United States Patent

Kamazuka

[15] **3,665,898**

[45] **May 30, 1972**

[54] DRIVING DEVICE FOR FUEL INJECTION SOLENOID VALVES

[72] Inventor: **Isezi Kamazuka**, Kariya-shi, Japan

[73] Assignee: **Nippondenso Kabushiki Kaisha**, Kariya-shi, Japan

[22] Filed: **Dec. 16, 1969**

[21] Appl. No.: **885,470**

[30] **Foreign Application Priority Data**

Dec. 24, 1968 Japan 43/94839
Jan. 16, 1969 Japan 44/3054

[52] **U.S. Cl.** ..... **123/32 EA**, 123/119
[51] **Int. Cl.** **F02m 51/00**
[58] **Field of Search** ..... 123/32, 32 E, 32 EA, 119 R, 123/139 E

[56] **References Cited**

UNITED STATES PATENTS

2,815,009	12/1957	Pribble	123/32 EA
2,934,050	4/1960	Pribble	123/32 EA
3,240,191	3/1966	Wallis	123/32 EA
3,433,207	3/1969	Bassot et al.	123/32 EA

Primary Examiner—Laurence M. Goodridge
Attorney—Cushman, Darby & Cushman

[57] **ABSTRACT**

A driving system for solenoid valves in an electrical fuel injection system of an internal combustion engine, wherein said solenoid valves are adapted to inject the fuel into the engine cylinders upon application thereto of a fuel injection pulse synchronized with the valve opening timing of the air intake valves in the internal combustion engine and having a pulse width corresponding to the load of the engine and the like.

2 Claims, 5 Drawing Figures

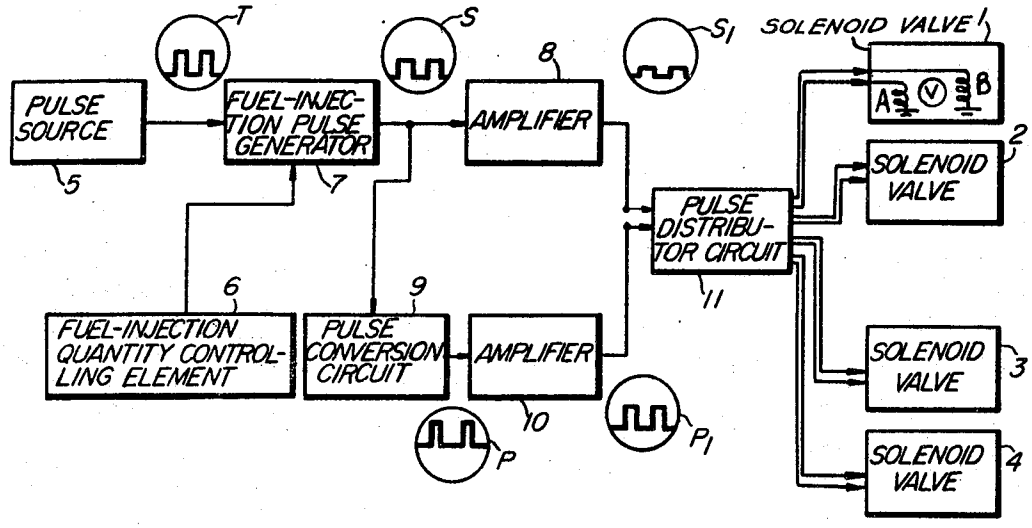


FIG. 1

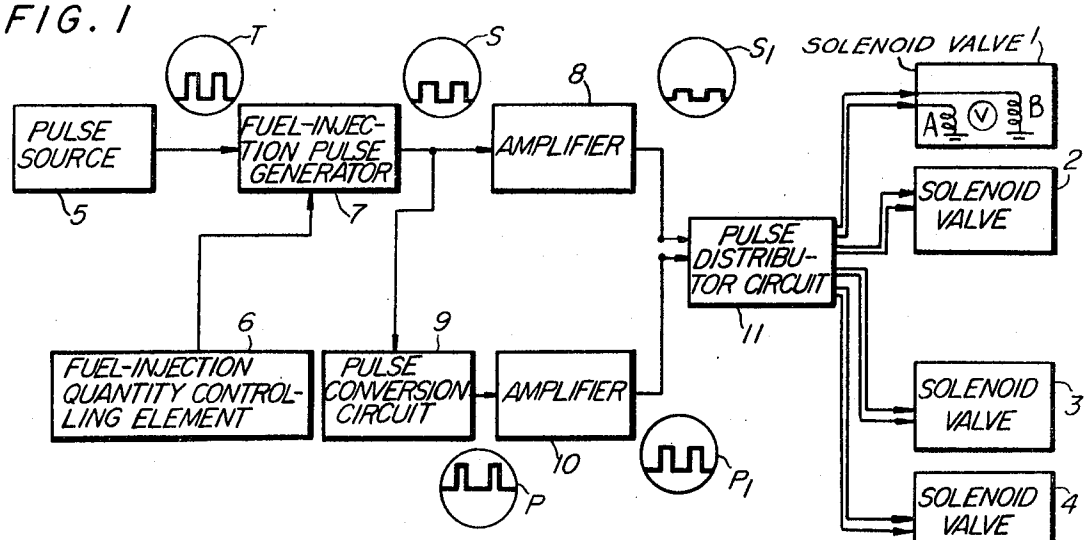


FIG. 3

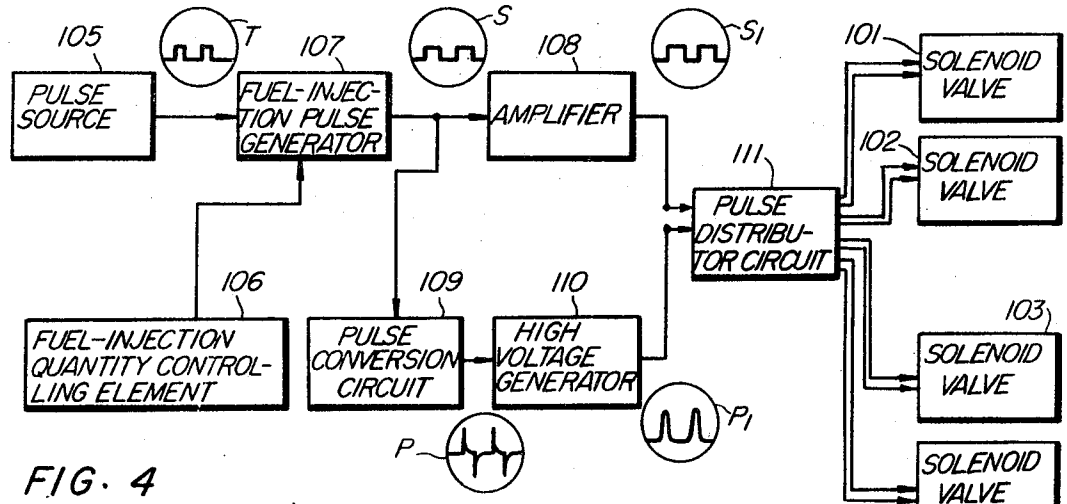


FIG. 4

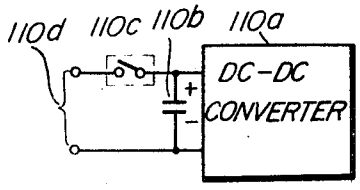


FIG. 2

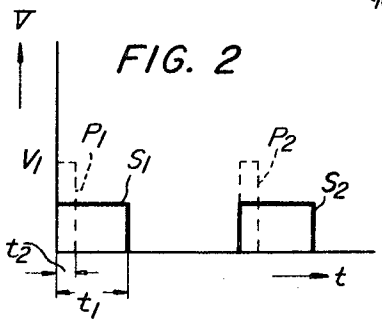
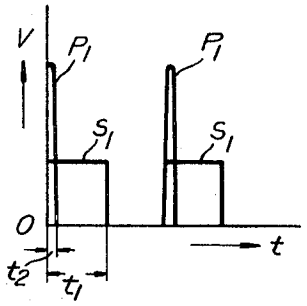


FIG. 5



INVENTOR

Isezi Kamezuka

BY Cushman, Darby & Cushman

ATTORNEYS

DRIVING DEVICE FOR FUEL INJECTION SOLENOID VALVES

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an electrical fuel injection system for internal combustion engines, and more particularly to a driving system for solenoid valves adapted to inject the fuel into the engine cylinders when a pulse is applied thereto which is synchronized with the valve opening timing of the air intake valves in the internal combustion engine and which has a pulse width corresponding to the load of the engine and the like.

2. Description of the Prior Art

With the conventional electrical fuel injection systems for internal combustion engines, a pulse synchronized with the valve opening timing of the intake valves in the engine and having a pulse width corresponding to the amount of fuel to be injected as determined by taking into consideration among others the load of the engine and the like, is subjected to the low voltage amplification to provide the fuel injection pulse of a low voltage value which is in turn applied to a single solenoid of the respective solenoid valves to inject the fuel into the engine cylinders. However, in spite of the fact that it would be highly desirable to improve the response property of these solenoid valves, the voltage values of fuel injection pulse have hitherto been held at low levels in disregard of this property, for such reasons as will be explained hereunder. In other words, if the voltage value of such fuel injection pulse were raised up to the supply voltage of the DC voltage source provided in the internal combustion engine to improve the response property of the solenoid valve, the coil of the solenoid valve would unavoidably generate heat and, especially with the engine running at high speeds, the fuel injection cycle would tend to be shorter due to a rise in the number of revolutions of the engine. Thus, the voltage value of the fuel injection pulse has been limited to a low level for fear that the coil of the solenoid valve may burn out in the worst case.

However, no good scheme which could improve the response property of the solenoid valve has ever been found, and consequently the prior art injection systems have been open to the objection that the low voltage value of the fuel injection pulse resulted in a longer rise time for the current that would flow through the solenoid and therefore the valve opening timing of the solenoid valve or the fuel injection timing lagged behind the valve opening timing of the intake valve, whereby, when the engine was operated at high speeds, the fuel injection pulses tended to overlap one another causing the fuel to be injected continuously. There has been another drawback that errors in the amount of fuel being injected duing the closing time of the solenoid valve are inevitable.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a driving system for a fuel injection solenoid valve, wherein the solenoid is composed of a driving coil and a holding coil such that the fuel injection pulse is applied to said driving coil in the form of a solenoid valve driving pulse having a minimum pulse width to merely open the solenoid valve and further having the voltage value at least equal to the power supply voltage, while said fuel injection pulse is subjected to a low voltage amplification to impart thereto a minimum voltage value to hold said solenoid valve open and the pulse is then applied to said holding coil in synchronism with the rising time of said solenoid valve driving pulse.

Another object of the present invention is to provide a driving system for fuel injection solenoid valves comprising a separate high voltage generator, wherein the fuel injection pulse is subjected to a waveform conversion to provide the trigger pulse such that said high voltage generator is triggered by said trigger pulse to produce the valve actuating pulse having a minimum pulse width to merely open the solenoid valve, said fuel injection pulse is subjected to a low voltage amplification to provide the open valve holding pulse having a minimum voltage value to hold said solenoid valve open and said holding pulse is then synchronized with the rising time of said valve actuating pulse such that said holding pulse is applied, together with said valve actuating pulse, to the solenoid of said solenoid valve.

According to the present invention, there are remarkable effects attributable thereto that in opening the solenoid valve, the valve opening operation can be completed in a very short period of time since the electro-magnetic forces by the two coils are added to energize the solenoid valve and that the driving pulse for said solenoid valve has a voltage value which is at least equal to the power supply voltage. There are further remarkable effects in that since the solenoid of the solenoid valve which has hitherto taken the form of a single coil is now composed of the two coil portions in the present invention as previously described, the inductance or DC resistance of the driving coil is reduced to a relatively small magnitude and moreover the pulse width of said solenoid valve driving pulse has a minimum value to merely open the solenoid valve with a result that there is no possibility of the driving coil abnormally generating heat.

According to the present invention, since the solenoid valve holding pulse which is applied to the holding coil to hold the solenoid valve in the open position until the very moment that the solenoid valve is closed is a low voltage and low current pulse, the effect of the residual magnetism due to said solenoid valve holding pulse is reduced to a very small and unimportant degree with a result that almost at the instant said solenoid valve holding pulse dissipates, the solenoid valve may be accurately and rapidly closed. Moreover, there are still further remarkable effects that since the said solenoid valve holding pulse has both low voltage and low current, the inductance or DC resistance of the holding coil can also be limited to a relatively small magnitude and therefore the desired degree of freedom for design is also attained. These remarkable effects result, in cooperation with one another, in still further remarkable effects that for all the engine operating conditions ranging from low-speed to high-speed operations, the fuel can be positively injected without the timing of fuel injection lagging behind the valve opening timing of intake valves and without unnecessarily extending the time that the valve is opened.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram showing an embodiment of the driving system for fuel injection solenoid valves according to the present invention.

FIG. 2 is a diagram showing the waveform of a fuel injection composite pulse to be applied to the fuel injection solenoid in the system according to the present invention.

FIG. 3 is a block diagram showing another embodiment of the driving system for fuel injection solenoid valves according to the present invention.

FIG. 4 is a wiring diagram showing an embodiment of the high voltage generator used in the system according to the present invention.

FIG. 5 is a diagram showing the waveform of a composite pulse to be applied to the fuel injection solenoid valves by means of the system according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. 1, numerals 1, 2, 3 and 4 designate solenoid valves disposed near the air intake valves of the respective cylinders in a four-cylinder internal combustion engine, each of these solenoid valves being provided with a solenoid composed of a driving coil A and a holding coil B, as shown schematically for solenoid valve 1. Numeral 5 designates a pulse source for generating pulses T synchronized with the valve opening timing of the air intake valves for the respective engine cylinders, the pulse source being adapted to derive said pulses T from a rotary member such as a crankshaft and a

camshaft correlated with the engine rpm through a switch element and the like. Numeral 6 designates a fuel-injection quantity controlling element for producing a signal which determines the pulse width of the pulse T generated by the pulse source 5 additionally taking into consideration the engine load as represented by the engine intake vacuum pressure and the like or the ambient conditions such as the temperature of the external air, the temperature of the cooling water, atmospheric pressure and the like. Numeral 7 designates a fuel injection pulse generator for providing the fuel injection pulse S which is the pulse T generated by the pulse source 5 and whose pulse width or the fuel-injection quantity is determined by the signal from said fuel-injection quantity controlling element 6. Numeral 8 designates an amplifier for amplifying the voltage value of the fuel injection pulse generated by said fuel injection pulse generator 7 to a minimum necessary to hold the solenoid valves 1, 2, 3 and 4 in an open position. Numeral 9 designates a pulse conversion circuit for converting the fuel injection pulse S generated by the fuel injection pulse generator 7 into the solenoid valve driving pulse P having a minimum pulse width necessary to open the solenoid valves 1, 2, 3 and 4 and a voltage value equal at least to the power supply voltage, and this conversion circuit is composed of a monostable multivibrator and the like. Numeral 10 designates an amplifier for amplifying the solenoid valve driving pulse P. Numeral 11 designates a pulse distributor circuit to apply the pulse S_1 and P_1 to the solenoid of the corresponding one of the solenoid valves 1, 2, 3 and 4, these pulses being provided by synchronizing the rising times of the solenoid valve holding pulse S_1 produced by the amplifier 8 and the solenoid valve driving pulse P_1 from the amplifier 10. And FIG. 2 shows these pulses S_1 and P_1 in a graphic representation wherein the horizontal axis represents time t and the voltage V is represented on the vertical axis.

With the arrangement described above, the operation of the system according to the present invention will be explained hereinafter. The operation explained in the description to follow will relate only to the operation with respect to the solenoid valve 1 provided for the first cylinder. As the pulse T is provided from the pulse source 5 in synchronism with the valve opening timing of the intake valve for the first cylinder, this pulse T is made into the fuel injection pulse S of a proper pulse width in the fuel injection pulse generator 7 by the signal from the fuel-injection quantity controlling element 6. From there, the fuel injection pulse S with its waveform now having the pulse width t_1 is applied to the pulse distributor circuit 11 through the amplifier 8 as the solenoid valve holding pulse S_1 of a minimum value necessary to hold the solenoid valve 1 in the open position. On the other hand, the fuel injection pulse S is applied to the pulse conversion circuit 9 where it is converted into the solenoid valve driving pulse P having a minimum pulse width t_2 necessary to merely open the solenoid valve 1 and a voltage value equal at least to the supply voltage V_1. And this solenoid valve driving pulse P is amplified through the amplifier 10 and the thus amplified solenoid valve driving pulse P_1 is applied to the pulse distributor circuit 11 in synchronism with the rising time of the solenoid valve holding pulse S_1. Consequently, the pulse distributor circuit 11 applies to the solenoid valve 1 of the first cylinder in question the solenoid valve holding pulse S_1 and the solenoid valve driving pulse P_1. In this case, the solenoid valve holding pulse S_1 is applied to the holding coil and the solenoid valve driving pulse P_1 is applied to the driving coil so that when the solenoid valve 1 is to be opened, the electromagnetic attractive forces of these two coils are added to energize the solenoid valve 1 to thereby complete the opening of the solenoid valve 1 in a very short period of time. Then, as the solenoid valve 1 is completely opened and the solenoid valve driving pulse P_1 dissipates after the time t_2, the holding coil is energized by the solenoid valve holding pulse S_1 to hold the solenoid valve 1 in the open position and simultaneously the fuel is injected into the cylinder during the pulse duration t_1 of the solenoid valve holding pulse S_1. Thereafter, as the solenoid valve holding pulse S_1 dissipates after the time t_1, the solenoid valve 1 is deenergized and closes. And again in this closing operation of the solenoid valve 1, it may be positively and rapidly closed almost simultaneously with the dissipation of the solenoid valve holding pulse S_1 since the solenoid valve holding pulse S_1 is a low voltage and low current pulse and the effect of the residual magnetism is therefore unimportant.

Moreover, as the voltage value of the solenoid valve driving pulse P_1 applied to the driving coil is equal at least to the power supply voltage, the inductance or DC resistance of this driving coil may be reduced to a relatively small value so that a large current with a good build-up characteristic may be supplied to the driving coil. Furthermore, since the pulse width of the solenoid valve driving pulse P_1 is limited to a minimum necessary to merely open the solenoid valve 1, there is no likelihood that the driving coil will become overheated. Still further, since the solenoid valve holding pulse S_1 applied to the holding coil is a low voltage and low current pulse of a minumum value necessary to hold the solenoid valve in the open position, the inductance or DC resistance of the holding coil may be maintained at a relatively low level.

Similarly as with the above described first cylinder, this series of operation may take place with respect to the remaining second, third and fourth engine cylinders by means of the pulses T which are generated by the pulse source 5 and synchronized with the valve opening timing of the associated air intake valves of the cylinders.

While the above description of the embodiment has been made in connection with a four-cylinder engine, the present invention may be worded with any other multiple-cylinder engines as well as any other single-cylinder engines in the similar manner as with the above described four-cylinder engine. In the case of a single-cylinder engine, however, the pulse distributor circuit 11 is unnecessary and the solenoid valve holding pulse S_1 and the solenoid valve driving pulse P_1 may be directly applied to the holding coil and the driving coil respectively to attain the desired effects.

Now referring to FIGS. 3 through 5, the second embodiment of the present invention will be explained. Those elements which are designated by numerals 101 through 109 correspond to the elements designated by numerals 1 through 9 of the first embodiment shown in FIG. 1. In this embodiment, an amplifier 108 produces the open valve holding pulse S_1 which is a fuel injection pulse S generated by a fuel injection pulse generator 107 and subjected to a low voltage amplification to impart thereto a minimum value necessary to hold solenoid valves 101, 102, 103 and 104 in their open positions. A pulse conversion circuit 109 converts the fuel injection pulse S into the trigger pulse P for providing a trigger action and it may be composed of any one of the differentiator circuit, transformer circuit, monostable multivibrator circuit and the like. A high voltage generator 110 is provided separately and its concrete circuit construction is shown in FIG. 4. Numeral 110*a* designates a DC—DC converter; 110*b* a capacitor adapted to charge and discharge the high voltage output from the DC—DC converter. Numeral 110*c* designates a switching element such as a silicon controlled rectifier and a transistor, the conduction and non-conduction of this element being controlled by means of the trigger pulse generated by the pulse conversion circuit 109 to charge and discharge the capacitor 110*b* such that the valve actuating pulse P_1 of high voltage is developed at an output terminal 110*d* of the capacitor 110*b*, which has a minimum pulse width necessary to merely open the solenoid valves 101, 102, 103 and 104 and which is synchronized with the rising time of the open valve holding pulse S_1 generated by the amplifier 108. A pulse distributor circuit 111 applies to the solenoid of the corresponding one of the solenoid valves 101, 102, 103 and 104 the pulses S_1 and P_1 which are produced by synchronizing the rising times of the open valve holding pulse S_1 generated by the amplifier 108 and the valve actuating pulse P_1 provided by the high voltage generator 110. FIG. 5 shows these pulses S_1 and P_1 in a graphical representation wherein the horizontal axis represents the time t and the vertical axis represents the voltage V.

With the arrangement described above, the operation of the second embodiment of the present invention will be explained hereinafter. The description of the operation to follow will relate only to the operation with respect to the solenoid valve **1** provided for the first engine cylinder. When the pulse T is generated by the pulse source **105** which is synchronized with the valve opening timing of the air intake valve for the first cylinder, this pulse T is made into the fuel injection pulse S of a proper pulse width in the fuel injection pulse generator **107** by means of the signal from the fuel-injection quantity controlling element **106**. Then, this fuel injection pulse S with its waveform now having the pulse width t_1 is applied to the pulse distributor circuit **111** through the amplifier **108** as the open valve holding pulse S_1 having a minimum voltage value necessary to hold the solenoid valve **101** in its open position. On the other hand, the fuel injection pulse S is applied to the pulse conversion circuit **109** where it is converted into the trigger pulse P which in turn triggers a switching element **110***c* of the high voltage generator **110** to cause the conduction thereof. Whereupon, the capacitor **110***b* discharges through the switching element **110***c*, thereby producing the valve actuating pulse P_1 of high voltage which is synchronized with the rising time of the open valve holding pulse S_1 and which has a minimum pulse width t_2 necessary to merely open the solenoid valve **101**. This valve actuating pulse P_1 is then applied to the pulse distributor circuit **111** where the rising times of both the open valve holding pulse S_1 and the valve actuating pulse P_1 are synchronized with each other as shown in FIG. **5**, which are in turn applied to the solenoid of the solenoid valve **101**. Consequently, the solenoid valve **101** is energized by the high-voltage valve actuating pulse P_1 applied to the solenoid thereof so that it rapidly opens completely in a very short period of time. Then, as the opening of the solenoid valve **101** is completed and the valve actuating pulse P_1 dissipates after the time t_2, the continued energization of the solenoid is maintained by means of the open valve holding pulse S_1 to hold the solenoid valve **101** in the open position and fuel is injected into the intake manifold during the pulse duration t_1 of the open valve holding pulse S_1. Thereafter, upon dissipation of the open valve holding pulse S_1 after the time t_1, the solenoid valve **101** is deenergized and closes. During the time that the valve **101** closes, the effect of the residual magnetism is small and unimportant owing to the low voltage level of the open valve holding pulse S_1 which maintains the open position of the solenoid valve **101**, whereby the solenoid valve **101** positively and rapidly closes almost simultaneously with the dissipation of the open valve holding pulse S_1.

Furthermore, since the voltage value of the valve actuating pulse P_1 can be made larger than the power supply voltage by means of the high voltage generator **110**, there is no need to reduce the inductance of the driving coil to permit the flow of a large current and furthermore the magnetomotive force can afford more rapid opening of the solenoid valve compared with the embodiment in FIG. **1**. Moreover, since the pulse width t_2 of the valve actuating pulse P_1 is the minimum necessary to merely open the solenoid valve **101**, there is no danger of the solenoid becoming overheated.

Similarly as with the above described first cylinder, this series of operation may take place with respect to the remaining second, third and fourth engine cylinders by means of the pulses T which are generated by the pulse source **105** and synchronized with the valve opening timing of the associated intake valves of the cylinders.

While the above description of the embodiment has been made in connection with a four-cylinder engine, the present invention may be worked with any other multiple-cylinder engines as well as any other single-cylinder engines in the similar manner as with the above described four-cylinder engine. It is to be noted here that even a multiple-cylinder engine will need only one high voltage generator **110**, and in the case of a single-cylinder engine the pulse distributor circuit **111** is unnecessary.

Furthermore, it is also possible to make the opening speed of the solenoid valve faster, if the solenoid is composed of two coils so that the valve actuating pulse P_1 is applied to one of the coils and the open valve holding pulse S_1 is applied to the other coil in synchronism with the rising time of the valve actuating pulse P_1, whereby, when the solenoid valve is to be opened, the solenoid valve is energized by means of the added magnetomotive forces of the two coils.

I claim:

1. A driving system for fuel injection solenoid valves in an electrical fuel injection system for an internal combustion engine having time operated air intake valves, comprising:

driving and holding coils independently provided to each of said fuel injection solenoid valves,

a pulse source for producing timing pulses in synchronism with the timing with which said air intake valves in said engine are operated,

first means for determining the time intervals during which each one of said injection solenoid valves is opened depending upon the operating condition of said engine,

second means for producing valve holding pulses in synchronism with said timing pulses and each having a voltage level only sufficient to hold one of said solenoid valves open when applied to the holding coil of said one and having a pulse width determined by said time interval determined by said first means,

third means for producing valve driving pulses in synchronism with said timing pulses and each having a voltage level and a pulse width only sufficient to open one of said solenoid valves instantly when applied to the driving coil of said one valve, and

means for applying said driving and holding pulses respectively to said driving and holding coils of the corre-sponding one of said solenoid valves.

2. A driving system according to claim **1**, wherein said third means comprises a high voltage generator which is successively triggered by pulses produced responding to said timing signals.

* * * * *