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(54) Fuel injection control system for a diesel engine.

(57) A plunger reciprocates axially in accordance with rotation of the engine crankshaft. A pressure chamber contracts as the plunger moves in one axial direction, and expands as the plunger moves in the opposite axial direction. Fuel can be drawn into the pressure chamber when the pressure chamber expands. Fuel can be forced out of the pressure chamber toward an engine combustion chamber when the pressure chamber contracts. A fuel return passage extends from the pressure chamber to a fuel tank. A valve controllably blocks and opens the fuel return passage.

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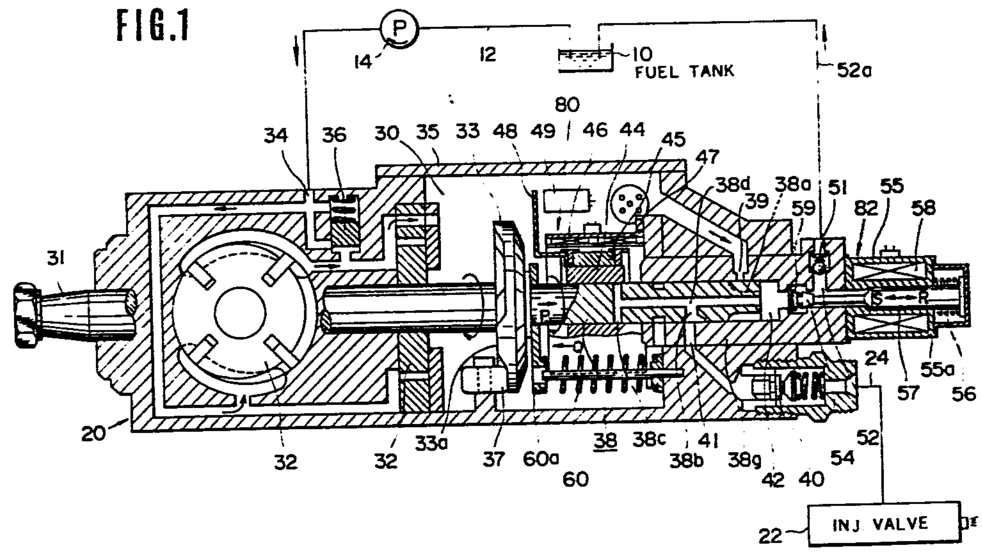
EP 0 101 966 A1

FIG.1



P
14
12
10
FUEL TANK
52a
80
34
36
30
35
33
48
49
46
44
45
47
38d
38a
39
51
55
59
82
58
31
20
32
32
33a
37
60a
60
38
38c
38b
41
38g
42
40
54
52
24
57
55a
56
22
INJ VALVE

FUEL INJECTION CONTROL SYSTEM FOR A DIESEL ENGINE

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to a fuel injection quantity and/or timing control system for a diesel engine.

Description of the Prior Art

Diesel internal combustion engines are supplied with fuel intermittently by means of fuel injection systems. To maintain optimal operation of the diesel engine under varying engine operating conditions, it is necessary to control the quantity and the timing of each fuel injection in response to the engine operating conditions, such as engine load and engine speed. Conventional devices to control the fuel injection timing and quantity are relatively intricate.

SUMMARY OF THE INVENTION

It is an object of this invention to provide a simple control system for diesel engine fuel injection timing and/or quantity.

In accordance with this invention, a fuel injection control system is applied to a diesel engine having a rotatable crankshaft and a combustion chamber. The fuel injection control system includes a fuel tank containing fuel. A suitable pump serves to drive fuel from the fuel tank to a pump chamber. A plunger is connected to the crankshaft to reciprocate axially in accordance with the rotation of the crankshaft. A pressure chamber contracts as the plunger moves in one axial direction, and expands as the plunger moves in the opposite axial direction. Fuel can be drawn from the pump chamber toward the pressure chamber when the plunger moves in the axial direction of expanding the pressure chamber. Fuel can be forced out of the pressure chamber toward the combustion chamber when the plunger moves in the direction of contracting the pressure chamber. A fuel return passage extends from the pressure chamber to the fuel tank. A valve controllably blocks and opens the fuel return passage.

The above and other objects, features and advantages of this invention will be apparent from the following description of preferred embodiments thereof, taken in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a diagrammic view of a fuel injection pump and associated peripheral devices of a fuel injection control system according to a first embodiment of this invention.

Fig. 2 is a block diagram of the electrical circuitry of the fuel injection control system according to the first embodiment.

Fig. 3 is a graph of the relationship between fuel injection advance angle θa and engine rotational speed N at a constant engine coolant temperature T.

Fig. 4 is a graph of the relationship between fuel injection advance angle θa and engine coolant temperature T at a constant engine rotational speed N.

Fig. 5 is a graph of the relationship between fuel injection quantity Q and engine rotational speed N at various degrees of accelerator pedal depression α, in which the arrow designates the direction of increase of the accelerator pedal depression degree α.

Fig. 6 is a block diagram of the electrical circuitry of a fuel injection control system according to a second embodiment of this invention.

Fig. 7 is a flowchart of a program which controls operation of the control unit in Fig. 6.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

With reference to Fig. 1, a fuel injection control system according to a first embodiment of this invention includes a distribution-type fuel injection pump 20, which is provided with a drive shaft 31 and a casing or housing 35 rotatably accommodating the drive shaft 31. The drive shaft 31 projecting from the housing 35 is coupled to the crankshaft of a diesel engine (not shown) in a known way so as to rotate at half the speed of rotation of the crankshaft. A fuel feed pump 32 is mechanically connected to the drive shaft 31 to be driven by rotation of the drive shaft 31. Note that the feed pump 32 is illustrated in two ways, one being normal and the other being rotated through 90° about the vertical. A cam disc 33 located within the housing 35 is mounted coaxially on the drive shaft 31 to rotate together with the drive shaft 31.

The housing 35 is formed with a fuel inlet 34 communicating via a suitable line 12 with a fuel tank 10 containing fuel. A pre-supply pump 14 is disposed along the line 12 to draw fuel from the fuel tank 10 and drive it toward the fuel inlet 34. The feed pump 32 serves to draw fuel through the inlet 34 and drive it into a pump chamber 30 defined within the housing 35. A pressure control valve 36 is provided to regulate the fuel pressure across the feed pump 32.

The mounting of the cam disc 33 on the drive shaft 31 includes a key engagement or connection designed to allow axial movement of the cam disc 33 relative to the drive shaft 31 while ensuring rotation of the cam disc 33 in conformity with the rotation of the drive shaft 31. One surface of the cam disc 33 is formed with cam protrusions 33a spaced at fixed angular intervals. The number of the cam protrusions 33a equals that of the combustion chambers of the engine. A roller 37 disposed within the pump chamber 30 is attached to the housing 35 in such a manner as to be rotatable about its axis. The roller 37 axially adjoinds the cam surface of the disc 33. A spring 60 disposed within the pump chamber 30 urges the cam disc 33 axially toward the roller 37 via a plate 60a so that the cam surface of the disc 33 is always in contact with the roller 37. The plate 60a is designed to allow free rotation of the cam disc 33. As the cam disc 33 rotates, the roller 37 also rotates about its axis while remaining in contact with the cam disc 33 due to the force of the spring 60. When the roller 37 relatively "ascends" the cam protrusions 33a as the cam disc 33 rotates, the cam disc 33 moves in the axial direction designated by the arrow P in Fig. 1. When the roller 37 relatively "descends" the cam protrusions 33a as the cam disc 33 rotates, the cam disc 33 moves in the opposite axial direction designated by the arrow Q in Fig. 1. In this way, as the drive shaft 31 rotates, the cam disc 33 rotates together therewith and also reciprocates axially.

A plunger 38 is coaxially secured to the cam disc 33, so that the plunger 38 rotates circumferentially and reciprocates axially as the drive shaft 31 rotates. A cylinder or barrel 38g attached to the housing 35 has an axial bore into which the plunger 38 movably extends. A fuel intake passage 39 formed in the walls of the housing 35 and the cylinder 38g extends from the pump chamber 30 to the circumferential inner surface of the barrel 38g. The end of the plunger 38 within the cylinder 38g is provided with axial grooves 38a circumferentially spaced at equal intervals. The number of the axial grooves 38a equals that of the combustion chambers of the engine. As the plunger 38 rotates, the axial grooves 38a move sequentially into and out of register with the intake passage 39. The adjacent ends of the plunger 38 and the cylinder 38g define a high pressure chamber 42, with which the axial grooves 38a communicate. As the plunger 38 moves axially toward and away from the pressure chamber 42, the pressure chamber 42 contracts and expands, respectively. While the plunger 38 moves in the axial direction of expanding the pressure chamber 42, the intake passage 39 is generally in communication with one of the axial grooves 38a so that fuel is drawn toward the pressure chamber 42 from the pump chamber 30 via the intake passage 39 and the axial groove 38a. This results in a fuel intake stroke. The movement of the plunger 38 in the direction of expanding the pressure chamber 42 is defined as expansion stroke.

The plunger 38 has an axial passage 38d, one end of which opens into the pressure chamber 42. The plunger 38 has a radially-extending fuel discharge passage 38b, the inner end of which opens into the axial passage 38d. The outer end of the discharge passage 38b opens onto the peripheral surface of the plunger 38 within the cylinder 38g. Fuel delivery passages 41 formed in the walls of the cylinder 38g and the housing 35 extend from the circumferential inner surface of the cylinder 38g to the outer surface of the housing 35. The number of the delivery passages 41 equals that of the combustion chambers of the engine. The ends of the delivery passages 41 in the cylinder 38g extend radially and are spaced circumferentially at equal angular intervals. As the plunger 38 rotates, the discharge passage 38b communicates with each of the delivery passages 41 sequentially. While the plunger 38 moves in the axial direction of contracting the pressure chamber 42, the discharge passage 38b is generally in communication with one of the delivery passages 41 so that fuel is forced out of the pressure chamber 42 toward the delivery passage 41 via the axial passage 38d and the discharge passage 38b. This results in a fuel injection stroke, since each of the delivery passage 41 leads to a fuel injection valve or nozzle 22 via a suitable line 24 so that fuel is driven along the delivery passage 41 and the associated line 24 to the fuel injection nozzle 22 before being injected therethrough into the combustion chamber of the engine associated with the fuel injection nozzle 22. It should be noted that communication between the intake passage 39 and the axial grooves 38a is blocked while the plunger 38 moves in the axial direction of contracting the pressure chamber 42. A check-type fuel delivery valve 40 is provided in each of the delivery passages 41 to prevent the fuel from flowing back toward the discharge passage 38b. The movement of the plunger 38 in the direction of contracting the pressure chamber 42 is defined as contraction stroke.

The plunger 38 has a diametrical spill port 38c opening onto the peripheral surface thereof located in the pump chamber 30. The axial passage 38d opens into the spill port 38c. A control sleeve 44 located in the pump chamber 30 is slidably, concentrically mounted on the plunger 38 to selectively close and open the spill port 38c as the plunger 38 reciprocates axially. As the plunger 38 moves through its contraction stroke, the spill port 38c is at first blocked by the control sleeve 44 and then is uncovered. Sealing the spill port 38c allows fuel to be forced out of the pressure chamber 42 toward the delivery passage 41, thereby enabling the fuel injection. When the spill port 38c is exposed by the control sleeve 44, fuel driven out of the pressure chamber 42 is allowed to return to the relatively low-pressure pump chamber 30 via the axial passage 38d and the spill port 38c so that fuel injection is interrupted or disabled. As a result, the axial position of the control sleeve 44 determines the timing of the end of each fuel injection stroke in terms of the rotational angle of the plunger 38, that is, the crank angle of the engine. In addition, the axial position of the control sleeve 44 determines the axial travel of the plunger 38 during which fuel injection is performed, and thus determines the quantity of fuel injected during each injection stroke.

The control sleeve 44 is made of a non-magnetic material. An annular magnet 45 concentrically, fixedly fits around the control sleeve 44. A hollow cylindrical actuator 80 located in the pump chamber 30 is fixed to the housing 35, and concentrically surrounds the magnet 45 with a predetermined annular gap left therebetween. The actuator 80 includes annular control windings 46 and 47 disposed coaxially and spaced axially from each other. The actuator 80 cooperates with the magnet 45 to adjust the axial position of the control sleeve 44 in response to control in the magnitude and/or polarity of electrical current passing through the control windings 46 and 47. An urging member, such as a spring or a diaphragm, may be provided between the control sleeve 44 and the cylinder 38g or the housing 35 to bias the control sleeve 44 axially. The combination of the actuator 80 and the magnet 45 is similar to that disclosed in U.S. Patent Application Serial No. 432,382, filed September 30, 1982, entitled "Fuel Injection Quantity Adjustment Apparatus for Fuel Injection Quantity", which is incorporated into the present invention on this point as well as other points described hereinafter in citing similarities.

A strip 48 made of magnetic material is attached to one pole of the magnet 45, so that the strip 48 moves together with the control sleeve 44. A displacement sensor 49 located in the pump chamber 30 adjacently opposes the strip 48 in the axial direction with respect to the control sleeve 44. The displacement sensor 49 including a magnetic-field responsive element cooperates with the strip 48 to sense the distance therebetween, that is, the axial position of the control sleeve 44. The displacement sensor 49 generates an electrical signal representative of the axial position of the control sleeve 44 which determines the quantity of fuel injected during each injection stroke. The combination of the strip 48 and the displacement sensor 49 is also similar to that disclosed in the previous U.S. Patent Application Serial No. 432,382.

A fuel return passage 52 formed in the walls of the cylinder 38g extends from the pressure chamber 42 to the outer surface of the cylinder 38g. The outer end of the return passage 52 leads to the fuel tank 10 via a suitable line 52a. A check valve 51 is provided in the return passage 52 to permit fuel flow only in the direction from the pressure chamber 42 to the fuel tank 10. An electrically-driven or solenoid poppet valve 82 is provided in the return passage 52 upstream of the check valve 51 to controllably block and open the return passage 52.

The poppet valve 82 includes a conical valve member 54 and an electrical actuator 55 for driving the valve member 54. The electrical actuator 55 is provided with a casing 55a, which accommodates a compression return spring 56, a solenoid plunger 57, and a control winding 58. The casing 55a is fixed to the cylinder 38g. The control winding 58 is supported by the casing 55a, and has a hollow cylindrical outline through which the solenoid plunger 57 movably extends. The return spring 56 is seated between the casing 55a and a flanged end of the solenoid plunger 57 to bias the plunger with respect to the casing 55a. The solenoid plunger 57 moves in response to electrical energization and de-energization of the control winding 58. The solenoid plunger 57 movably protrudes from the casing 55a into the return passage 52 through the wall of the cylinder 38g. The valve member 54 movably located in the return passage 52 is mounted on the free end of the solenoid plunger 57. The inner surface of the cylinder 38g defining the return passage 52 is provided with an inwardly-extending annular step opposing the conical surface of the valve member 54. This step forms a valve seat for the member 54. The inner surface of the cylinder 38g is formed with another inwardly-extending annular step seating one end of an auxiliary return spring 59. The other end of the return spring 59 engages the valve member 54 to urge the latter with respect to the cylinder 38g. While the control winding 58 is electrically de-energized, the solenoid plunger 57 and the valve member 54 are held by the force of the springs 56 and 59 in their normal positions in which the conical surface of the valve member 54 is in contact with the valve seat and thus the return passage 52 is blocked. This condition represents the closed state of the poppet valve 82. When the control winding 58 is electrically energized, the solenoid plunger 57 and the valve member 54 are displaced from their normal positions against the force of the springs 56 and 59 in the direction denoted by the arrow S in Fig. 1, thereby disconnecting the valve member 54 from the valve seat and allowing fuel flow through the return passage 52. This condition represents the open state of the poppet valve 82. When the control winding 58 is de-energized, the solenoid plunger 57 and the valve member 54 are returned by the force of the springs 56 and 59 to their normal positions in the direction denoted by the arrow R in Fig. 1.

In the case where the plunger 38 is moving through its contraction stroke and the spill port 38c remains blocked by the control sleeve 44, when the poppet valve 82 opens the return passage 52, fuel forced out of the pressure chamber 42 is mainly directed toward the fuel tank 10 via the return passage 52 so that fuel injection is disabled or interrupted. In the same case, when the poppet valve 82 blocks the return passage 52, fuel forced out of the pressure chamber 42 is all directed toward the selected fuel injection nozzle 22 via the passages 38d, 38b, and 41 so that fuel injection is effected. Thus, the change of the poppet valve 82 from the open to the closed state can determine the timing of start or commencement of each fuel injection.

Fig. 2 diagrammatically shows the electrical circuitry of the fuel injection control system, which includes an accelerator pedal position sensor 61, an engine speed sensor 62, an engine temperature sensor 63, a crank angle sensor 64, a fuel injection timing control circuit 65, and a fuel injection quantity control circuit 68.

The sensors 61 to 64 are conventional. The first sensor 61 is associated with an engine power controlling accelerator pedal (not shown) to detect the position of the accelerator pedal, that is, the degree of depression of the accelerator pedal. The first sensor 61 generates a signal 61S which varies as a function of the accelerator pedal depression degree α, which represents the engine load or the power required of the engine. The second sensor 62 is associated with the crankshaft or camshaft of the engine to detect the rotational speed of the engine. The second sensor 62 generates a signal 62S which varies as a function of the engine rotational speed N. The third sensor 63 has a temperature-responsive element exposed to coolant of the engine, in order to detect the temperature of the engine coolant. The third sensor 63 generates a signal 63S which varies as a function of the engine coolant temperature T. The fourth sensor 64 is associated with the crankshaft or camshaft of the engine to generate a signal 64S which indicates when the crankshaft passes one of a number of equally-spaced reference angular positions, that is, when the crank angle passes one of the equally-spaced reference points θc.

The timing control circuit 65 includes a fuel injection timing arithmetic circuit 66 and a fuel injection timing decision circuit 67. The arithmetic circuit 66 calculates a desired fuel injection advance angle θa on the basis of the accelerator pedal depression degree α, the engine rotational speed N, and/or the engine coolant temperature T derived from the signals 61S, 62S, and 63S, respectively. The arithmetic circuit 66 generates a signal 66S indicative of the advance angle θa. The signal 66S is conducted to the decision circuit 67. The decision circuit 67 calculates a desired fuel injection start or commencement timing td ($td=f_3(\theta a,N)$) on the basis of the engine rotational speed N and the advance angle θa derived from the signals 62S and 66S, respectively. The decision circuit 67 generates a signal 67S by reference to the desired timing td and the reference crank angle θc derived from the signal 64S. The signal 67S is conducted to the electrical actuator 55 to controllably drive the latter. The signal 67S is designed such that fuel injection begins at the desired timing td.

Specifically, the decision circuit 67 starts to de-energize the electrical actuator 55 and thus close the poppet valve 82 at the desired timing td during the contraction stroke of the plunger 38, so that the start or commencement timing of each fuel injection is coincident with the desired point td. The decision circuit 67 starts to energize the electrical actuator 55 and thus open the poppet valve 82 at a suitable timing during the expansion stroke of the plunger 38. The decision circuit 67 holds the electrical actuator 55 de-energized until the start of the subsequent energization thereof. The decision circuit 67 holds the electric actuator 55 energized until the start of the subsequent de-energization thereof. Under certain conditions, the decision circuit 67 holds the electrical actuator 55 de-energized, and thus the poppet valve 82 closed, at all times. In this case, the desired and actual fuel injection start timings remain at their earliest or most advanced limits coincident with the start of the contraction stroke of the plunger 38.

The timing control circuit 65 determines the desired timing td (the advance angle θa) at which the plunger 38 starts to effect compression of fuel on the basis of the engine rotational speed N, the accelerator pedal depression degree α, and/or the engine coolant temperature T. The advance angle θa is preferably chosen so as to vary as a function of the engine rotational speed N as shown by Fig. 3 and also vary as a function of the engine coolant temperature T as shown by Fig. 4. The timing control circuit 65 de-energizes the electric actuator 55 at the desired timing td with respect to the reference crank angle θc. The timing control circuit 65 calculates when the plunger 38 starts to move in the direction denoted by the arrow Q in Fig. 1 on the basis of the reference crank angle θc and the engine rotational speed N, and energizes the electrical actuator 55 at a timing within a crank angle range where the plunger 38 moves in the direction denoted by the arrow Q in Fig. 1.

In the case where the de-energization of the electrical actuator 55 allows fuel injection, since a diode (not shown) connected in parallel with the control winding 58 of the electrical actuator 55 can eliminate the retarding influence of the reactance of the control winding 58, quick response in the fuel injection start timing control can be realized by choosing the mass of the solenoid plunger 57 and the setting force of the return spring 56 suitably. In the same case, since a relatively quick response of the poppet valve 82 in the change from the closed to the open state is unnecessary, the force exerted on the solenoid plunger 57 by the energization of the control winding 58 should be chosen to be slightly greater than the setting force of the return spring 56, resulting in the smallest size and the lowest electrical power rating possible for the electrical actuator 55.

The quantity control circuit 68 includes a desired fuel injection quantity arithmetic circuit 69, a fuel injection quantity correction circuit 70, and a fuel injection quantity decision circuit 71. The arithmetic circuit 69 calculates a desired fuel injection quantity Q on the basis of the accelerator pedal depression degree α and the engine rotational speed N derived from the signals 61S and 62S, respectively. The desired fuel injection quantity Q preferably varies in accordance with the engine rotational speed N and the accelerator depression angle α as shown in Fig. 5. The arithmetic circuit 69 generates a signal 69S indicative of the desired quantity Q, which is applied to the decision circuit 71. The correction circuit 70 calculates a correction value ΔQ for the fuel injection quantity on the basis of the engine rotational speed N and the desired timing td derived from the signals 62S and 67S, respectively. Thus, the correction value ΔQ depends on the advance angle θa. The correction circuit 70 generates a signal 70S indicative of the correction value ΔQ, which is applied to the decision circuit 71. The decision circuit 71 calculates a desired position Pd ($Pd=f_1(Q)+f_2(\Delta Q)$) of the control sleeve 44 on the basis of the desired quantity Q and the correction value ΔQ derived from the signals 69S and 70S, respectively. The decision circuit 71 generates a signal 71S indicative of the control sleeve desired position Pd.

A servo amplifier 72 receives the signal 71S from the decision circuit 71 and also a signal 49S from the displacement sensor 49 which represents the actual position Pa of the control sleeve 44. The servo amplifier 72 generates a signal 72S for controllably energizing the controlling windings 46 and 47 of the actuator 80. The generation of the signal 72S includes a stage for determining the difference between the desired position Pd and the actual position Pa and another stage for processing the difference via an proportion-integration-differentiation (PID) and gain correction. The signal 72S is designed such that the actual position Pa follows the desired position Pd.

The control of the axial position of the control sleeve 44 adjusts the end timing of each fuel injection stroke which in turn determines the fuel injection quantity as described previously. The control of the poppet valve 82 adjusts the start timing of each fuel injection stroke which in turn determines the fuel injection timing. In order to hold the fuel injection quantity at a constant level independent of variations in the fuel injection timing, the axial position of the control sleeve 44 therefore needs to be adjusted in accordance with the variations in the fuel injection timing. This fact demands that the axial position of the control sleeve 44 should be corrected in accordance with the fuel injection timing. The quantity control circuit 68 performs this correction as described below.

First, the quantity control circuit 68 calculates the desired fuel injection quantity Q by means of a predetermined function of the accelerator pedal depression degree α and the engine rotational speed N. Second, the quantity control circuit 68 converts the fuel injection quantity Q into a corresponding position P_1 of the control sleeve 44. Third, the quantity control circuit 68 calculates the fuel injection quantity correction value ΔQ on the basis of the fuel injection advance angle θa and converts the correction value ΔQ into a corresponding correction displacement P_2 of the control sleeve 44. Fourth, the quantity control circuit 68 calculates the final desired position P_0 of the control sleeve 44 which is the sum of the values P_1 and P_2. Fifth, the quantity control circuit 68 generates a signal 68S indicative of the final desired position P_0, which is applied to the servo amplifier 72.

The above control of fuel injection timing and quantity is effected under normal engine operating conditions. Additional control procedures are provided for special engine operating conditions. For example, when the engine is to be started, the position of the control sleeve 44 is forced to its limit at which the fuel injection quantity is maximized in order to facilitate engine start-up. When the engine is idling, the position of the control sleeve 44 is controlled in accordance with the difference between a desired engine idle speed and the actual engine rotational speed to hold the actual speed at the desired level. When a conventional engine key switch (not shown) is returned to its rest position, the poppet valve 82 is forced to open to suspend the fuel supply to the engine for a predetermined length of time in order to stop the operation of the engine.

Instead of the combination of the actuator 80 and the magnet 45, a torque motor or a servo motor may be used to adjust the axial position of the control sleeve 44.

The fuel injection timing control circuit 65 and the fuel injection quantity control circuit 68 may consist of a microcomputer system.

The servo amplifier 72 is similar to the combination of a controller and a drive unit of the previous U.S. Patent Application Serial No. 432,382.

The mechanical portion of a second embodiment of this invention is similar to that of the first embodiment. The electrical circuitry of the second embodiment differs that of the first embodiment as described below.

As shown in Fig. 6, the second embodiment includes a control unit 100, a crank angle sensor 102, an accelerator pedal position sensor 104, and an engine temperature sensor 106. The control unit 100 consists of a digital microcomputer unit, which includes an input/output (I/O) circuit 108, a central processing unit (CPU) 110, a read-only memory (ROM) 112, and a read/write or random-access memory (RAM) 114. The central procesing unit 110 is connected to the I/O circuit 108, and the memories 112 and 114.

The crank angle sensor 102 is associated with the crankshaft or the camshaft of the engine to generate short-pulse signals S_1 and S_2 indicative of predetermined angles of engine revolution, that is, predetermined crank angles. For example, the pulses of the signal S_1 are outputted at predetermined crankshaft angular positions spaced at regular intervals of 120^o in the case of a six-cylinder engine. In contrast, the pulses of the signal S_2 are outputted at regular intervals of 1^o of engine revolution. In more detail, the sensor 102 may comprise the combination of a toothed disc and two magnetic pickups. In this case, the disc is mounted on the crankshaft or the camshaft of the engine, and the pickups are fixedly placed near the disc. The teeth of the disc belong to two groups, one for the 1° pulses and the other for the 120° pulses. The first pickup is designed to generate an alternating voltage corresponding to the 1° pulse signal S_2. The second pickup is designed to generate an alternating voltage corresponding to the 120° pulse signal S_1. The sensor 102 also includes two waveform shaping circuits to convert the alternating voltages into the corresponding pulse signals S_1 and S_2.

The accelerator pedal position sensor 104 is associated with the engine power controlling accelerator pedal to detect the position of the accelerator pedal, that is, the degree of depression of the accelerator pedal. The sensor 104 generates an analog signal S_3 whose voltage varies as a function of the accelerator pedal depression degree α. In general, the power required of the engine depends on the accelerator pedal depression degree α.

The engine temperature sensor 106 includes a temperature-responsive element whose internal resistance varies as a function of the temperature thereof. This element is exposed to engine coolant, so that the temperature of the element conforms to the engine coolant temperature. This element is electrically connected across a series combination of a fixed resistor and a constant voltage source, so that the voltage across the element varies as a function of the engine coolant temperature T. This voltage is outputted by the sensor 106 as an analog signal S_4 indicative of the engine coolant temperature T.

The I/O circuit 108 includes a frequency detector 116, and analog-to-digital (A/D) converters 118 and 120. The frequency detector 116 receives the 1° pulse signal S_2 from the crank angle sensor 102 and monitors the frequency thereof, which is proportional to the engine rotational speed N. The frequency detector 116 generates a digital signal indicative of the engine rotational speed N. The central processing unit 110 fetches the engine speed value N from the frequency detector 116. The first A/D converter 118 receives the accelerator pedal position signal S_3 from the sensor 104 and converts it to a corresponding digital signal indicative of the accelerator pedal depression degree α. The central processing unit 110 fetches the accelerator pedal depression degree value α from the A/D converter 118. The second A/D converter 120 receives the engine temperature signal S_4 from the sensor 106 and converts it to a corresponding digital signal as an indication of the engine coolant temperature T. The central processing unit 110 fetches the engine temperature value T from the A/D coverter 120.

The I/O circuit 108 includes a register 122, a presettable down counter 124, a reset-set flip-flop 126, and a driver 128. The central processing unit 110 generates a digital signal S_5 indicative of a desired fuel injection start timing td in accordance with the engine rotational speed N, the accelerator pedal depression degree α, and the engine coolant temperature T derived from the signals S_2, S_3, and S_4 respectively. The desired start timing signal S_5 from the central processing unit 110 is applied to the input terminal of the register 122, which holds the signal S_5. The output terminal of the register 122 is connected to the preset input terminal of the counter 124 to apply the signal S_5 thereto. The preset-enable terminal of the counter 124 is connected to the crank angle sensor 102 to receive the 120° pulse signal S_1 therefrom. When the preset-enable terminal receives one of the 120° pulses, the count content of the counter 124 is set to the value given by the desired start timing signal S_5. The clock input terminal of the counter 124 is connected to the crank angle sensor 102 to receive the 1° pulse signal S_2 therefrom. As the clock input terminal of the counter 124 subsequently receives each 1° pulse, the count number of the counter 124 drops by one in accordance with the counter's down-count function. The counter 124 has a carry-out terminal, which outputs a pulse when the count number of the counter 124 changes from one to zero. In this way, the carry-out terminal of the counter 124 outputs a pulse at a crank angle offset by the desired start timing signal S_5 from the predetermined crank-angle position defined by the 120° pulse signal S_1. Specifically, the crank angle of generation of pulses from the carry-out terminal of the counter 124 is distant, in the direction of increasing crank angle, from each of the predetermined crank-angle positions defined by the 120^{o} pulses, the crank angle interval between the carry-out terminal pulse and the 120^{o} pulse being equal to the value defined by the desired start timing signal S_5.

The reset terminal of the flip-flop 126 is connected to the carry-out terminal of the counter 124 to receive the pulse therefrom. The set terminal of the flip-flop 126 is connected to the crank angle sensor 102 to receive the 120^{o} pulse signal S_1 therefrom. When the flip-flop 126 receives one of the pulses from the counter 124, the flip-flop 126 is reset so that the output thereof goes low. As the flip-flop 126 subsequently receives each 120^{o} pulse, the flip-flop 126 is set so that its output goes high. The output terminal of the flip-flop 126 is connected to the input terminal of the driver 128. The driver 128 consists of a DC amplifier and amplifies the output from the flip-flop 126. The output terminal of the driver 128 is connected to the control winding 58 of the poppet vale 82 to drive the poppet valve 82. The poppet valve 82 is designed in a manner similar to that of the previous first embodiment of this invention. When the output of the flip-flop 126 goes high, the driver 128 electrically energizes the control winding 58 so that the poppet valve 82 opens. When the output from the flip-flop 126 goes low, the driver 128 electrically de-energizes the control winding 58 so that the poppet valve 82 closes. The 120^{o} pulse signal S_1 is designed so that each opening of the poppet valve 82 falls within the expansion stroke of the plunger 38 (see Fig. 1) and each closing of the poppet valve 82 falls within the contraction stroke of the plunger 38. As can be understood from the previous description of the first embodiment of this invention, the closing of the poppet valve 82 enables fuel injection. Therefore, each fuel injection stroke starts at the desired timing td indicated by the signal S_5.

The I/O circuit 108 includes a register 130 and a digital-to-analog (D/A) converter 132. The central processing unit 110 generates a digital signal S_6 indicative of a desired position Pd of the control sleeve 44 (see Fig. 1) in accordance with the engine rotational speed N, the accelerator pedal depression degree α, and the engine coolant temperature T derived from the signals S_2, S_3, and S_4 respectively. The desired position signal S_6 from the central processing unit 110 is applied to the input terminal of the register 130, which holds the signal S_6. The output terminal of the register 130 is connected to the input terminal of the D/A converter 132. The D/A converter 132 converts the signal S_6 into a corresponding analog signal whose voltage varies as a function of the control sleeve desired position Pd.

One input terminal of a difference amplifier 134 is connected to the output terminal of the D/A converter

132 to receive the analog signal indicative of the control sleeve desired position Pd. The other input terminal of the difference amplifier 134 is connected to the output terminal of the displacement sensor 49 to receive the signal indicative of the actual position Pa of the control sleeve 44 (see Fig. 1). The displacement sensor 49 is similar to that of the first embodiment of this invention. The voltage of the output signal from the displacement sensor 49 varies as a function of the control sleeve actual position Pa. In response to the signals from the D/A converter 132 and the displacement sensor 49, the difference amplifier 134 generates an analog signal whose voltage varies as a function of the difference between the control sleeve desired and actual positions Pd and Pa. The output terminal of the difference amplifier 134 is connected to the input terminal of an integrating circuit 136, which integrates the signal from the difference amplifier 134 and generates a signal indicative of the integrated result. The output terminal of the circuit 136 is connected to the input terminal of a driver 138, which amplifies the signal from the circuit 136. The driver 138 consists of a DC amplifier. The output terminal of the driver 138 is connected to the parallel combination of the control windings 46 and 47 of the actuator 80 to drive the actuator 80. The actuator 80 is similar to that of the previous first embodiment of this invention.

In general, the force exerted on the control sleeve 44 (see Fig. 1) by the actuator 80 varies with the current passing through the control windings 46 and 47. The force exerted on the control sleeve 44 by the urging device (see the previous first embodiment) varies with the displacement of the control sleeve 44. Therefore, the position of the control sleeve 44 depends on the current passing through the control windings 46 and 47. The combination of the difference amplifier 134, the integrating circuit 136, and the driver 138 is designed to control the current passing through the control windings 46 and 47 in accordance with the signals from the D/A converter 132 and the displacement sensor 49 so that the actual position Pa of the control sleeve 44 will follow the desired position Pd thereof. The combination of the difference amplifier 134, the integrating circuit 136, and the driver 138 may be replaced by the combination of a controller and a drive unit disclosed in the previous U.S. Patent Application Serial No. 432,382.

Fig. 7 is a flowchart for a program executed by the control unit 100. This program is stored in the memory 112.

In a first step 200, the central processing unit 110 inputs or receives the engine rotational speed N, the accelerator pedal depression degree α, and the engine coolant temperature T derived from the outputs of the frequency detector 116, and the A/D converters 118 and 120, respectively. In a second step 202 subsequent to the first step 200, the central processing unit 110 determines the desired fuel injection start timing td on the basis of the engine rotational speed N, the accelerator pedal depression degree α, and the engine coolant temperature T. The memory 112 holds a table in which a set of values of desired fuel injection start timing td are plotted as a function of the engine rotational speed N, the accelerator pedal depression degree α, and the engine coolant temperature T. The determination of the desired timing td is performed by means of a known table look-up technique employing the above table. After the second step 202, the operation of the central processing unit 110 proceeds to a third step 204, in which the central processing unit 110 outputs the desired fuel injection start timing td to the register 122 via the signal S_5 indicative thereof.

In a fourth step 206 subsequent to the third step 204, the central processing unit 110 determines the desired fuel injection quantity Q on the basis of the engine rotational speed N and the accelerator pedal depression degree α. The memory 112 holds a table in which a set of values of desired fuel injection quantity Q are plotted as a function of the engine rotational speed N and the accelerator pedal depression degree α. The determination of the desired fuel injection quantity Q is performed by means of a known table look-up technique employing the above table. After the fourth step 206, the operation of the central processing unit 110 proceeds to a fifth step

208, in which the central processing unit 110 calculates the desired position Pd of the control sleeve 44 (see Fig. 1) on the basis of the desired fuel injection start timing td and the desired fuel injection quantity Q by means of a predetermined equation. It should be noted that the desired fuel injection start timing td and the desired fuel injection quantity Q define a desired fuel injection end timing which is determined by the position of the control sleeve 44. In a sixth step 210 subsequent to the fifth step 208, the central processing unit 110 outputs the desired control sleeve position Pd to the register 130 via the signal S_6 indicative thereof.

Control of the central processing unit 110 returns to the first step 200 after the sixth step 210, so that the central processing unit 110 repeats the above sequential operation periodically. As the engine rotational speed N, the accelerator pedal depression degree α, and/or the engine coolant temperature T vary, the desired fuel injection start timing td outputted to the register 122 and the desired control sleeve position Pd outputted to the register 130 are updated periodically. The register 122 holds the desired fuel injection start timing until the central processing unit 110 outputs a subsequent or new desired timing value thereto. The register 130 holds the desired control sleeve position until the central processing unit 110 outputs a subsequent or new desired position value thereto.

It should be understood that further modifications and variations may be made in this invention without departing from the spirit and scope of this invention as set forth in the appended claims.

WHAT IS CLAIMED IS:

1. A fuel injection control system for a diesel engine having a rotatable crankshaft and a combustion chamber, the system comprising:

(a) a fuel tank for containing fuel;

(b) means for defining a pump chamber;

(c) means for transmitting fuel from the fuel tank to the pump chamber;

(d) a plunger connected to the crankshaft to reciprocate axially in accordance with the rotation of the crankshaft;

(e) means for defining a pressure chamber in conjunction with the plunger, the pressure chamber contracting as the plunger moves in one axial direction and expanding as the plunger moves in the opposite axial direction;

(f) means for allowing fuel to be drawn from the pump chamber toward the pressure chamber when the plunger moves in the axial direction of expanding the pressure chamber;

(g) means for allowing fuel to be forced out of the pressure chamber toward the combustion chamber to inject fuel into the combustion chamber when the plunger moves in the direction of contracting the pressure chamber;

(h) means for defining a fuel return passage extending from the pressure chamber to the fuel tank; and

(i) means for controllably blocking and opening the fuel return passage.

2. A fuel injection control system as recited in claim 1, further comprising:

(a) means for sensing an operating condition of the engine and generating a signal indicative thereof; and

(b) means for sensing the rotational angular position of the crankshaft and generating a signal indicative thereof;

(c) the blocking/opening means responsive to the engine operating condition signal and the crankshaft angular position signal to block the fuel return passage to enable fuel injection at a predetermined angular position of the crankshaft within a range where the plunger moves in the axial direction of contracting the pressure chamber, the predetermined angular position of the crankshaft depending on the engine operating condition, whereby fuel injection is started at the predetermined angular position of the crankshaft which depends on the engine operating condition.

3. A fuel injection control system as recited in claim 2, wherein the engine operating condition is the rotational speed of the crankshaft.

4. A fuel injection control system as recited in claim 2, wherein the engine operating condition is the

power required of the engine.

5. A fuel injection control system as recited in claim 2, wherein the engine operating condition is the temperature of the engine.

6. A fuel injection control system as recited in claim 2, further comprising means responsive to the engine operating condition signal and the crankshaft angular position signal for ending fuel injection at a second predetermined angular position of the crankshaft which depends on the engine operting condition so that the quantity of fuel injected during each fuel injection depends on the engine operating condition.

7. A fuel injection control system as recited in claim 1, further comprising a check valve disposed in the fuel return passage for permitting fuel flow only in the direction from the pressure chamber to the fuel tank.

8. A fuel injection control system as recited in claim 1, wherein the pressure-chamber-defining-means comprises a cylinder having a bore into which the plunger movably extends to define the pressure chamber, and wherein the cylinder comprises a wall through which the fuel return passage extends.

9. A fuel injection control system as recited in claim 8, wherein the blocking/opening means comprises a valve member located in the fuel return passage in the cylinder, and wherein the wall of the cylinder forms a valve seat for the valve member.

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FIG.1

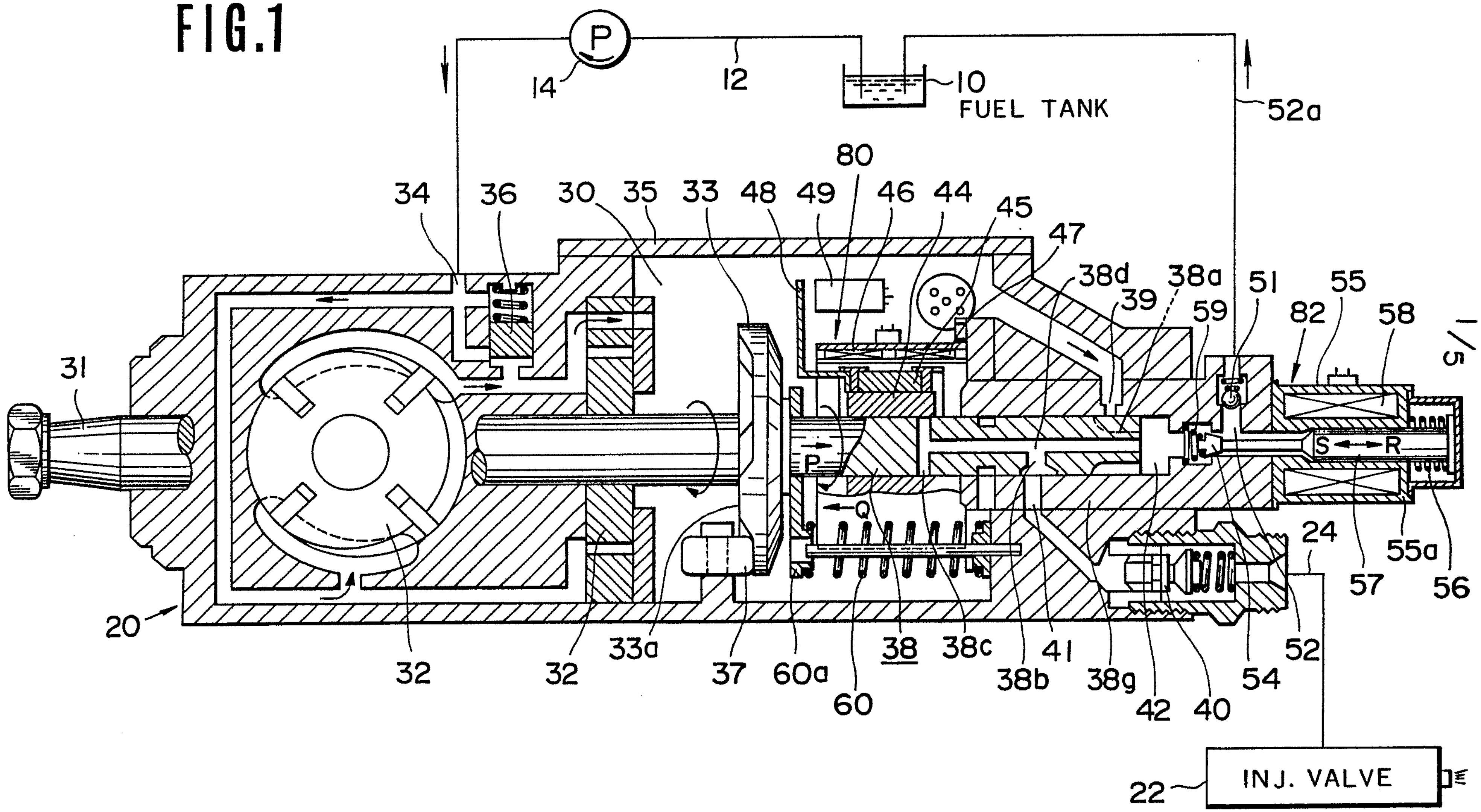


FIG.2

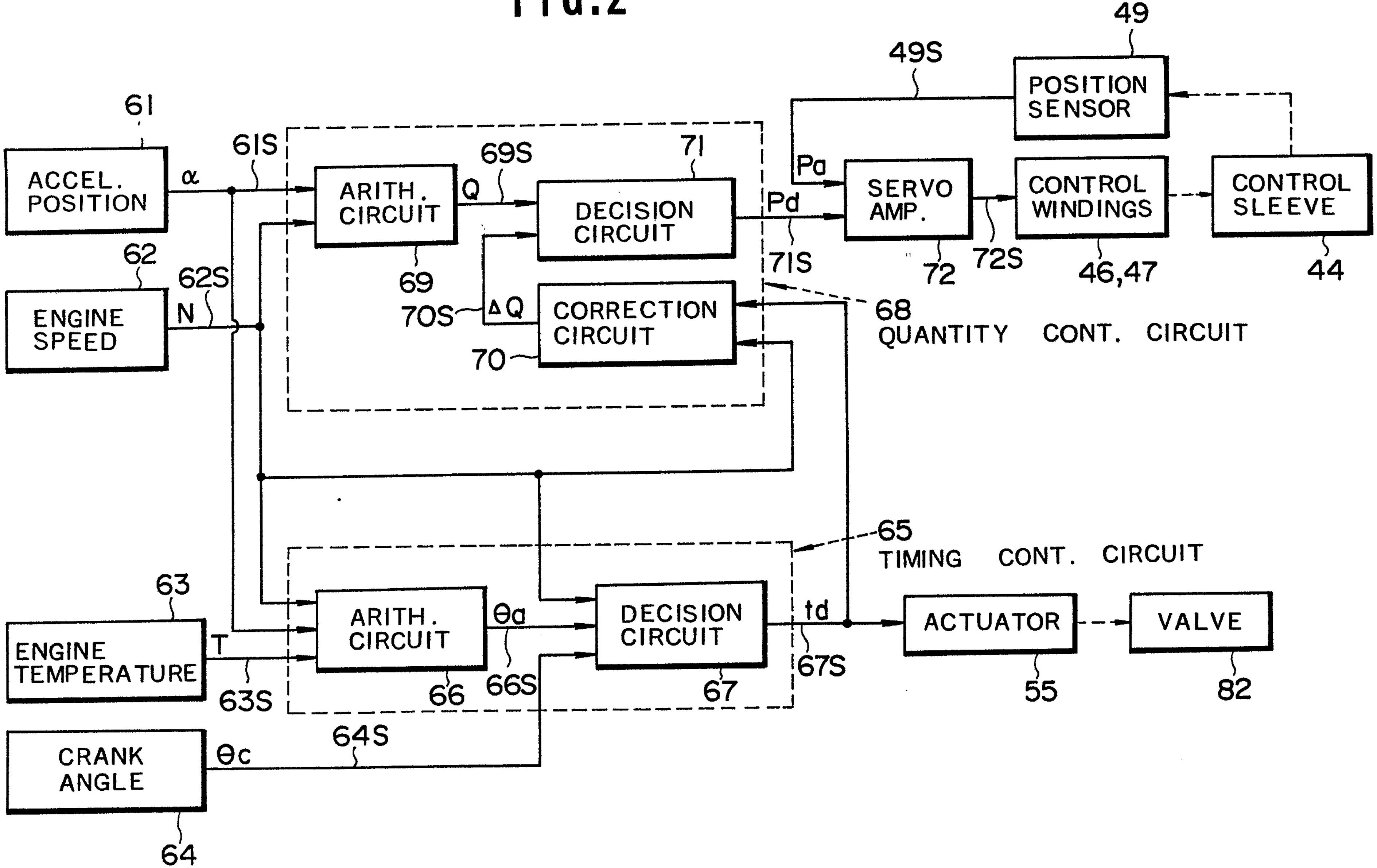

ACCEL. POSITION
61
α
61S
ENGINE SPEED
62
N
62S
ENGINE TEMPERATURE
63
T
63S
CRANK ANGLE
64
θc
64S
ARITH. CIRCUIT
69
Q
69S
DECISION CIRCUIT
71
CORRECTION CIRCUIT
70
ΔQ
70S
Pd
71S
68
QUANTITY CONT. CIRCUIT
SERVO AMP.
72
Pa
72S
POSITION SENSOR
49
49S
CONTROL WINDINGS
46,47
CONTROL SLEEVE
44
ARITH. CIRCUIT
66
θa
66S
DECISION CIRCUIT
67
td
67S
65
TIMING CONT. CIRCUIT
ACTUATOR
55
VALVE
82

FIG.3

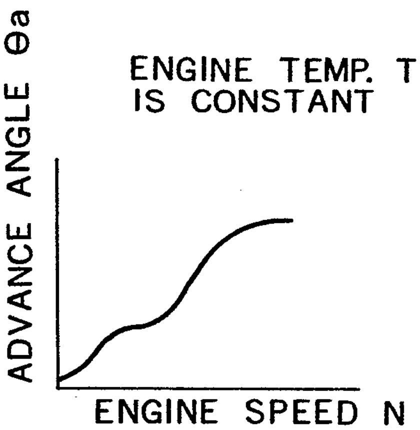


FIG.4

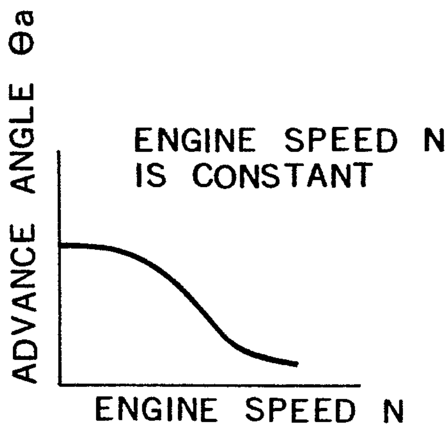


FIG.5

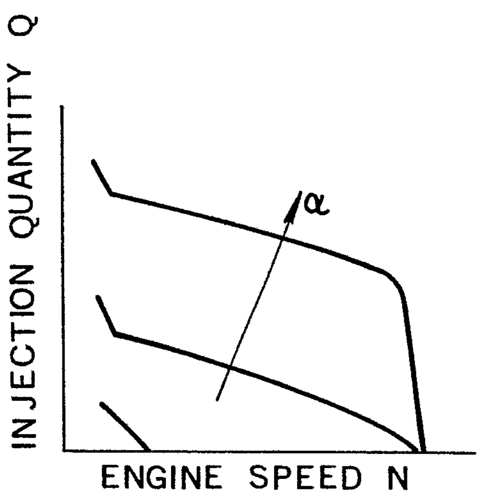


FIG.6

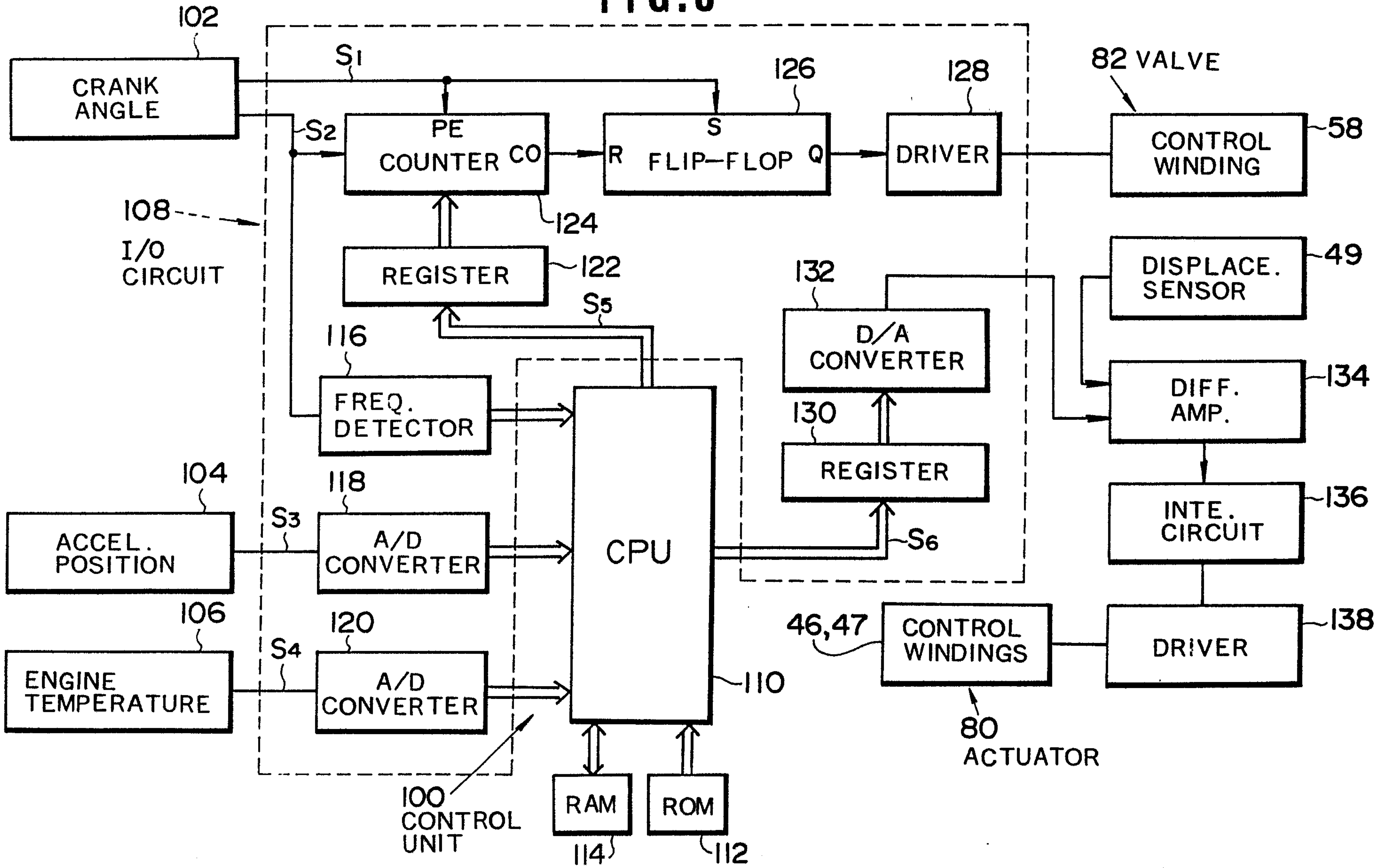
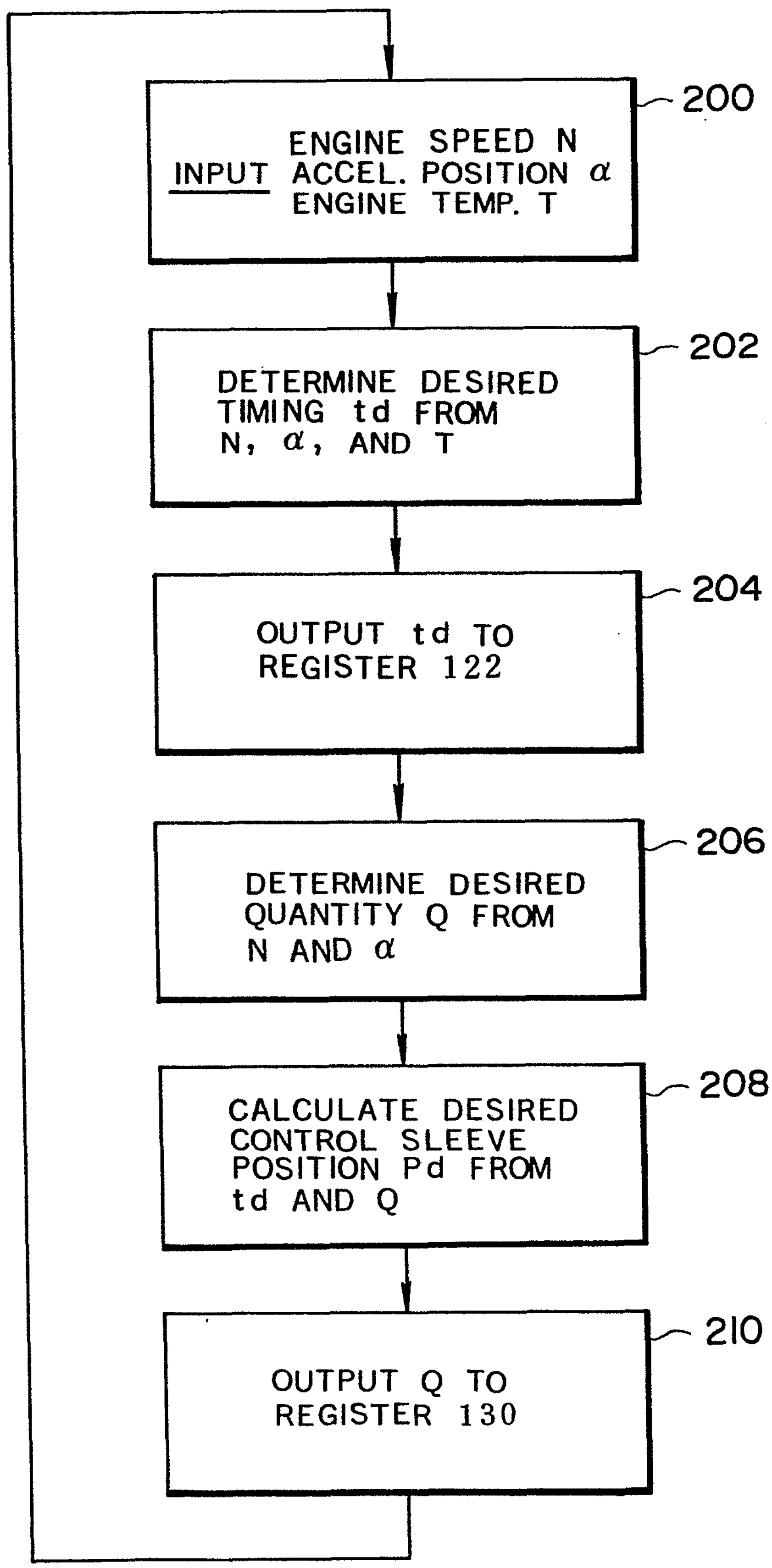

102
CRANK ANGLE
S1
S2
PE COUNTER CO
124
R FLIP—FLOP Q
S
126
DRIVER
128
82 VALVE
CONTROL WINDING
58
108
I/O CIRCUIT
REGISTER
122
S5
116
FREQ. DETECTOR
104
ACCEL. POSITION
S3
118
A/D CONVERTER
106
ENGINE TEMPERATURE
S4
120
A/D CONVERTER
CPU
110
RAM
114
ROM
112
100 CONTROL UNIT
132
D/A CONVERTER
130
REGISTER
S6
DISPLACE. SENSOR
49
DIFF. AMP.
134
INTE. CIRCUIT
136
DRIVER
138
46,47
CONTROL WINDINGS
80 ACTUATOR

FIG.7


INPUT ENGINE SPEED N
ACCEL. POSITION α
ENGINE TEMP. T
200
DETERMINE DESIRED TIMING td FROM N, α, AND T
202
OUTPUT td TO REGISTER 122
204
DETERMINE DESIRED QUANTITY Q FROM N AND α
206
CALCULATE DESIRED CONTROL SLEEVE POSITION Pd FROM td AND Q
208
OUTPUT Q TO REGISTER 130
210

EUROPEAN SEARCH REPORT

European Patent Office

0101966

Application number

EP 83 10 7564

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 3)
X	GB-A-2 076 561 (DIESEL KIKI) * Page 2, line 15 - page 4, line 116; figure 1 * ---	1-6,8, 9	F 02 M 59/36 F 02 M 41/12
X	US-A-4 129 253 (BADER) * Column 2, line 37 - column 6, line 63; figures 1-6 * ---	1	
X	GB-A-2 013 275 (LUCAS) * Page 1, line 101 - page 3, line 94; figure 1 * ---	1	
X	GB-A-2 061 403 (BOSCH) * Page 1, lines 69-116; figures 1,2 * -----	1	
			TECHNICAL FIELDS SEARCHED (Int. Cl. 3)
			F 02 M

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	17-11-1983	SCHMID R.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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L : document cited for other reasons

& : member of the same patent family, corresponding document