(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
10 November 2005 (10.11.2005)

PCT

(10) International Publication Number
WO 2005/104678 A2

(51) International Patent Classification: Not classified

(21) International Application Number: PCT/US2005/010364

(22) International Filing Date: 29 March 2005 (29.03.2005)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/557,429 29 March 2004 (29.03.2004) US

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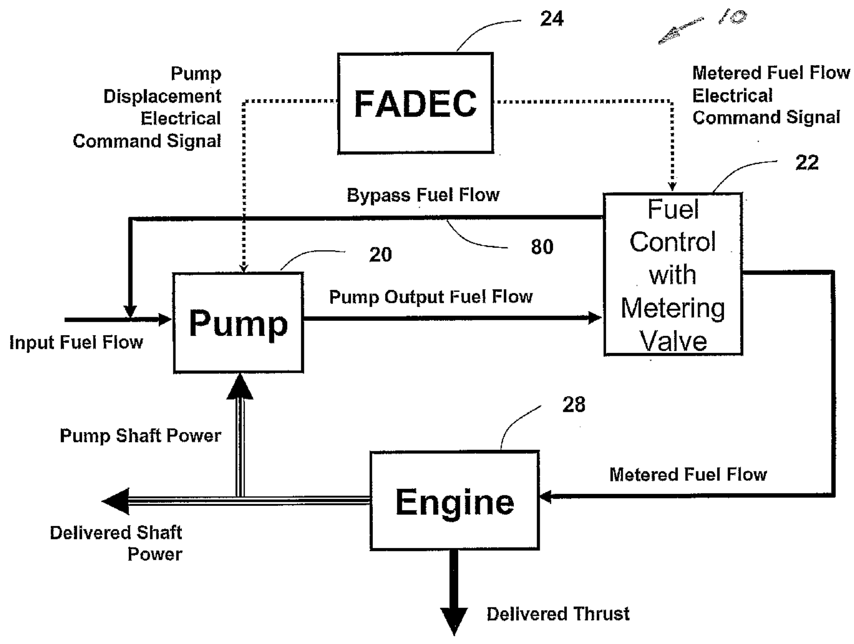
(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *without international search report and to be republished upon receipt of that report*

[Continued on next page]

(54) Title: TWO-DISPLACEMENT SETTING VARIABLE DISPLACEMENT PUMP USED AS ENGINE OVER-THRUST PROTECTION WITH FUEL SYSTEM THERMAL BENEFIT



(57) Abstract: A fuel delivery system (10) comprises a variable displacement pump (20) for pressurizing fuel. The variable displacement pump has a distinct first pump displacement setting for a first desired mass flow of fuel and a distinct second pump displacement setting for a second desired mass flow of fuel. The variable displacement pump operates in only one of the first and second pump displacement settings. A fuel control (22) with a metering valve downstream of the variable displacement pump selectively regulates fuel delivery.

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TWO-DISPLACEMENT SETTING VARIABLE DISPLACEMENT PUMP USED AS ENGINE OVER-THRUST PROTECTION WITH FUEL SYSTEM THERMAL BENEFIT

Cross Reference to Related Applications

[0001] This application claims priority from U.S. Provisional Patent Application Serial No. 60/557,429 filed March 29, 2004 and is incorporated herein by reference.

Background of the Invention

[0002] The present invention relates to a fuel delivery system. It finds particular application in conjunction with modern jet aircraft turbine engines, finding particular application during a control system failure, and will be described with particular reference thereto. However, it is to be appreciated that the present exemplary embodiment is also amenable to other applications.

[0003] Known fuel delivery systems have proven effective to date to provide desired fuel flow in a wide array of circumstances. Modern jet aircraft engines are now required to prevent even rare occurrences of uncontrolled engine over-thrust during control system failures. Cases of gross over-thrusting engines have resulted in several instances of loss of aircraft control due to substantial asymmetric thrust. As such, the Federal Aviation Administration (FAA) is considering new airworthiness regulations that dictate control system design that will prevent engine over-thrust conditions.

[0004] Engine over-thrust conditions are generally caused by a major loss of control functions that result in full fuel pump flow being delivered to an engine combustor. Many schemes are being considered that will bypass the pump delivered flow away from the engine combustor as to control flow delivered to the combustor, and thus engine thrust. These systems require additional hardware features that are independent of the normal control means.

[0005] In addition, as jet aircraft engines become more fuel efficient, modern engines have an ever increasingly difficult task of managing fuel system heat. Reduced windmill speeds add to the heat management task by forcing the engine fuel pump to be of a larger capacity, and therefore generate a larger quantity of heat to be dissipated.

[0006] Accordingly, there is a need for an improved fuel delivery system which provides over-thrust protection with improved fuel system thermal benefit.

Brief Description of the Invention

[0007] A new and improved fuel delivery system for a jet aircraft turbine engine is provided.

[0008] According to one aspect of the invention, the fuel delivery system comprises a system that has only two distinct pump displacement settings. The fuel delivery system preferably employs a variable displacement pump for pressurizing fuel. The variable displacement pump has a distinct first pump displacement setting for a first desired mass flow of fuel and a distinct second pump displacement setting for a second desired mass flow of fuel. The variable displacement pump operates in only one of the first and second pump displacement settings. A metering valve downstream of the variable displacement pump selectively regulates fuel delivery.

[0009] In the first position, the variable displacement pump is positioned to deliver a first predetermined, high mass flow, fuel displacement setting as would be required for a large amount of flow such as starting and takeoff. The pump is operative in a second predetermined, low mass flow, fuel displacement setting where reduced flow requirements are needed such as high altitude cruising or descent. A metering valve downstream of the variable displacement pump selectively regulates fuel delivery. A controller selectively positions the pump in only one of the first and second fuel displacement settings. Positioning the pump to operate in the second fuel displacement setting in the event of failure of the controller prevents engine over-thrust. The two-displacement pumping scheme provides a means of preventing engine over-thrust where in the event of major control system failure, the pump is positioned in the second of low flow displacement setting so that the pump will not produce an amount of flow that will enable the engine to accelerate to full power.

[0010] According to yet another aspect of the invention, a method of delivering fuel for an associated jet aircraft turbine engine is provided. Fuel is pressurized with a variable displacement pump. The pump has first and second fixed displacement settings for first and second predetermined mass flows of fuel and is set to only one of the first and second displacement settings. The fuel is metered through a metering valve for supply to fuel nozzles of the engine.

[0011] A benefit of the present invention is the ability to prevent engine over-thrust through the use of a variable displacement pump.

[0012] Another benefit of the present invention is the ability to minimize pump heating during a low flow displacement setting since the pump will contribute less heat to the fuel system, and permit fuel system heating to avoid fuel system icing at cold operating conditions by commanding the pump to its high flow displacement setting under substantially all conditions, regardless of system flow needs.

[0013] Still other benefits and aspects of the invention will become apparent from a reading and understanding of the detailed description of the preferred embodiments hereinbelow.

Brief Description of the Drawings

[0014] The present invention may take physical form in certain parts and arrangements of parts, preferred embodiments of which will be described in detail in this specification and illustrated in the accompanying drawings which form a part of the invention.

[0015] FIGURE 1 is a simplified schematic of the fuel delivery system according to one embodiment of the present invention.

[0016] FIGURE 2 is a cross-sectional view of a preferred variable flow pump in a first displacement setting used in the fuel delivery system of FIGURE 1.

[0017] FIGURE 3 is a cross-sectional view of the variable flow pump in a second displacement setting.

[0018] FIGURE 4 is a graphical representation of speed versus fuel flow of the variable displacement pump operative in either the first or second displacement settings.

Detailed Description of the Invention

[0019] It should, of course, be understood that the description and drawings herein are merely illustrative and that various modifications and changes can be made in the structures disclosed without departing from the spirit of the invention. Like numerals refer to like parts throughout the several views.

[0020] As schematically illustrated in FIGURE 1, a fuel delivery system **10** of the present invention includes a high pressure variable displacement pump **20**, a fuel control **22**, a controller **24** and an engine such as a jet aircraft turbine engine **28**. Generally, fuel is inlet to a centrifugal boost stage (not shown), initially pressurized and passed through a fuel/oil heat exchanger (not shown) and a filter (not shown) before being input to the pump **20**. As shown in FIGURES 2 and 3, and also described in greater detail in co-pending US patent application Serial No. 10/474,225 (publication 20040136853), filed October 3, 2003 based on PCT/US02/09298, filed March 27, 2002, the preferred, variable displacement pump **20** includes a rotor **40**, which has multiple vanes **42** extending therefrom. A cam ring **44** surrounding the rotor and vanes is free to rotate relative to the vanes **42**. Thus, substantial losses between the outer tips of the vanes and a stationary cam ring as used in a typical vane pump are not encountered with the present invention. The cam ring **44** is supported in a continuous fluid bearing **46** defined by the pumped fuel. A spacer ring **50** is received around the rotor **40**. The spacer ring has a flat or planar cam rolling surface **52** and receives a pin **54**. The pin cooperates with a cam sleeve **56** that is received around the rotor **40** to reposition the rotor and vanes to desired pumping positions.

[0021] First and second lobes or actuating surfaces **58, 60** are provided on the sleeve **56**, typically at a location opposite the pin. The lobes cooperate with first and second actuator assemblies **64, 66** to define means for altering a position of the cam sleeve **56**. The altering means selectively alter the stroke or displacement of the pump in a manner well known in the art. This variable displacement pump is preferred, although it will be understood that still other pumps may be used without departing from the scope and intent of the present invention.

[0022] In accordance with the present invention, the variable displacement pump **20** has a distinct, predetermined first pump displacement setting for a first desired mass flow of fuel (FIGURE 2) and a distinct, predetermined second pump displacement setting for a second desired mass flow of fuel (FIGURE 3). In use, the pump **20** operates in only one of the first and second pump displacement settings, the first pump displacement setting being a high mass flow displacement setting and the second pump displacement setting being a low mass flow displacement setting.

[0023] With reference to FIGURE 2, the actuating assemblies **64**, **66** are actuated so that the cam sleeve **56** is positioned to vary the stroke of the pump **20**. That is, the cam sleeve **56** is positioned so that a close clearance is defined between the cam sleeve and the spacer ring **50** along the left-hand quadrants of the pump as illustrated in FIGURE 2. In this position, the pump **20** is fixed in its first displacement setting, the high mass flow displacement setting. This flow setting is selected while operational (i.e., does not have to be set while inoperative) so that sufficient fuel flow is provided to the system where large flows are required during operation such as starting and takeoff.

[0024] With reference to FIGURE 3, the positions of the actuating assemblies **64**, **66** are altered when compared to FIGURE 2. The cam sleeve **56** is moved to vary the stroke of the vane pump to a second displacement setting, or the low mass flow displacement setting. This position is used during low flow conditions such as high altitude cruising or descent where flow requirements are reduced.

[0025] Thus, as shown in FIGURES 2 and 3, the pump **20** includes a distinct first stop and a distinct second stop, the first and second stops defining first and second positions of pump stroke travel. The first and second positions of pump stroke travel, in turn, define the respective first and second displacement settings (i.e. the operational parameters for pump stroke travel). These are the only two steady, commanded operational positions of the pump in accordance with the present invention. The pump either operates in a first or low flow condition or in a second or high flow position. It is recognized that the pump will transition through intermediate positions between the first and second displacement settings, however, the actuators and the pump control are operative so that the pump is commanded or directed to operate in these one of the two distinct positions only. That is, if the pump is at the first displacement position and commanded to the second displacement position, the pump proceeds to the second position without stopping and operating steadily at any intermediate position.

[0026] The pump **20** delivers a controllable amount of fuel flow in response to control signals. As shown in FIGURE 1, the output flow from the pump travels in a flow path through the fuel control **22** that includes a metering valve (not shown) where the fuel is directed to the turbine engine **28** and combusted to produce power. The fuel control **22** is downstream of the pump **20** for selectively regulating fuel delivery to the engine. A bypass **80** is provided at the fuel control **22** for returning bypass flow to the pump inlet. Bypass flow is the remaining portion of the variable displacement pump **20** output flow that is not used for combustion purposes. The bypass flow is generally returned through a bypass valve (not shown) to the inlet of the pump **20** after passing through another fuel/oil heat exchanger (not shown). In this system, metered flow is established by adjusting the position of the metering valve of the fuel control **22** to obtain the desired mass flow. The metering valve position of the fuel control **22** is set by the controller **24**.

[0027] As noted above, prior art fuel control systems have been inadequate in controlling engine speed in the event of a control system failure. For example, incorporating a hydro-mechanical overspeed governor function to limit engine speed has been used as one solution in the event of a control system failure that would otherwise cause the engine to be uncontrollable. However, typical incorporation of the overspeed governor uses features of the fuel control which are responsible for normal flow regulation and may in fact be the cause for such an uncontrollable event. The present system of FIGURE 1 uses the variable displacement pump **20** to reduce the maximum flow and thereby limit delivered metered fuel flow to the engine **28** and thus prevent the occurrence of a gross over-thrust situation.

[0028] With continued reference to FIGURE 1, the controller **24** positions the pump **20** in one of the first pump displacement setting (FIGURE2) and the second pump displacement setting (FIGURE 3). The controller **24** can be a solenoid valve, for example, which is responsive to an electronic control signal for actuating the pump **20** to only one of the first and second pump displacement settings. Thus, the solenoid valve is commanded by the controller **24** and positions the pump **20** to one of its first and second modes of operation. In the event of a control system failure that would otherwise cause the engine **28** to over-thrust, the controller **24** positions the pump **20** to operate in the second fuel displacement setting whereby pump flow to the engine is limited.

[0029] In operation, fuel is pressurized through the pump **20** that has first and second fixed displacement settings for first and second predetermined mass flows of fuel. The fuel is metered through a fuel control **22** having a metering valve for supply to fuel nozzles of the engine **28**. The pump **20** is set to only one of the first and second displacement settings (FIGURES 2 and 3).

[0030] With the above operation, fuel system temperature is advantageously controlled by operating the variable displacement pump **20** in either its fixed high mass flow displacement setting (and avoiding fuel system icing in cold operating conditions) or fixed low mass flow displacement setting (and thereby reducing excess heat). Fuel exiting the fuel control **22** is bypassed to recirculate a portion of fuel to the pump **20**.

[0031] In summary, the present system uses the variable displacement pump **20** with physical stops of pump stroke travel, thereby setting two distinct pump displacement settings. Under normal conditions requiring a large amount of pumped flow (such as starting and takeoff), the pump **20** is stroked to the high flow displacement setting (FIGURE 2) to provide the complete range of required engine operation. As flow requirements reduce (at conditions such as high altitude cruise or descent), the pump **20** is placed to its low flow displacement setting (FIGURE 1). With the low flow displacement setting, the pump **20** contributes less heat to the fuel system. A control means such as a solenoid valve commanded by the controller **24** positions the pump **20** to each displacement setting.

[0032] In addition to minimizing pump heating, the proposed system configuration permits fuel system heating to avoid fuel system icing at cold operating conditions. Fuel system heating is accomplished by commanding the pump **20** to its high flow displacement setting under all conditions, regardless of system flow needs.

[0033] In addition to providing benefit to the thermal management aspect of the engine, the two-displacement pumping scheme of the pump **20** provides a means of preventing engine over-thrust. In the event of major control system failure that results in full pump flow being delivered to the engine **28**, the pump **20** would be set to the low flow displacement setting. At this low flow setting, the pump **20** will not produce an amount of flow that will enable the engine **28** to accelerate to full power. Engine speed (and thus thrust level) will equilibrate at a level depending on the displacement chosen for the low flow setting. In this way, engine over-thrust protection is provided without adding control hardware to the fuel delivery system.

[0034] It will be appreciated that other types of pumps may be used, namely any type of pump that could be set up into two displacement modes. It could even be a two stage gear pump, one of which bypasses flow directly and the other stage doing the pumping. However, the illustrated and described variable pump is preferred.

[0035] Moreover, although other solutions have been considered, these alternative solutions add additional components to the system, thereby adding to the cost, complexity, and/or the potential that other components could fail.

[0036] In one example as shown in FIGURE 4, the first position is 100% flow capacity while the second position is approximately 33% of the pump flow capacity. However, these values are illustrative only and are not to be construed as requirements to achieve the benefits and advantages described above.

[0037] The present invention has been described with reference to the preferred embodiment. Obviously, modifications and alterations will occur to others upon reading and understanding the preceding detailed description. It is intended that the exemplary embodiment be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.

What is claimed is:

What is claimed is:

1. A fuel delivery system for an associated jet aircraft turbine engine during a control system failure comprising:

a pump for pressurizing fuel, the pump having a distinct first pump displacement setting for a first desired mass flow of fuel and a distinct second pump displacement setting for a second desired mass flow of fuel, wherein the pump operates in only one of the first and second pump displacement settings; and,

a metering valve downstream of the pump for selectively regulating fuel delivery.

2. The fuel delivery system of claim 1 wherein the first pump displacement setting is a high mass flow displacement setting.

3. The fuel delivery system of claim 1 wherein the second pump displacement setting is a low mass flow displacement setting.

4. The fuel delivery system of claim 3 wherein the pump is activated to the second pump displacement setting in response to a control system failure.

5. The fuel delivery system of claim 3 further comprising means for preventing engine over-thrust operatively associated with the pump for positioning the pump in the second pump displacement setting in response to a control system failure whereby pump flow to the associated engine is limited to provide over-thrust protection.

6. The fuel delivery system of claim 1 further comprising means for preventing engine over-thrust operatively associated with the pump for positioning the pump in the second pump displacement setting in response to a control system failure whereby pump flow to the associated engine is limited to provide over-thrust protection.

7. The fuel delivery system of claim 1 wherein the pump includes distinct first and second stops defining operational parameters for pump stroke travel.

8. The fuel delivery system of claim 1 further comprising a controller for positioning the pump in one of the first and second pump displacement settings.

9. The fuel delivery system of claim 8 wherein the controller is a solenoid valve responsive to an electronic control signal for actuating the pump to only one of the first and second pump displacement settings.

10. The fuel delivery system of claim 1 further comprising a bypass passage downstream of the pump for returning excess flow to a pump inlet.

11. The fuel delivery system of claim 1 further comprising a solenoid valve, the solenoid valve being commanded by the electronic control for positioning the pump to one of the first and second modes of operation.

12. The fuel delivery system of claim 1 wherein the second pump displacement setting contributes less heat to the fuel system.

13. The fuel delivery system of claim 1 wherein the first pump displacement setting permits fuel system heating for avoiding fuel system icing at cold operating conditions.

14. The fuel delivery system of claim 1 wherein the pump is a variable displacement pump.

15. A method of delivering fuel for an associated jet aircraft turbine engine comprising the steps of:

pressurizing fuel through a pump having first and second fixed displacement settings for first and second predetermined mass flows of fuel;

metering the fuel through a metering valve for supply to associated fuel nozzles; and,

setting the pump to only one of the first and second displacement settings.

16. The method of claim 15 comprising the further step of controlling fuel system temperature by operating the pump in its fixed high mass flow displacement setting.

17. The method of claim 15 comprising the further step of bypassing fuel exiting the metering valve to recirculate a portion of fuel to the pump.

18. A fuel delivery system for preventing engine over-thrust for an associated jet aircraft turbine engine comprising:

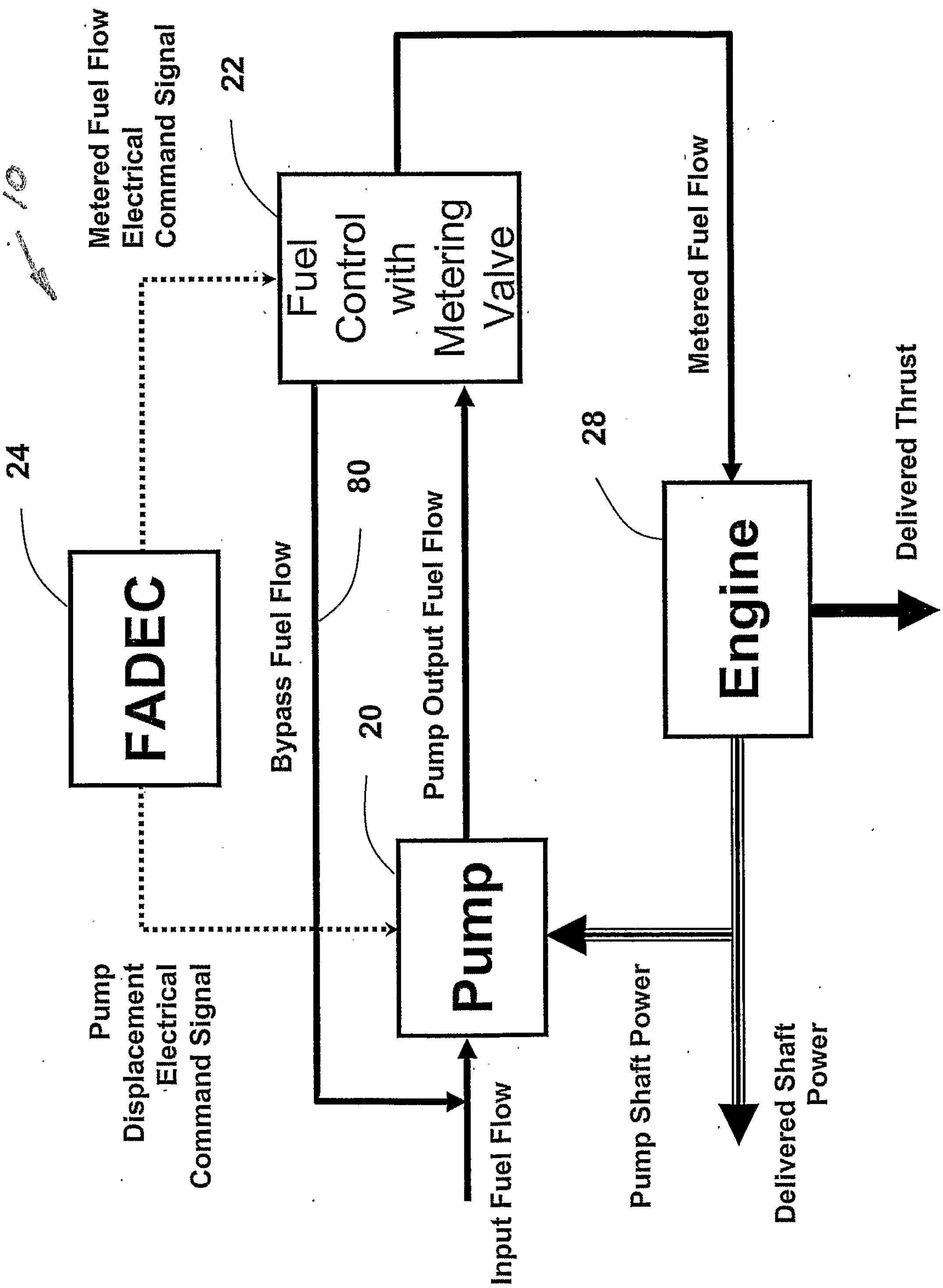
a variable displacement pump for pressurizing fuel operative in either a first predetermined, high mass flow, fuel displacement setting or a second predetermined, low mass flow, fuel displacement setting;

a metering valve downstream of the variable displacement pump for selectively regulating fuel delivery; and,

a controller for selectively positioning the pump in only one of the first and second fuel displacement settings, and positioning the pump to operate in the second fuel displacement setting in the event of failure of the controller thereby preventing engine over-thrust.

19. The fuel delivery system of claim 18 wherein the pump includes first and second stops in first and second extremes of pump stroke travel.

20. The fuel delivery system of claim 19 wherein the first and second extremes of pump stroke travel define the respective first and second displacement setting.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Metered Fuel Flow Electrical Command Signal
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Fuel Control with Metering Valve
24
FADEC
80
Bypass Fuel Flow
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Pump Displacement Electrical Command Signal
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Metered Fuel Flow
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Engine
Delivered Thrust
Pump Shaft Power
Delivered Shaft Power

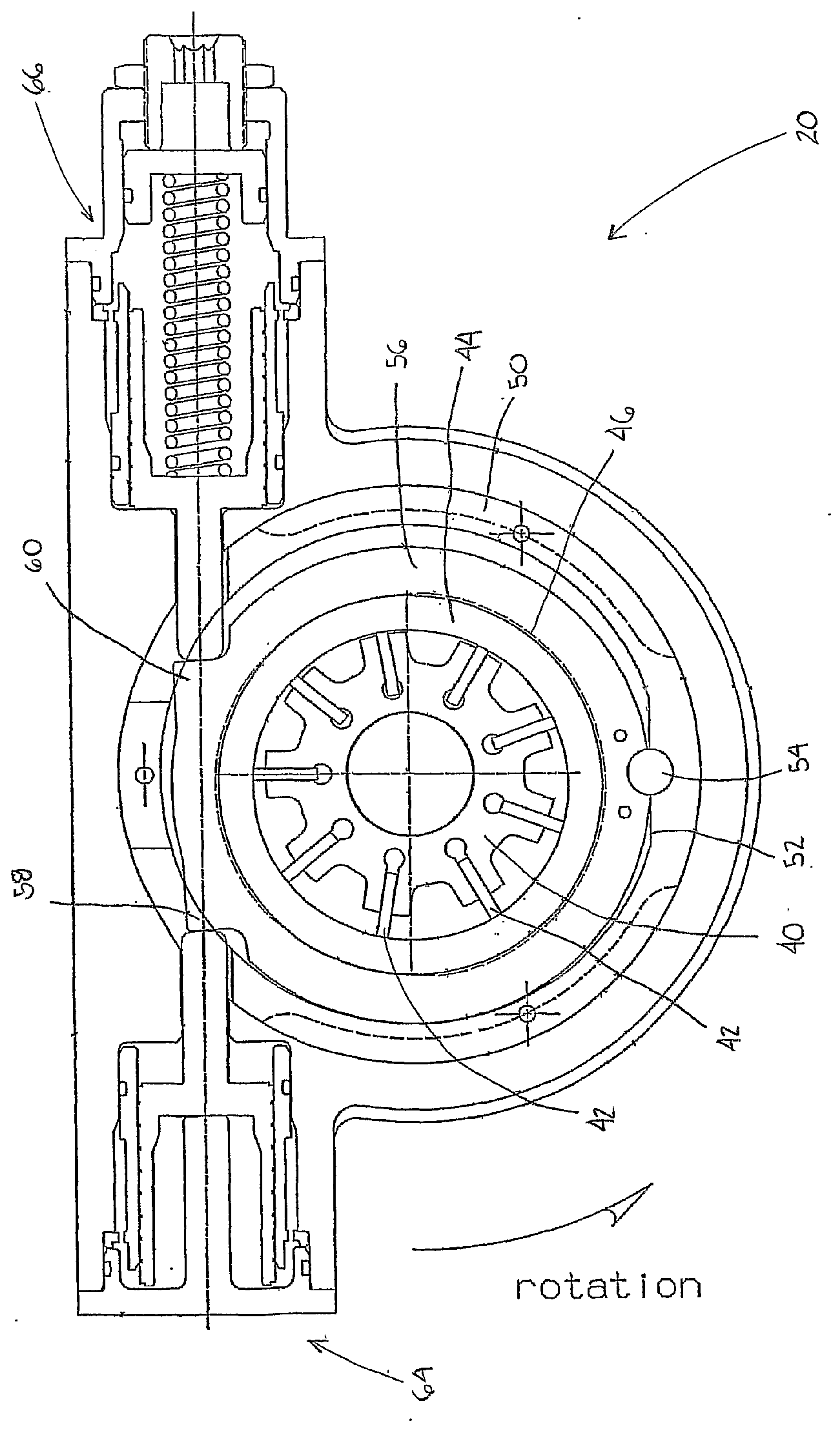

FIGURE 2

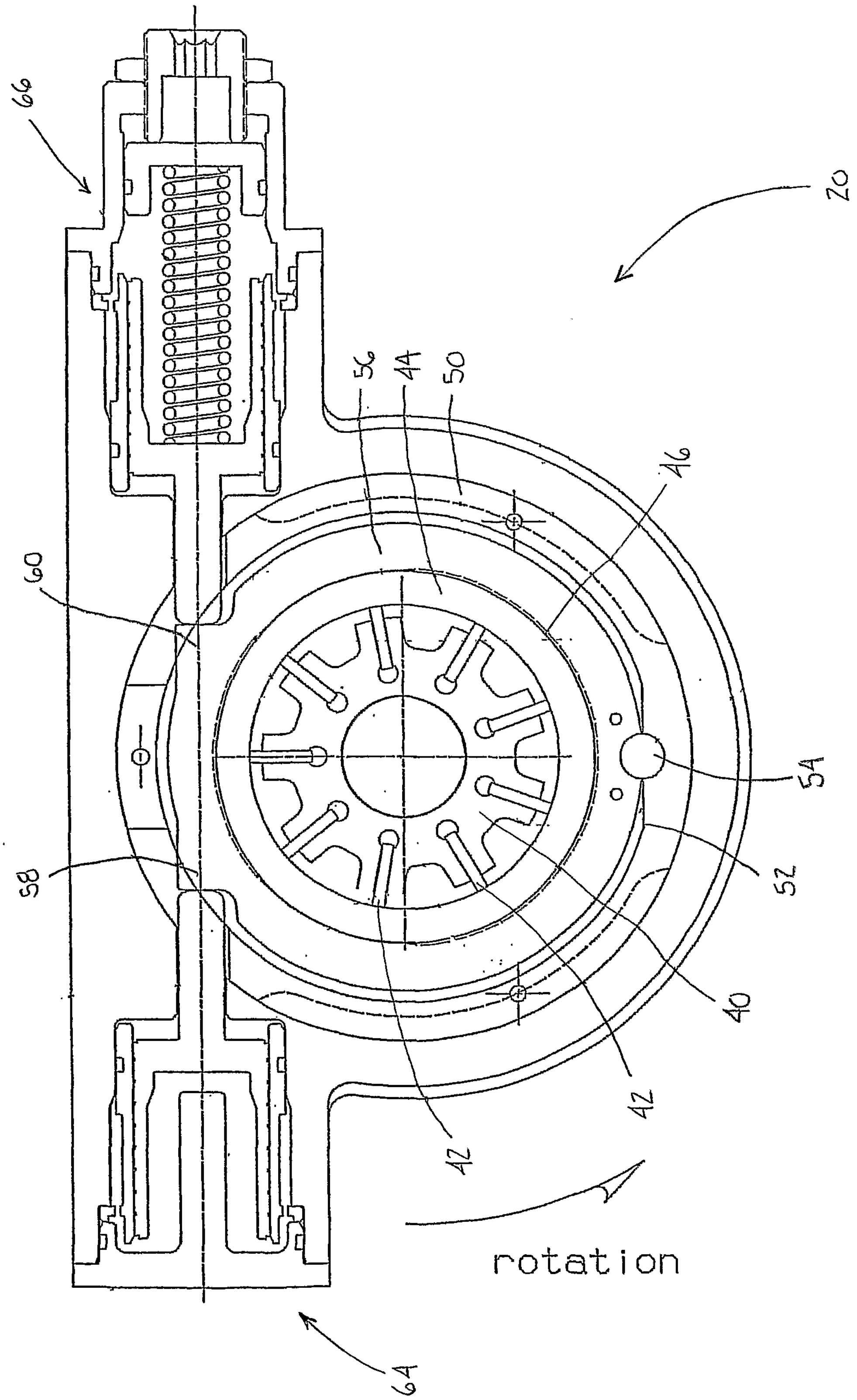

FIGURE 3

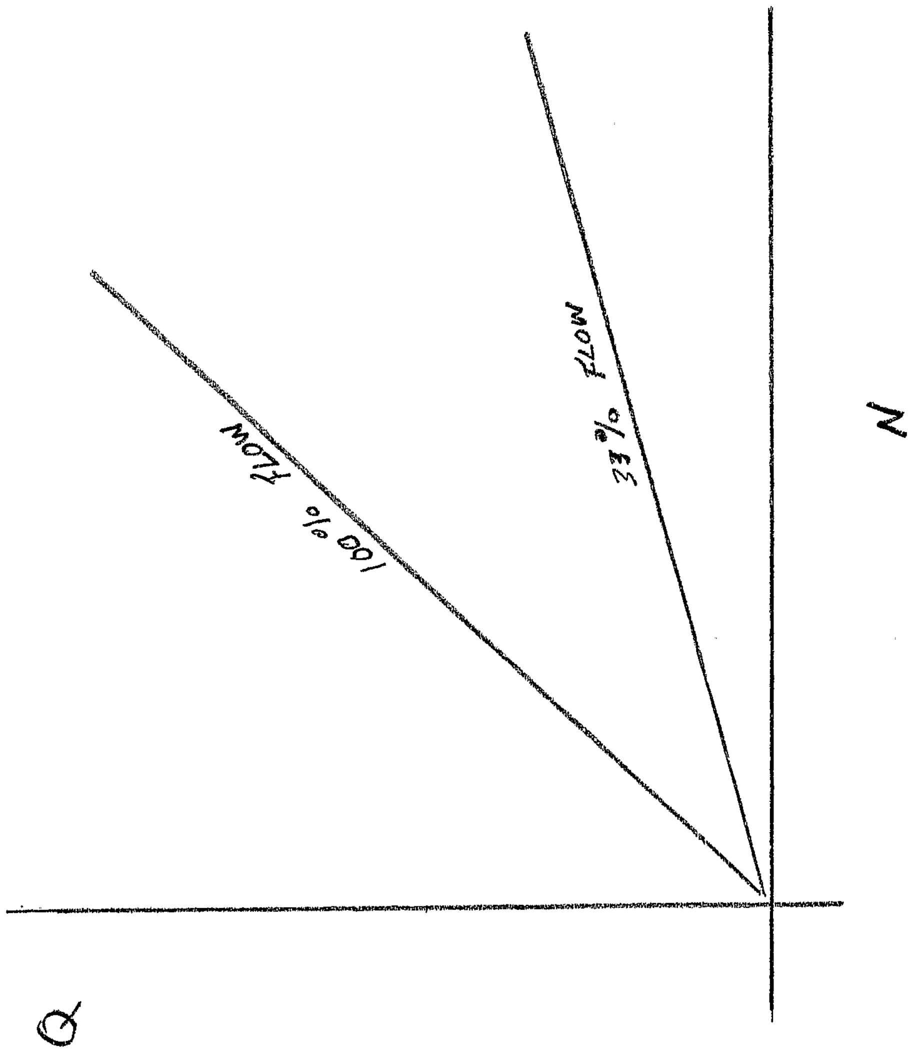

FIG. 4