United States Patent [19]

Hobo et al.

[11] **3,762,379**

[45] **Oct. 2, 1973**

[54] **SYSTEM FOR INJECTING METERED QUANTITY OF FUEL INTO ENGINE**

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[22] Filed: **July 29, 1971**

[21] Appl. No.: **167,299**

[30] **Foreign Application Priority Data**

Aug. 10, 1970 Japan 45/69926

[52] **U.S. Cl.. 123/32 AE,** 123/139 E, 123/139 AW, 123/139 AS, 123/139 AU

[51] **Int. Cl.** **F02b 3/00,** F02m 39/00

[58] **Field of Search** ..... 123/32 EA, 32 AE, 123/139 E, 139 AW

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[57] **ABSTRACT**

A system for injecting a metered quantity of fuel into an engine having a fuel injection pump, an electrically controlled metering valve, and a fluid passage connecting the fuel outlet port of the metering valve to the fuel suction port of the fuel injection pump. In the system, the volume of the fluid passage is suitably selected to lie within a specific range so that the metering of fuel by the metering valve is continued for a period of time more than that during which the fuel suction port of the fuel injection pump is kept open.

2 Claims, 2 Drawing Figures

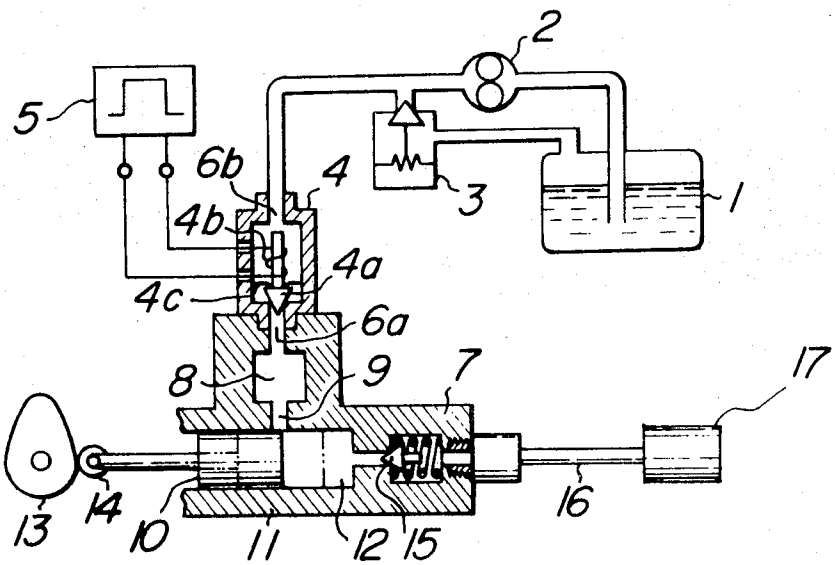


FIG. 1

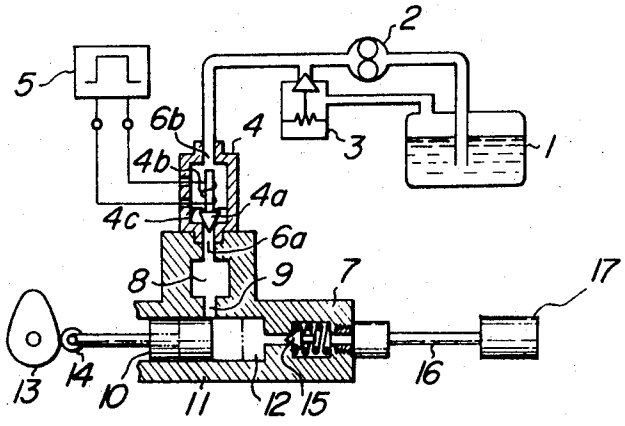
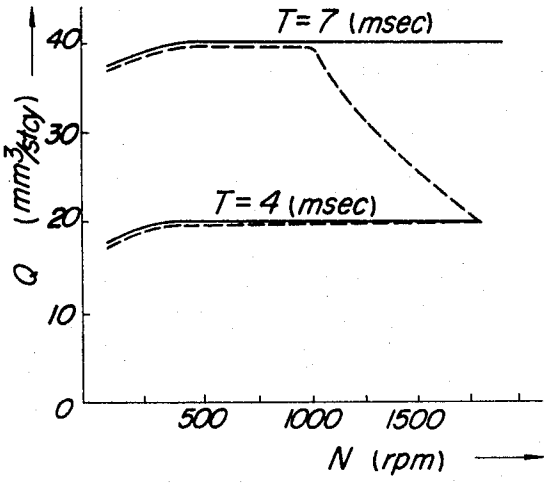


FIG. 2



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SYSTEM FOR INJECTING METERED QUANTITY OF FUEL INTO ENGINE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to fuel injection systems for injecting fuel into engines such as diesel engines, and more particularly to a fuel injection system in which an electromagnetically operated metering means and electrical control means for applying a timing pulse to the electromagnetically operated metering means are used for supplying a metered quantity of fuel to a fuel injection pump in each operating cycle of the fuel injection pump.

2. Description of the Prior Art

A fuel injection pump adapted for intermittent injection of fuel is generally so constructed that the fuel suction port in the pump cylinder communicates with the pump chamber at the end of the suction stroke of the pump plunger during the operating cycle of the fuel injection pump, and in the delivery stroke of the pump plunger, the pump plunger closes the fuel suction port in the pump cylinder so as to supply fuel under pressure to the fuel injection nozzle.

In a system commonly employed for controlling the quantity of delivery or quantity of fuel injected in each operating cycle of a fuel injection pump of the kind as above described, an electromagnetically or solenoid operated valve is interposed in the fluid passage leading to the fuel suction port of the fuel injection pump from a fuel feed pump supplying fuel at a low pressure of the order of 2 kilograms per square centimeter and a timing pulse is applied to the solenoid operated valve from electrical control means in each fuel suction stroke of the pump plunger of the fuel injection pump so that the solenoid operated valve is opened and maintained in such a position for a period of time determined by the duration of the timing pulse for the metering of fuel. The inventors have experimentally ascertained the fact that, in such a system, the volume of the space in the fluid passage ranging from the fuel suction port of the fuel injection pump to the fuel outlet port of the solenoid operated valve open and closed by the needle valve member (which space will hereinafter be referred to as a stabilizing chamber) is intimately related with the duration of the timing pulse or period of time during which the metering can be carried out by the solenoid operated valve. More precisely, when the fuel outlet port of the solenoid operated valve is disposed in close proximity to the fuel suction port of the fuel injection pump and thus the stabilizing chamber has a sufficiently small volume, the period of time during which the fuel can be metered by the solenoid operated valve is limited to the period of time during which the fuel suction port is open and communicates with the pump chamber in the suction stroke of the pump plunger of the fuel injection pump. On the other hand, when the fuel outlet port of the solenoid operated valve is suitably spaced from the fuel suction port of the fuel injection pump and thus the stabilizing chamber of a suitably large volume is provided in the fluid passage therebetween, the fuel can be metered by the solenoid operated valve not only during the period of time in which the fuel suction port is in its open position in the suction stroke of the pump plunger but also during the delivery stroke of the pump plunger.

Thus, the provision of the stabilizing chamber is especially effective when a single solenoid operated valve is disposed in the fluid passage leading to the fuel suction port of a fuel injection pump for metering the fuel to be distributed to the cylinders of a multi-cylinder diesel engine. Suppose, for example, that a fuel injection pump of the distributor type fuel injection pump from which fuel is distributed to each cylinders of a four-cylinder diesel engine is driven from a drive shaft of the distributor type injection pump rotating at a maximum speed of 1,800 r.p.m., then one operating cycle of the fuel injection pump occupies a period of time of $60/1800 \times 1/4 = 0.0083$ second. When, in this case, the solenoid operated valve is disposed in close proximity to the fuel suction port of the fuel injection pump and a period of time during which the solenoid operated valve is held in its open position is varied to meter a suitable quantity of fuel to be drawn into the pump chamber in each operating cycle of the fuel injection pump, the solenoid operated valve can only meter the fuel during a limited period of time which ranges from the time at the end of the suction stroke of the pump plunger to the time immediately before the subsequent delivery stroke of the pump plunger takes place in the operating cycle of the fuel injection pump. This period of time is equal, at the most, to the half of the entire period of time occupied by one operating cycle of the fuel injection pump. Thus, the metering period of time is of the order of 0.004 second at the most when the pump is driven by the shaft rotating at the maximum speed of 1,800 r.p.m. and it is difficult to attain the metering with high precision.

Further, when the stabilizing chamber has an excessively large volume, the variation in the quantity of fuel delivered from the fuel injection pump occurs with a certain time lag relative to the variation in the quantity of fuel metered by the solenoid operated valve in each operating cycle. The use of such a fuel injection pump with such a poor response characteristics for a diesel engine is undesirable in that hunting occurs in the diesel engine.

SUMMARY OF THE INVENTION

With a view to overcome the defects described above, it is a primary object of the present invention to provide an improved fuel injection system of the electromagnetically metering type capable of metering fuel with high precision. According to the present invention, the stabilizing chamber provided in the fluid passage leading from the fuel outlet port of the solenoid operated valve to the fuel suction port of the fuel injection pump is selected to have a suitable volume lying within a predetermined range so that the solenoid operated valve can meter the fuel over a period of time which is more than the period of time in which the fuel suction port is in its open position in one complete operating cycle of the fuel injection pump. By virtue of the above arrangement, the solenoid operated valve can meter the fuel over a period of time which is substantially equal to the period of time occupied by one complete operating cycle of the fuel injection pump, and the metering period of time can be substantially extended to 0.0083 second when, for example, the shaft driving the pump is rotating at its maximum speed of 1,800 r.p.m.

The above and other objects, features and advantages of the present invention will be apparent from the

following detailed description of a preferred embodiment thereof taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic front elevational view partly in section of an embodiment of the present invention.

FIG. 2 is a chart illustrating the operation of the fuel injection pump in the system according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 1, a fuel feed pump 2 draws fuel from a fuel reservoir 1 to supply same to a fuel injection pump 7 through an electromagnetically or solenoid operated valve 4. A pressure regulator 3 is connected between the outlet of the fuel feed pump 2 and the fuel reservoir 1. The solenoid operated valve 4 comprises a needle valve member 4*a* of magnetic material, an energizing coil or solenoid 4*b*, a spring 4*c* normally urging the needle valve member 4*a* against the valve seat, a fuel outlet port 6*a* and a fuel inlet port 6*b*. An electrical control means 5 generates a timing pulse of a duration corresponding to the quantity of the fuel required by a diesel engine so as to apply this timing pulse to the solenoid 4*b* of the solenoid operated valve 4. The fuel injection pump 7 comprises a pump cylinder 11, a pump plunger 10 slidably received in the pump cylinder 11, a fuel suction port 9 bored in the wall of the pump cylinder 11, and a pump chamber 12 defined within the pump cylinder 11 by the pump plunger 10. A stabilizing chamber 8 is formed in the fluid passage connecting the fuel outlet port 6*a* of the solenoid operated valve 4 to the fuel suction port 9 of the fuel injection pump 7. A cam follower 14 carried by a rod connected to the pump plunger 10 engages the cam surface of a cam 13 which is rotated in interlocking relation with the drive shaft of the diesel engine. A delivery valve 15 is connected to a fuel injection nozzle 17 by a high pressure conduit 16.

In operation, the pressure of fuel discharged from the fuel feed pump 2 is maintained at a constant value of about 2 kilograms per square centimeter by the pressure regulator 3. In response to the application of the timing pulse from the electrical control means 5 to the solenoid 4*b* of the solenoid operated valve 4, the needle valve member 4*a* is urged away from the valve seat against the force of the spring 4*c* so that the solenoid operated valve 4 is urged to the open position and kept in such a position for a period of time which is determined depending on the duration of the timing pulse. Thus, during this period of time, a metered quantity of fuel is discharged through the fuel outlet port 6*a*. The rotation of the cam 13 in interlocking relation with the drive shaft of the diesel engine causes reciprocating movement of the cam follower 14, and this reciprocating movement is transmitted to the pump plunger 10 which makes reciprocating movement within the pump cylinder 11 to carry out the pumping action. The fuel outlet port 6*a* of the solenoid operated valve 4 communicates now with the fuel suction port 9 of the fuel injection pump 7 through the stabilizing chamber 8. Due to the reciprocating movement of the pump plunger 10 relative to the pump cylinder 11, the fuel suction port 9 communicates with the pump chamber 12 for a period of time which ranges from the time at the end of the suction stroke of the pump plunger 10 to the time immediately before the subsequent delivery stroke of the pump plunger 10 takes place in the operating cycle of the fuel injection pump 7, and the fuel metered by the solenoid operated valve 4 flows into the pump chamber 12. The number of operating cycles of the solenoid operated valve 4 is selected to be equal to the number of operating cycles of the fuel injection pump 7 so that the quantity of fuel supplied to the fuel injection pump 7 in each operating cycle is approximately equal to the quantity of fuel passed through the fuel outlet port 6a of the solenoid operated valve 4 each time it is energized. This fuel is forced through the delivery valve 15 and the high pressure conduit 16 to be injected by the fuel injection nozzle 17 during the delivery stroke of the pump plunger 10.

If the fuel outlet port 6*a* of the solenoid operated valve 4 is disposed in close proximity to the fuel suction port 9 of the fuel injection pump 7 and thus the fluid passage connecting therebetween has a sufficiently small volume, the period of time during which the fuel is supplied into the pump chamber 12 of the fuel injection pump 7 due to the open position of the solenoid operated valve 4 is naturally limited to the period of time during which the fuel suction port 9 communicates with the pump chamber 12. However, due to the fact that the stabilizing chamber 8 is provided in the fluid passage leading from the fuel outlet port 6*a* of the solenoid operated valve 4 to the fuel suction port 9 of the fuel injection pump 7 and the total volume of the fluid passage including the stabilizing volume chamber 8 is selected to be larger than a predetermined value as seen in FIG. 1, a space is produced in a portion of the stabilizing chamber 8 for receiving therein the quantity of fuel to be metered by the subsequent operation of the solenoid operated valve 4. Thus, this quantity of fuel metered by the solenoid operated valve 4 can pass through the fuel outlet port 6a into this space irrespective of whether or not the fuel suction port 9 of the fuel injection pump 7 communicates with the pump chamber 12. This quantity of fuel is delivered to the fuel injection nozzle 17 in the subsequent delivery stroke of the pump plunger 10 of the fuel injection pump 7.

The stabilizing volume chamber 8 may have a largest possible volume as far as the supply of the fuel metered by the solenoid operated valve 4 into the fuel injection pump 7 is concerned, but there is a minimum stabilizing which is determined by various factors including the period of time in which the solenoid operated valve 4 is kept open, the maximum discharge capacity of the fuel injection pump 7, the period of time in which the solenoid operated valve 4 is in its open position and the fuel suction port 9 of the fuel injection pump 7 communicates with the pump chamber 12, and the quantity of fuel metered by the solenoid operated valve 4.

FIG. 2 shows the results of measurement on the fuel injection pump 7 which is adapted for distributing fuel to four cylinders of a diesel engine and in which the volume of the pump chamber varies by $Vb = 120\ mm^3$ in each operating cycle for supplying fuel to one cylinder. In FIG. 2, the horizontal axis represents the number of revolutions N per minute of the shaft driving the pump, the vertical axis represents the quantity of delivery Q mm^3/stcy per cylinder in each operating cycle, and the period of time T during which fuel is metered by the solenoid operated valve 4 is taken as a parameter. The solid lines in FIG. 2 represent the operating character-

istics when the stabilizing chamber **8** has a volume Va = 150 mm^3, while the broken lines represent similar characteristics when the fuel outlet port **6***a* of the solenoid operated valve **4** is disposed in close proximity to the fuel suction port **9** of the fuel injection pump **7** so that the stabilizing chamber **8** has an extremely small volume Va = 20 mm^3. It will be apparent from FIG. 2 that, when the volume Va of the stabilizing chamber **8** is Va = 150 mm^3 and the metering period of time T of the solenoid operated valve **4** lies within the range of T = 7 msec, the quantity of delivery Q is independent of the number of revolutions N of the drive shaft of the fuel injection pump and is determined primarily by the duration of the timing pulse applied to the solenoid **4***b* of the solenoid operated valve **4**, and the metering can be reliably attained up to the number of revolutions N = 1,800 r.p.m. However, with the volume Va = 20 mm^3 of the stabilizing chamber **8**, the quantity of delivery Q is abruptly decreased with the increase in the number of revolutions N beyond N = 1,000 r.p.m. in the case of the metering period of time T = 7 msec and thus reliable metering of fuel cannot be attained.

Therefore, as far as the metering of fuel is concerned, the volume Va of the stabilizing chamber **8** should be so selected as to satisfy the relation $Va \geqq \epsilon Vb$ where ϵ is a constant which lies in the range of 0.1 to 1 and Vb is the variation in the volume of the pump chamber **12** of the fuel injection pump **7** in each operating cycle. The metering of fuel by the solenoid operated valve **4** can be reliably carried out when Va is selected to satisfy the above relation. However, the provision of the stabilizing chamber **8** adversely affects the transient response of the fuel injection pump **7** and this transient response becomes worse with the increase in the volume Va of the stabilizing chamber **8**.

The lag of the variation in the quantity of fuel delivered from the fuel injection pump **7** relative to the variation in the quantity of fuel metered by the solenoid operated valve **4** may be considered as a first order lag. The rate of variation v in the volume per second is given by $v = N/60 \cdot M \cdot Vb$ where Vb is the variation in the volume of the pump chamber **12** in one operating cycle of the fuel injection pump **7**, N is the number of revolutions per minute of the shaft driving the pump, and M is the number of operating cycles of the fuel injection pump **7** during one rotation of the drive shaft. In this case, the time constant Td of the first order lag is given by $Td = Va/v = 60/N \cdot Va/MVb$.

Hunting in the rotational speed of the diesel engine equipped with the fuel injection pump **7** having such operating characteristics is closely associated with factors such as the coefficient of inertia of the engine and the operating conditions of the engine, but no problem of hunting arises when the volume Va of the stabilizing chamber **8** has an experimentally determined approximate value satisfying the relation $Va \leqq \eta MVb$ where η is a constant which lies in the range of 1 to 5.

From the above discussion, the practically preferred value of the volume Va of the stabilizing chamber **8** should lie in the following range:

$$0.1\ Vb \leqq Va \leqq 5\ MVb \quad (1)$$

When the volume Va of the stabilizing chamber **8** is selected to be a suitable value lying within the range satisfying the relation (1) above described, the fuel can be metered by the solenoid operated valve **4** even when the fuel suction port **9** of the fuel injection pump **7** is closed by the reciprocating pump plunger **10** and thus the metering period of time of the solenoid operated valve **4** can be extended to a value which is substantially equal to the total period of time occupied by one operating cycle of the fuel injection pump **7**. Further, the diesel engine equipped with this fuel injection pump **7** is quite free from undesirable hunting.

It will be understood from the foregoing description that, in the system according to the present invention, the volume Va of the fluid passage leading from the fuel outlet port of the solenoid operated valve open and closed by the needle valve member to the fuel suction port of the fuel injection pump is selected to lie within the range satisfying the relation $0.1\ Vb \leqq Va \leqq 5$ MVB, where Vb is the variation in the volume of the pump chamber during one operating cycle of the fuel injection pump and M is the number of operating cycles of the fuel injection pump during one rotation of the drive shaft of the diesel engine. By virtue of the above arrangement, the solenoid operated valve can meter the fuel for a period of time which is more than that during which the fuel suction port of the fuel injection pump is kept open due to the suction stroke of the pump plunger. That is to say, the solenoid operated valve can meter the fuel even in the period in which the fuel suction port of the fuel injection pump is closed due to the delivery stroke of the pump plunger, and thus the metering period of time can be substantially extended to the period of time occupied by one complete operating cycle of the fuel injection pump. The present invention is therefore advantageous in that fuel can be metered with high precision and no hunting occurs in the diesel engine equipped with the fuel injection pump.

We claim:

1. A system for injecting a metered quantity of fuel into an engine having a crankshaft comprising:

a cam shaft rotated at a constant speed reduction ratio by said engine crankshaft,

a fuel injection pump, including a cylinder, a piston reciprocated in said cylinder to deliver fuel and defining within said cylinder a pump chamber, said cylinder having a fuel suction port for receiving fuel which is opened by said piston during a fuel receiving cycle portion and closed by said piston during a fuel delivery cycle portion,

electromagnetically operated metering means having a fuel inlet port and a fuel outlet port,

electrical control means connected to said electromagnetically operated metering means for applying a timing signal having a time duration determining the amount of fuel injected during a cycle to said metering means to operate said metering means during said cycle portions, and

means defining a fluid passage connecting the fuel outlet port of said electromagnetically operated metering means to said fuel suction port of said fuel injection pump for receiving via said metering means during each said cycle a quantity of fuel as determined by said timing signal so that the fuel in said fluid passage passes via said fuel suction port into said pump chamber during each said fuel receiving cycle portion,

wherein the volume Va of said fluid passage is so selected as to lie within the range satisfying the rela-

tion 0.1 Vb ≦ Va ≦ 5 MVb, where Vb is the variation in the volume of the pump chamber during one operating cycle of said fuel injection pump and M is the number of operating cycles of said fuel injection pump during one rotation of the drive shaft, whereby the metering of fuel by said electromagnetically operated metering means is continued for a period of time which is more than that during which the fuel suction port of said fuel injection pump is kept open.

2. A system as claimed in claim **1**, in which said electromagnetically operated metering means is a solenoid operated valve having a needle valve member normally closing the fuel outlet port.

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