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Blizard et al.

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[54] **DOUBLE PULSING ELECTRONIC UNIT INJECTOR SOLENOID VALVE TO FILL TIMING CHAMBER BEFORE METERING CHAMBER**

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[73] Assignee: **Cummins Engine Company, Inc.**, Columbus, Ind.

[21] Appl. No.: **518,987**

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[51] **Int. Cl.**^{6} **F02M 37/04**

[52] **U.S. Cl.** **123/501**; 123/446

[58] **Field of Search** 123/446, 447, 123/500, 501, 357, 467

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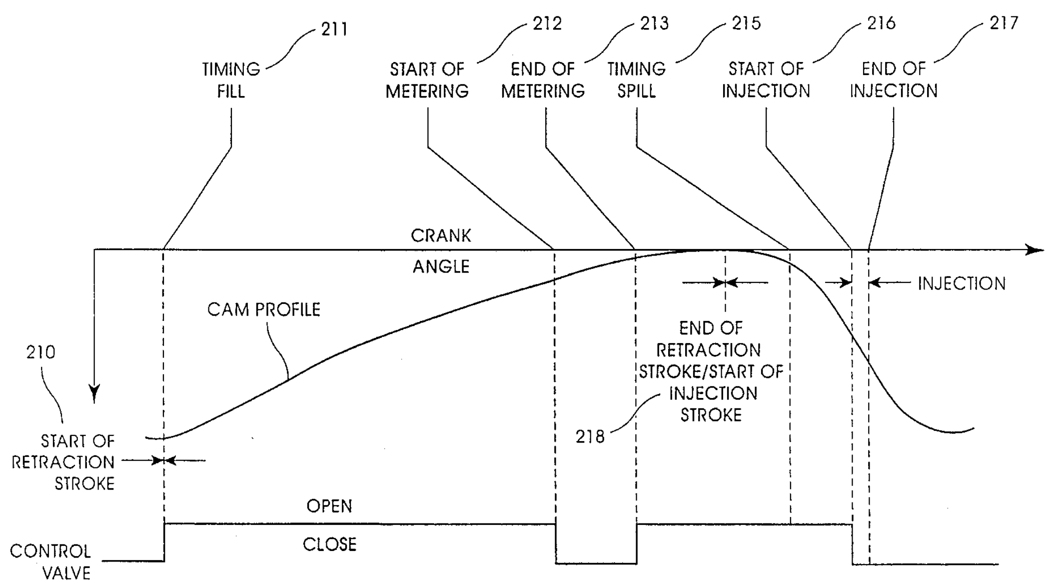
[57] **ABSTRACT**

An electronic fuel injector includes a metering chamber defined by a metering piston and the sides and bottom of a bore defined within the injector body, and a timing chamber defined by the metering piston, the bore sides and a timing plunger slidably disposed within the bore. A biasing spring is connected to opposing surfaces of the timing plunger and metering piston for biasing the metering piston away from the timing plunger. The metering chamber is in constant fuel communication with a pressurized fuel source and the timing chamber receives fuel from the fuel source according to the actuation of a solenoid actuated control valve disposed therebetween. A fueling strategy for such an injector requires actuating the control valve to substantially fill the timing chamber before filling the metering chamber, for subsequent injection into the engine, when the force of the biasing spring is at a minimum.

10 Claims, 4 Drawing Sheets



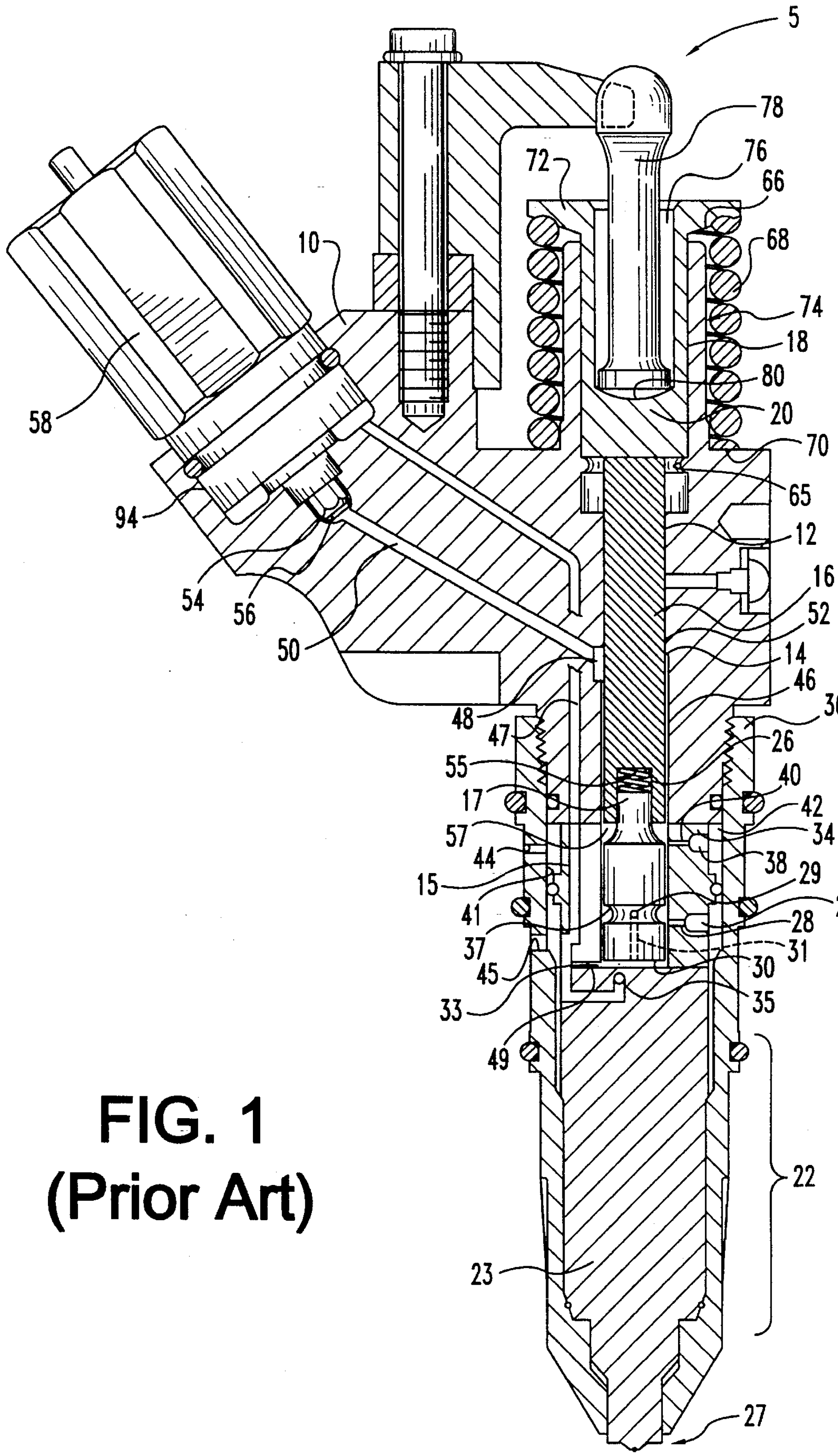


FIG. 1
(Prior Art)

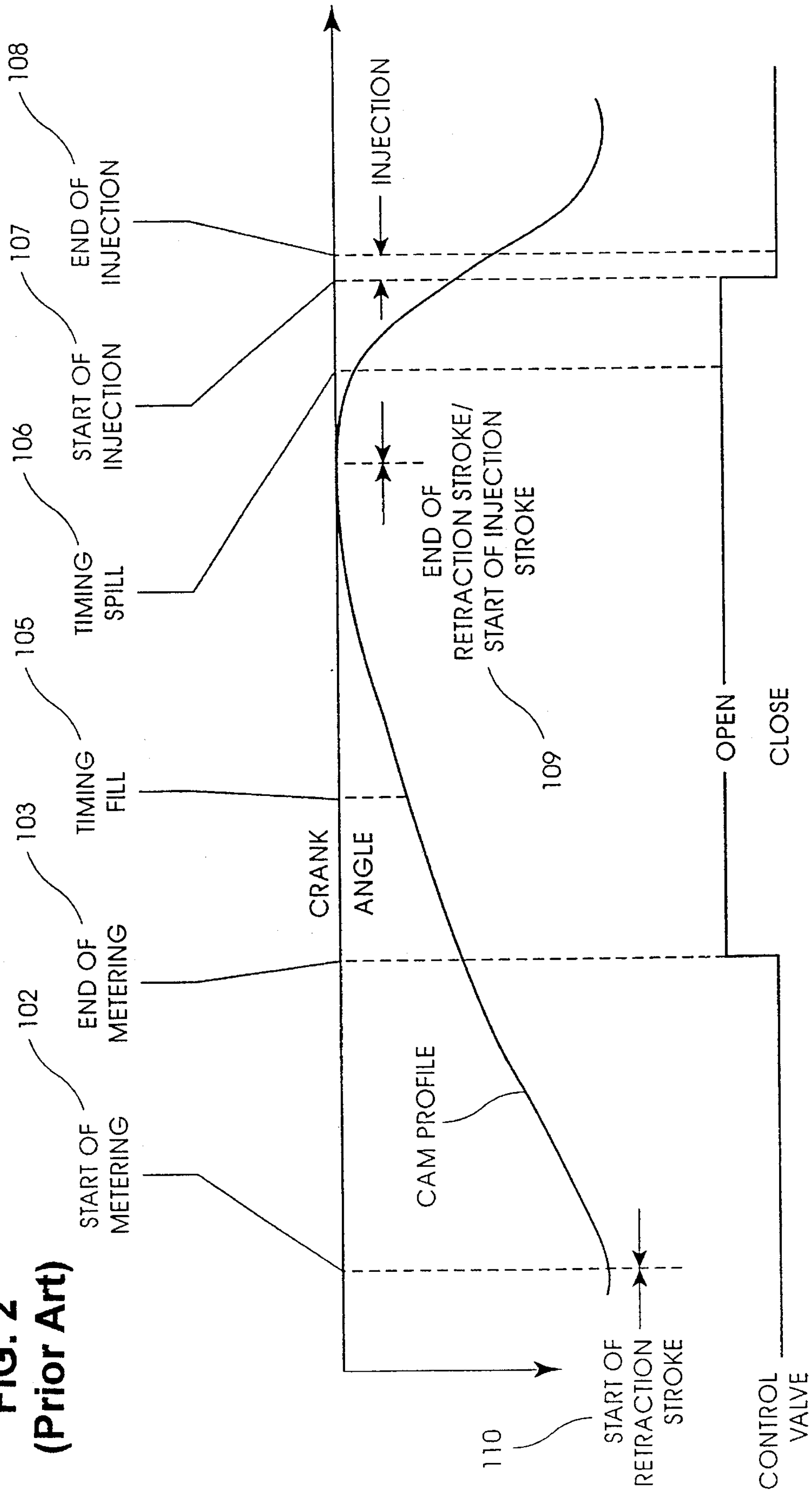


FIG. 2
(Prior Art)

FIG. 3

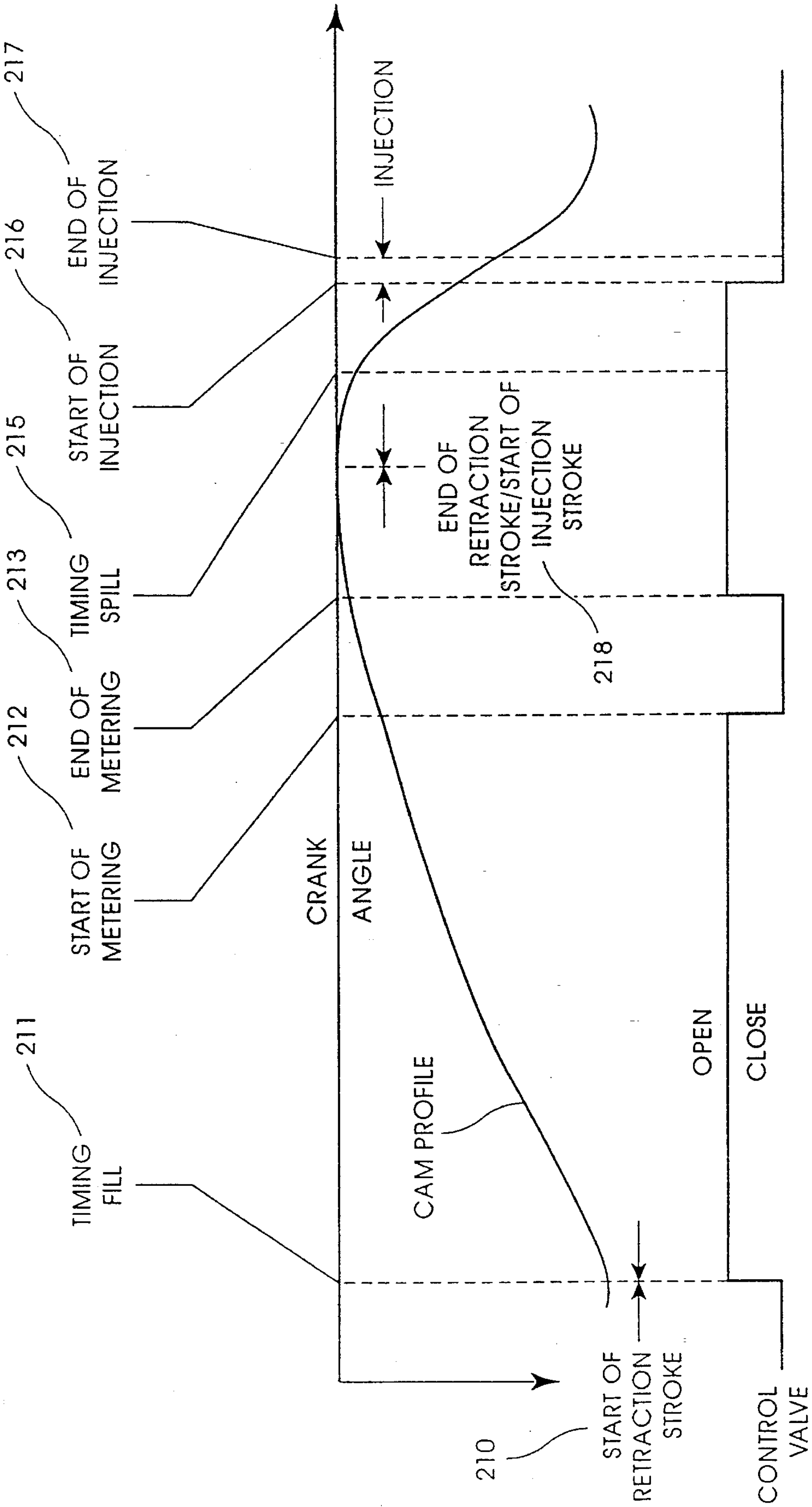
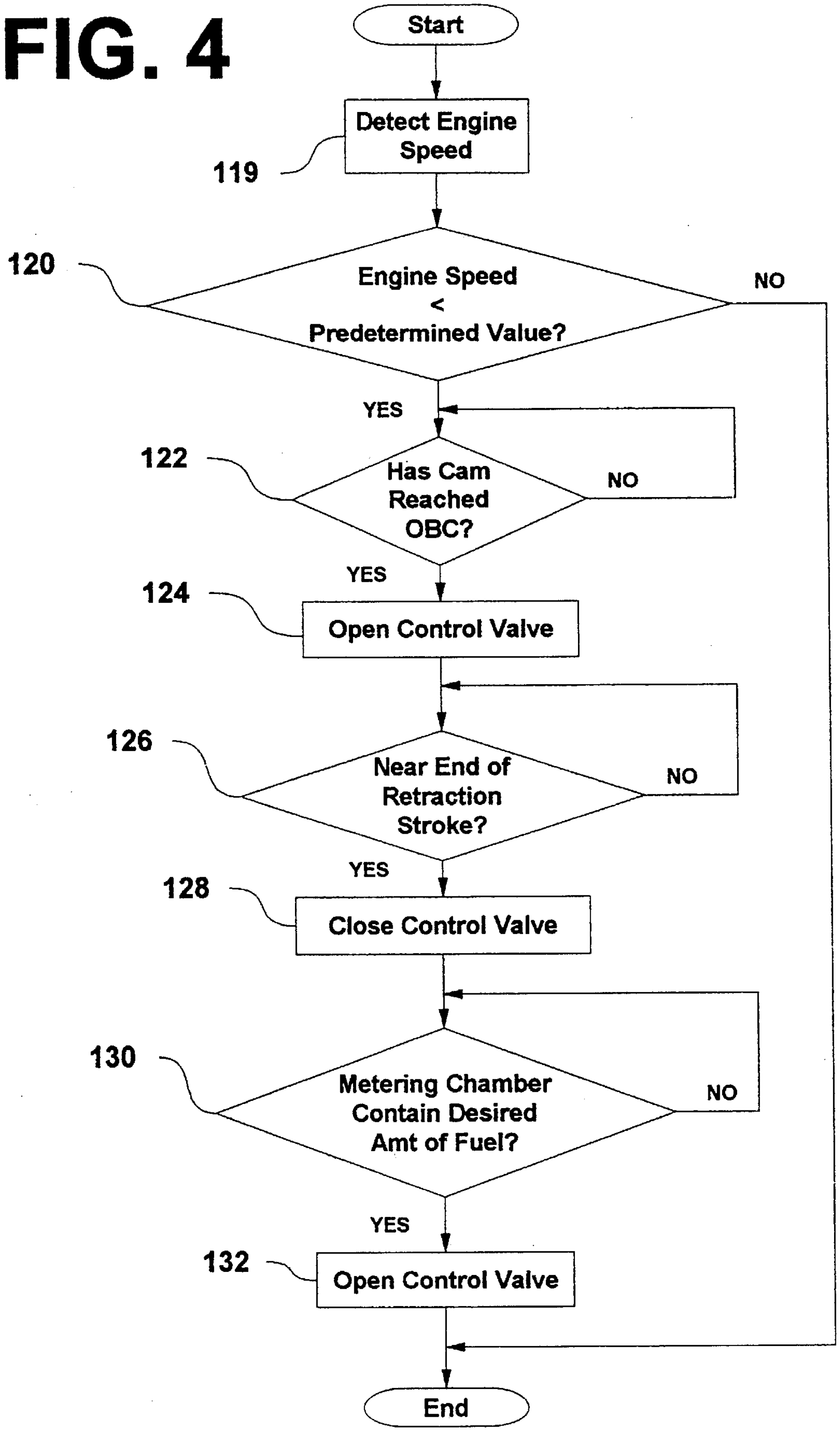

217
216
215
213
212
211
END OF INJECTION
START OF INJECTION
TIMING SPILL
END OF METERING
START OF METERING
TIMING FILL
INJECTION
END OF RETRACTION STROKE/START OF INJECTION STROKE
218
CRANK ANGLE
CAM PROFILE
OPEN
CLOSE
210
START OF RETRACTION STROKE
CONTROL VALVE

FIG. 4


Start
Detect Engine Speed
119
120
Engine Speed < Predetermined Value?
NO
YES
122
Has Cam Reached OBC?
NO
YES
124
Open Control Valve
126
Near End of Retraction Stroke?
NO
YES
128
Close Control Valve
130
Metering Chamber Contain Desired Amt of Fuel?
NO
YES
132
Open Control Valve
End

DOUBLE PULSING ELECTRONIC UNIT INJECTOR SOLENOID VALVE TO FILL TIMING CHAMBER BEFORE METERING CHAMBER

BACKGROUND OF THE INVENTION

This invention relates in general to fuel injectors for an internal combustion engine and more specifically to an electronic fuel injector in which the timing chamber is filled with fuel before filling the metering chamber.

Electronic fuel injectors are frequently used in today's internal combustion engines. The electronic fuel injector provides precise and reliable fuel delivery into the cylinder of compression ignition and spark ignition engines. The precision and reliability of the electronic fuel injector has contributed to the goals of fuel efficiency, maximum practicable power output and control of undesired products of combustion. These and other benefits of electronic fuel injection systems are well-known and appropriately used to beneficial effect and the design of modern internal combustion engines.

In recent years, electronically controlled fuel injectors have found applications in the heavy duty engine market and, more particularly, the diesel engine market. An example of a system utilizing electronic fuel injectors is the CELECT Engine Control System manufactured by Cummins Engine of Columbus, Indiana and available with their N-14 engine, as well as other engine models. In this system, an electronic fuel injector, such as the injector **5** shown in FIG. **1** for example, is used to implement various CELECT fueling strategies. As is known in the art, the injector body **10** is connected to a nozzle assembly **22** via a nozzle retainer **36**. A timing chamber **26** is defined by a portion of the central cylindrical bore **14**, the lower exposed surface of the timing plunger **16** and the upper exposed face of the metering piston **17**. A metering barrel **34** is located between the interior portions of the injector body **10** and nozzle assembly **22**. A metering chamber **33** is defined by a cylindrical bore **15** of the metering barrel **34**, the lower exposed surface of the metering plunger **17** and the upper exposed surface of a nozzle spacer **23**. The timing plunger **16** protrudes into the base of a central cylindrical bore **18** but is not mechanically coupled to the coupling member **20**. The coupling member **20** abuts the timing plunger **16** such that only a compressive load may be transferred from the coupling member **20** to the timing plunger **16**.

The coupling member **20** is equipped with an annular stop **65**, located at the bottom end of the coupling member **20**. The stop **65** limits the translation of the coupling member **20** in the direction of the injection stroke. Extending further radially outward on a flange **72** of the coupling member **20** is a spring seat **66**, through which a return spring **68** acts upon the coupling member **20** biasing it upward in the direction of the retraction stroke. The opposite end of the return spring **68** acts upon a spring seat **70**, located on the injector body **10** at the base of a collar **74**.

At the exposed end of the coupling member **20**, pocket **76** and a bearing surface **80** are formed, upon which a link **78** acts to force coupling member **20** against the force created by the return spring **68** during the injection stroke. The link **78** is typically in direct or indirect contact with the injection train cam shaft (not shown) and reciprocates along the central axis of injector assembly **5** in response to the angular rotation of the actuating cam (not shown). Thus, rotational motion of the cam shaft is converted into reciprocal motion of the injector assembly **5** axial components so as to provide force useful in pressurizing the timing chamber **26** and, ultimately, the metering chamber **33**.

The fuel inlet port **45** is in communication with two separate fuel inlet branches. The first branch communicates the port **45** to the metering chamber **33** through a metering inlet **49** and check valve **35**. The second branch communicates the port **45** to a control chamber **54**, and ultimately the timing chamber **26**, through a control inlet passage **47**. Fuel flow from the control chamber **54** to the timing chamber **26** is accomplished by allowing the fuel to flow through the control valve **56**, a control passage **50**, a plunger chamber control orifice **48**, and a plunger chamber passage **46** formed by an annular gap between the timing plunger **16** and the central cylindrical bore **14**.

The basic operation of the injector is well-known in the art. A predetermined quantity of fuel is metered into injector assembly **5** during a retraction stroke and injected into the engine during an injection stroke. Fuel metering is controlled by the movement of the timing plunger **16**, the metering piston **17**, and the opening of a control valve **56** of the control solenoid **58**. At the start of the retraction stroke (as shown in FIG. **1**), the timing plunger **16** is substantially bottomed against the metering piston **17**, the metering piston **17** is bottomed against the nozzle spacer **23** and the control valve **56** is closed.

As the fuel enters the injector body **10**, fuel at rail pressure of 150 psi passes through the inlet passage **49** and opens the check valve **35** and enters the then very small volume of the metering chamber **33**. The pressure of the fuel acting on the bottom of the metering piston **17** within metering chamber **33** forces metering piston **17** upward, thus creating additional pressure in timing chamber **26**. As the cam profile allows the link **78** and the coupling member **20** to move upward under the urging of the spring **68** the pressure in timing plunger chamber **26** acts on the bottom surface area of timing plunger **16** thereby causing both the timing plunger **16** and metering piston **17** to independently move upward, with timing plunger **16** maintaining contact with coupling member **20**. Fuel continues to flow through the check valve **35** into the expanding volume of metering chamber **33** as long as the control valve **56** is closed, which prevents fuel flow through the passage **50**, the orifice **48** and the passage **46** into the collapsed timing chamber **26**. When the control solenoid **58** is actuated by well-known means, the control valve **56** is commanded open and the metering of fuel into metering plunger chamber **33** ceases. This is accomplished by supplying fuel, also at rail pressure of 150 psi, from the control chamber **54**, through the control valve **56**, the passage **50** and the orifice **48**, and the passage **46** into the timing chamber **26**, thereby causing equal pressures to exist in both the timing chamber **26** and the metering chamber **33**. Equal pressures acting on both ends of the metering piston **17** tends to stop its upward motion. Thus, a fixed and predetermined amount of fuel will remain in the metering chamber **33**.

A bias spring **55**, located within the timing chamber **26** and bearing against the opposing surfaces of the timing plunger **16** and the metering piston **17**, ensures that the metering piston **17** remains stationary and does not drift up as the timing chamber **26** fills with fuel thereby continuing to force the timing plunger **16** upward. At the beginning of the retraction stroke, when the timing plunger **16** is bottomed against the metering piston **17**, the spring **55** exerts a bias on these opposing surfaces of approximately 40 psi. As the timing chamber **26** fills with fuel, thereby causing the timing plunger **16** to move away from the metering piston **17**, the biasing force of spring **55** decreases linearly. When the timing plunger **16** is maximally displaced from the metering piston **17** at the end of the retraction stroke, the bias of spring **55** is approximately 20 psi. Thus, at the end of the retraction stroke, the bias of spring **55** reduces to approximately 50% of its bias value at the beginning of the retraction stroke. The spring **55** also exerts enough force on the check valve **35**, through the metering piston **17** and the hydraulic link created by the fuel located in the metering chamber **33**, to keep the check valve **35** seated, preventing any change in the volume of fuel contained in the metering chamber **33**. Thus, a precisely metered quantity of fuel is trapped in the metering chamber **33**. This fuel is the quantity of fuel that will be injected into the engine during the subsequent injection stroke. As the retraction stroke continues, the timing plunger **16** continues to rise and the timing plunger chamber **26** continues to be filled with fuel at rail pressure until the end of the retraction stroke.

Details of the injection stroke including timing spill **106**, start of injection **107** and end of injection **108**, are not germane to the present invention, although a complete explanation may be found in U.S. Pat. No. 5,067,464, issued Nov. 26, 1991 to Rix, et al. herein incorporated by reference.

Referring to FIG. **2**, a timing diagram of this well-known fuel strategy is shown. Under normal operation, the control valve **56** is closed at the beginning of the retraction stroke **110**, thereby inhibiting the passage of fuel to the timing chamber **26**. The fuel rail pressure of 150 psi is more than adequate to overcome the bias on spring **55** so that fuel enters the metering chamber **33** and displaces both the metering piston **17** and the timing plunger **16** away from the metering chamber **33**. This initiates the start of metering **102**. When a predetermined quantity of fuel has entered the metering chamber **33**, the control valve **56** opens and permits fuel, at rail pressure of 150 psi, to enter the timing chamber **26**. Since the pressure in the timing chamber **26** is now equal to the pressure in the metering chamber **33**, the upward motion of the metering piston **17** ceases, thereby trapping in the metering chamber **33**, the predetermined quantity of fuel to be injected into the engine during the injection stroke. This opening of the control valve **56** thus signals the end of metering **103**. As the injector assembly **5** continues through its retraction stroke, the timing plunger **16** is forced by incoming fuel to continue moving away from the metering chamber **33**. This portion of the retraction stroke is known as timing fill **105**. At the end of the retraction stroke **106**, the metering chamber **33** holds a predetermined amount of fuel to be injected into the engine and the timing chamber **26** holds a quantity of fuel defined by the top of the metering piston **17** and the bottom of the timing plunger **16**.

A problem with the CELECT fuel system is known to occur during cranking at start up and at low rpm operation. When the N-14 engine operates at less than 1000 rpm, the fuel pressure may be less than 40 psi due to internal leakage. This may be inadequate to overcome the bias of spring **55** at the beginning of the retraction stroke and could therefore result in inadequate fueling during start up and operation below 1000 rpm. To address this problem, the N-14 uses a large fuel pump (1.25" PTG-based) and the CELECT strategy calls for full fueling (350 mm^3/stroke). However, this strategy results in uncontrolled smoke and emissions during start up. Preliminary estimates indicate that this uncontrolled start up mode accounts for approximately 12% of particulate emissions as measured on the EPA cycle. Moreover, estimates of fueling required for N-14 start up are in the range of 100 mm^3/stroke. Thus the actual fueling strategy overfuels the engine during cranking and start up and at engine speeds of less than 1000 rpm.

If metering could occur later during the retraction stroke, when the load on bias spring **55** is near 20 psi, controlled volumetric metering of fuel into metering chamber **33** could be accomplished. Such a fueling strategy would result in better smoke and particulate control during start up, since a precise quantity of fuel could be metered during the retraction stroke. Moreover, a smaller gear pump (0.75–1.00" PTG-based) may be adequate to supply fuel through the full operating range. A smaller and thus lower cost pump would be desirable if it could meet the cranking flow requirements. Finally, late metering may be advantageous in that it reduces the control delay between commanded fueling and combustion, thereby enabling a more precise control over speed, torque, emissions and smoke.

SUMMARY OF THE INVENTION

The present invention contemplates an injector fueling system where, under certain prescribed conditions, fuel metering occurs late in the retraction stroke. In accordance with the invention, the injector is of the type having a bore formed in the injector body, and a timing plunger and metering piston slidably disposed therein. A timing chamber is defined in the bore between the timing plunger and metering piston. A metering chamber is further defined in the bore below the metering piston. A spring is connected between the timing plunger and the metering piston for biasing the metering piston away from the timing plunger. The biasing force of the spring increases as the metering piston moves toward the timing plunger and decreases as the metering piston moves away from the timing plunger. A passage is formed in the injector body for providing continuous fuel communication to the metering chamber from the fuel source and a control valve is provided for either permitting or inhibiting the passage of fuel into the timing chamber.

At the beginning of the retraction stroke, the metering piston is essentially bottomed in the metering chamber and the timing plunger is essentially bottomed against the metering piston. Thus, both the metering chamber and the timing chamber have minimum volumes at the beginning of the retraction stroke.

According to one aspect of the present invention, the control valve is commanded open coincident with the start of the retraction stroke, and since fuel entering the timing chamber is at the same pressure as the fuel source, the metering piston stays bottomed in the metering chamber and no fuel enters the metering chamber. Instead, fuel enters the timing chamber causing the timing plunger to rise in the bore thereby decreasing the force of the biasing spring. As the injector nears the end of its retraction stroke, the control valve is commanded close. Since the timing chamber is now isolated from the pressure of the fuel source, the pressure of fuel against the bottom of the metering piston causes the piston to move upward, thereby permitting a predetermined quantity of fuel to be metered into the metering chamber. Since the timing plunger has been displaced away from the metering piston for most of the retraction stroke by the filling of the timing chamber, tile spring bias near the end of the retraction stroke should be decreased by approximately 50%. Lower fuel pressure is thus able to move the metering piston and thereby fill the metering chamber with the predetermined quantity of fuel needed for low rpm operation.

Another object of he present invention is to provide a method of metering a predetermined quantity of fuel into such a fuel injector for subsequent injection into an internal combustion engine. Tile method comprises the steps of: (a) determining the engine rpm; (b) performing the steps (c)–(f) so long as said engine rpm is less than a predetermined value; (c) determining the beginning of the retraction stroke; (d) enabling the control means to deliver pressurized fuel to the timing chamber at the beginning of the retraction stroke; (e) disabling the control means from delivering pressurized fuel to the timing chamber near the end of the retraction stroke thereby enabling fuel to enter the metering chamber; and (f) enabling the control means to deliver pressurized fuel to the timing chamber after a predetermined value of fuel has been metered into the metering chamber.

These and other objects of the present invention will become more apparent from the following description of the preferred embodiment.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a cross-sectional view of an electronic fuel injector of known design for which the fueling strategy of the present invention is adapted to actuate.

FIG. **2** is a timing diagram showing a known fuel strategy used with the electronic fuel injector of FIG. **1**.

FIG. **3** is a timing diagram showing the fueling strategy of the present invention to be used with the electronic fuel injector of FIG. **1**.

FIG. **4** is a flow chart showing the sequence of the steps to be performed in fueling the electronic fuel injector of FIG. **1** according to the timing diagram of FIG. **3**.

DESCRIPTION OF THE PREFERRED EMBODIMENT

For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the embodiment illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended, such alterations and further modifications in the illustrated device, and such further applications of the principles of the invention as illustrated therein being contemplated as would normally occur to one skilled in the art to which the invention relates.

The present invention, in the preferred embodiment, contemplates a new fueling strategy for an electronic fuel injector of the type shown in FIG. **1**. However, it is understood that other fuel injectors experiencing the problem addressed by the present invention, as discussed in the background of the invention, are contemplated for use with the fueling strategy of this invention.

In accordance with the preferred embodiment of the invention, a fueling strategy for the retraction stroke of an electronic fuel injector is provided, as shown in FIGS. **3** and **4**. Referring to the structural components of FIG. **1** and the timing components of FIG. **3**, the control valve **56** is commanded open at the beginning of the retraction stroke **210**. Since the fuel entering the timing chamber **26** is at the same pressure as the fuel in inlet passage **49**, the metering piston **17** stays bottomed in the metering chamber **33** and no fuel enters the metering chamber **33**. Instead, fuel enters the timing chamber **26**, initiating the timing fill **211** portion of the retraction stroke. Since the timing plunger **16** is not mechanically connected to coupling member **20**, low pressure fuel will cause the timing plunger **16** to maintain contact with coupling member **20** as it retracts from the bore **18** under the pressure of the return spring **68**. The upward motion of timing plunger **16** is further assisted by the bias of spring **55**. In the preferred embodiment, the bias of spring **55** at the beginning of the retraction stroke is approximately 40 psi.

As the injector nears the end of its retraction stroke, the control valve **56** is commanded closed thereby initiating the start of metering **212**. Since no fuel can enter the timing chamber **26**, the pressure of fuel against the bottom of the metering piston **17** through the inlet passage **49** causes the piston **17** to keep the timing plunger **16** in contact with the retracting coupling member **20**, thereby permitting a predetermined quantity of fuel to be metered into a metering chamber **33** only if the fuel pressure is high enough to overcome the bias on spring **55**. However, because of the timing chamber **26** has been filling since the beginning of the retraction stroke, and because no fuel has yet entered the metering chamber **33**, the bias on spring **55** near the end of the retraction stroke should be substantially reduced. In the preferred embodiment, the bias on spring **55** at the end of the retraction stroke, when the timing plunger **16** is maximally displaced from the metering piston **17**, is approximately 20 psi. Thus, the present invention contemplates that the bias on spring **55** will be reduced, at the end of the retraction stroke, to approximately 50% of its biasing force at the beginning of the retraction stroke. This fueling strategy thus requires lower fuel pressure to fill the metering chamber **33** than the fuel pressure required by the conventional fueling strategy. Since the fuel pressure at startup and low rpm operation is adequate to overcome the reduced spring bias, overfueling of the metering chamber **33** is no longer necessary to guarantee start up and low rpm engine operation. Thus, the fueling strategy of the present invention permits the metering chamber **33** to be filled with a more precise quantity of fuel needed for start up and low rpm operation. In the preferred embodiment, this quantity is 100 mm^3/stroke, but quantities in the range of 5–350 mm^3/stroke are contemplated. At or near the end of the retraction stroke, the control valve **56** is commanded open, thereby causing the end of metering **213** in the same manner as discussed in the background of the invention.

The timing spill **215**, start of injection **216** and end of injection **217** remain unchanged from the fueling strategy shown in FIG. **2**.

Referring now to FIGS. **3** and **4** (and to FIG. **1** for the structural components), a flow chart of the algorithm for implementing the fueling strategy of the present invention during the retraction stroke of an electronic fuel injector, such as the injector shown in FIG. **1**, is shown. At step **119**, the engine speed is determined using known techniques. At step **120**, the engine speed is tested. If the engine speed is below a predetermined value, the fueling strategy of the present invention is executed. In the preferred embodiment this predetermined level is 100 rpm, but the invention contemplates predetermined levels in the range of 50–150 rpm. If the engine speed is at or above the predetermined level, the algorithm of FIG. **4** is bypassed.

At step **122**, the algorithm determines the beginning of the retraction stroke **210** from the cam position using known techniques. When the retraction stroke begins, control valve **56** is commanded open at step **124**, thereby enabling delivery of fuel to the timing chamber **26** and commencing timing fill **211**. At step **126**, the algorithm tests whether enough time has elapsed within the retraction stroke to commence the start of metering **212**. The time length of the retraction stroke at any given engine speed may be determined using known methods. Thus, the only constraint on the start of metering **212** is that sufficient time must be allowed within the remaining retraction stroke to meter the desired quantity of fuel into the metering chamber **33**. At the desired point near the end of the retraction stroke **218**, the algorithm, at step **128**, commands the control valve **56** closed thereby enabling fuel to enter the metering chamber **33** and commencing the start of metering **212**. At step **130**, the algorithm tests whether enough time has elapsed within the metering phase of the retraction stroke to fill the metering chamber **33** with the desired volume of fuel. If not, the metering chamber **33** continues to fill with fuel. When the metering chamber **33** contains the desired volume of fuel, the algorithm, at step **132**, commands the control valve **56** open thereby establishing the end of metering **213**. For the remainder of the retraction stroke, the timing chamber **26** continues to fill with fuel. Thus, in one embodiment, the end of metering **213** occurs before the end of the retraction stroke **218**. In another embodiment, the end of metering **213** occurs coincident with the end of the retraction stroke **218**, thereby delaying the metering of fuel into meteerin chamber **33** until the bias on spring **55** has decreased to its minimum value.

While the invention has been illustrated and described in detail in the drawings and foregoing description, the same is to be considered as illustrative and not restrictive in character, it being understood that only the preferred embodiment has been shown and described and that all changes and modifications that come within the spirit of the invention are desired to be protected.

What is claimed is:

1. A fuel injector having an injection stroke and a retraction stroke for use in an internal combustion engine, said injector comprising:

an injector body having a bore formed therein;

a timing plunger disposed at a first location within said bore, said timing plunger being freely slidable within said bore during the retraction stroke;

a metering piston slidably disposed at a second location within said bore;

a timing chamber defined in said bore between said timing plunger and said metering piston;

means for biasing said metering piston away from said timing plunger with a variable force;

a metering chamber defined in said bore below said metering piston, said metering chamber and said timing chamber having minimum volumes at the beginning of the retraction stroke, said volumes being increasable as said injector travels through the retraction stroke;

a passage formed in said injector body for providing continuous fuel communication to said metering chamber; and

control means for permitting and inhibiting the passage of fuel into said timing chamber,

wherein

said control means permits the passage of fuel into said timing chamber at the beginning of the retraction stroke thereby forcing said timing plunger away from said metering piston and decreasing said biasing force of said biasing means,

and further wherein

said control means inhibits the passage of fuel into said timing chamber near the end of the retraction stroke thereby forcing a predetermined quantity of fuel into said metering chamber and causing said metering piston to move toward said timing plunger,

whereby a predetermined quantity of fuel is metered into said metering chamber after said force of said biasing means has decreased, said predetermined quantity of fuel being thereafter injected into the engine during the subsequent injection stroke.

2. The fuel injector of claim **1**, wherein said control means permits the passage of fuel into said timing chamber after said predetermined quantity of fuel has been forced into said metering chamber, but before the end of the retraction stroke.

3. The fuel injector of claim **2**, wherein said biasing means has a first biasing force at the beginning of the retraction stroke, said biasing force decreasing to a second biasing force at the end of the retraction stroke.

4. The fuel injector of claim **3**, wherein said forcing of a predetermined quantity of fuel into said metering chamber occurs just prior to said biasing means attaining said second biasing force during the retraction stroke.

5. The fuel injector of claim **4**, wherein said means for biasing includes a spring disposed within said timing chamber, said spring being connected at one end to said timing plunger and at its opposite end to said metering piston.

6. The fuel injector of claim **5**, wherein said first biasing force is approximately 40 psi and said second biasing force is approximately 20 psi.

7. A method of metering a predetermined quantity of fuel into a fuel injector during the retraction stroke for subsequent injection into an internal combustion engine at low engine rpm, wherein the injector includes a metering chamber in continuous fluid communication with a pressurized fuel source, a timing chamber, and control means for controlling the delivery pressurized fuel to either the timing chamber or the metering chamber, the method comprising the steps of:

(a) determining the engine rpm;

(b) performing the steps (c)–(f) so long as said the engine rpm is less than a predetermined value;

(c) determining the beginning of the retraction stroke;

(d) enabling said control means to deliver pressurized fuel to said timing chamber at the beginning of the retraction stroke;

(e) disabling said control means from delivering pressurized fuel to said timing chamber near the end of the retraction stroke thereby enabling fuel to enter said metering chamber; and

(f) enabling said control means to deliver pressurized fuel to said timing chamber after a predetermined volume of fuel has been metered into said metering chamber.

8. The method of claim **7** wherein said predetermined engine rpm value is 1000 rpm.

9. The method of claim **8** including the step of determining the end of the retraction stroke, and wherein step (f) occurs coincident with the end of the retraction stroke.

10. The method of claim **8**, wherein said predetermined volume of fuel is approximately 100 cubic mm.

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