic, of the compound pump may be thus obtained, as indicated by curve C of Fig. 4. Thus for example, if it is desired that the compound pump develop a discharge pressure of 175 p. s. i. at 2400 R. P. M. (10 per cent of maximum rated engine speed), and the centrifugal pump creates a discharge pressure (p_3) of 10 p. s. i. at that speed, the operation of valve **10** may be made such as to give a gear pump discharge pressure (p_2) of 165 p. s. i., as indicated by point D in Fig. 4, so that the compound pump discharge pressure (p_d) will be 175 p. s. i., as indicated at point E in Fig. 4. Since the gear pump discharge pressure (p_2) is reduced to zero at 100 per cent of maximum rated engine speed, curves B and C will coincide at maximum rated engine speed, as indicated by point F in Fig. 4.

From the foregoing description, it is clear that my improved compound pump may be made to have any speed-pressure characteristic as is necessary to deliver the proper amount of fuel for all engine speeds and other engine operating conditions which are controlled by the fuel control apparatus **67**, from which the variable control pressure (p_c) as indicated in Fig. 1 is obtained. It is further apparent that the novel arrangement of gear pump, centrifugal pump, control valve, and other elements of my invention, disclosed herein, provides in a single compact unit, a compound pump having the requirements of an aircraft fuel pump, as indicated in column 1, lines 22 to 31.

While I have shown and described the preferred embodiment of my invention, I desire it to be understood that I do not limit myself to the precise details of construction disclosed by way of illustrations, as these may be changed and modified by those skilled in the art without departing from the spirit of my invention or exceeding the scope of the appended claims.

I claim:

1. A rotary compound fuel pump for an internal combustion engine, comprising, in a single unit, a gear pump and a centrifugal pump arranged in series and driven through a common drive shaft by and in constant speed ratio with said engine, and means, responsive to a variable control pressure from said engine, for varying the discharge pressure of said compound pump in accordance with a preselected ratio between the discharge pressure and speed of said compound pump throughout the operating speed range of said engine.

2. A compound pump according to claim 1, including means for modulating the discharge pressure of said gear pump in accordance with the unit differential pressure between the discharge pressure of said compound pump and said control pressure.

3. A compound pump according to claim 2, wherein said modulating means is responsive to the pressure rise across said gear pump opposed by said differential pressure.

4. A compound pump according to claim 3, including a by-pass passage from the discharge to the inlet side of said gear pump and said modulating means comprises a valve means for regulating the flow through said by-pass passage.

5. A rotary compound fuel pump for an internal combustion engine, comprising, in a single unit, a gear pump and a centrifugal pump arranged in series and driven through a common drive shaft by and in constant speed ratio with said engine, means, responsive to a variable control pressure from said engine, for varying the discharge pressure of said compound pump in accordance with a preselected ratio between the discharge pressure and speed of said compound pump throughout the operating speed range of said engine, and means, responsive to the pressure rise across said gear pump, for maintaining a flow of fuel from the inlet of said gear pump to the inlet of said centrifugal pump, in the event of failure of said gear pump.

6. A rotary compound fuel pump for an internal combustion engine, comprising, in a single unit, a gear pump and a centrifugal pump arranged in series and driven through a common drive shaft by and in constant speed ratio with said engine, means, responsive to a variable control pressure from said engine, for varying the discharge pressure of said compound pump in accordance with a preselected ratio between the discharge pressure and speed of said compound pump throughout the operating speed range of said engine, and means, responsive to the discharge pressure of said gear pump, for indicating to the operator of said engine, a failure in the operation of said gear pump.

7. A rotary compound fuel pump for an internal combustion engine, comprising, in a single unit, a gear pump and a centrifugal pump arranged in series and driven through a common drive shaft by and in constant speed ratio with said engine, means for driving said centrifugal pump in a constant higher multiple speed ratio with said gear pump, and means, responsive to a variable control pressure from said engine, far varying the discharge pressure of said compound pump in accordance with a preselected ratio between the discharge pressure and speed of said compound pump throughout the operating speed range of said engine.

8. A rotary compound fuel pump for an internal combustion engine, comprising, in a single unit, a gear pump and a centrifugal pump arranged in series and driven through a common drive shaft by and in constant speed ratio with said engine, and means, responsive to a variable control pressure from said engine, for varying the discharge pressure of said compound pump in accordance with a preselected ratio between the discharge pressure and speed of said compound pump throughout the operating speed range of said engine; said gear pump comprising a pair of intermeshing gears, each journalled in an axially movable sleeve bearing having an annular flange contacting the side face of its adjacent gear, and means for subjecting the opposite side face of said flange to the discharge pressure of said gear pump.

9. A rotary compound fuel pump for an internal combustion engine, comprising, in a single unit, a gear pump and a centrifugal pump arranged in series and driven through a common drive shaft by and in constant speed ratio with said engine; and means, responsive to the differential of the discharge pressure of said compound pump and a control pressure from the engine, for coordinately controlling the simultaneous discharge rates of said gear and centrifugal pumps so that, at the low end of the engine speed range below a selected speed, the gear pump carries substantially all of the total pumping load and produces substantially all of the discharge pressure of the compound pump, while above said selected speed, the centrifugal pump carries a progressively increasing percentage of the total pumping load and produces a progressively increasing percentage of the discharge pressure of the compound pump, so that at the higher end of the engine range, the centrifugal pump carries substantially all of the total pumping load and produces substantially all of the discharge pressure of the compound pump.

10. A compound pump according to claim 9 wherein, near zero engine speed, the gear pump carries all of the total pumping load and produces all of the discharge pressure of the compound pump; while at maximum speed, the centrifugal pump carries all of the total pumping load and produces all of the discharge pressure of the compound pump.

11. A rotary compound fuel pump for an internal combustion engine, comprising, in a single unit, a gear pump and a centrifugal pump arranged in series and driven

through a common drive shaft by and in constant speed ratio with said engine; said gear and centrifugal pump being so arranged and coordinated that, at the low end of the engine speed range below a selected speed, the gear pump carries substantially all of the total pumping load and produces substantially all of the discharge pressure of the compound pump, while above said selected speed, the centrifugal pump carries a progressively increasing percentage of the total pumping load and produces a progressively increasing percentage of the discharge pressure of the compound pump, so that at the higher end of the engine range, the centrifugal pump carries substantially all of the total pumping load and produces substantially all of the discharge pressure of the compound pump; and near zero engine speed, the gear pump carries all of the total pumping load and produces all of the discharge pressure of the compound pump, while at maximum speed, the centrifugal pump carries all of the total pumping load and produces all of the discharge pressure of the compound pump; said compound pump having means, responsive to a variable control pressure from the engine, causing the gear and centrifugal pumps to operate in the specified manner.

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