

July 22, 1969

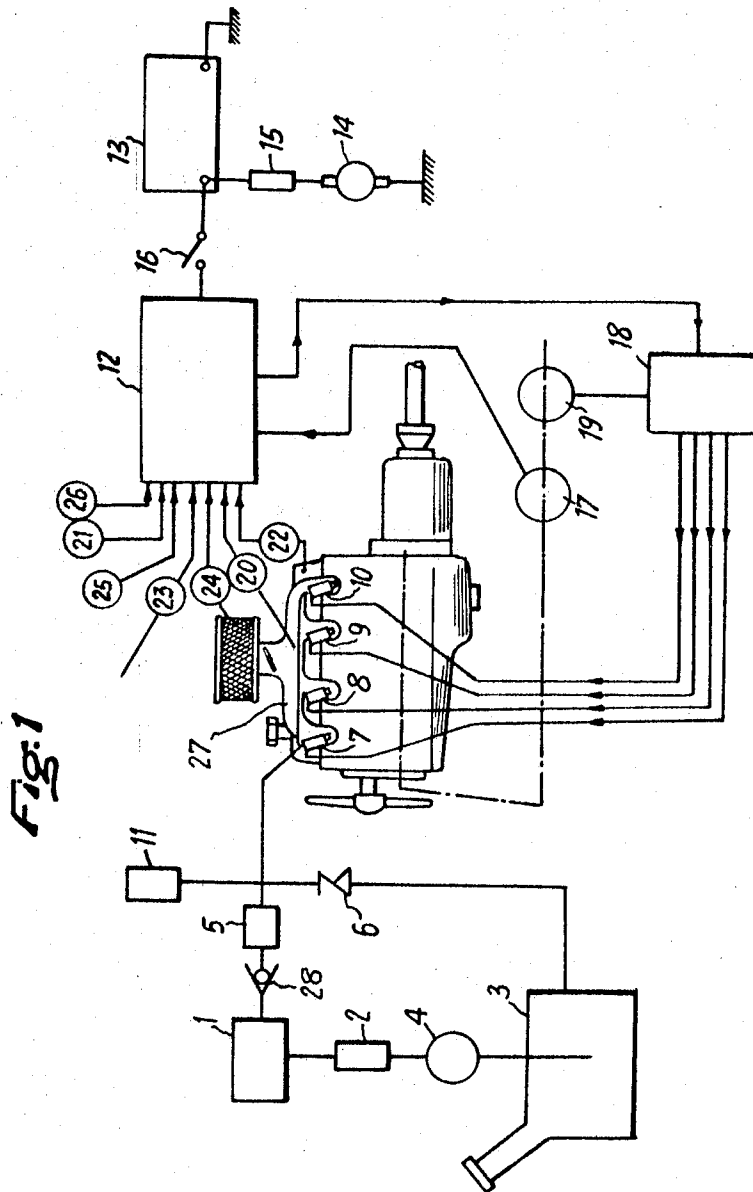
J. BASSOT ET AL

3,456,628

HIGH-SPEED FUEL INJECTION SYSTEM

Filed April 11, 1967

18 Sheets-Sheet 1



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July 22, 1969

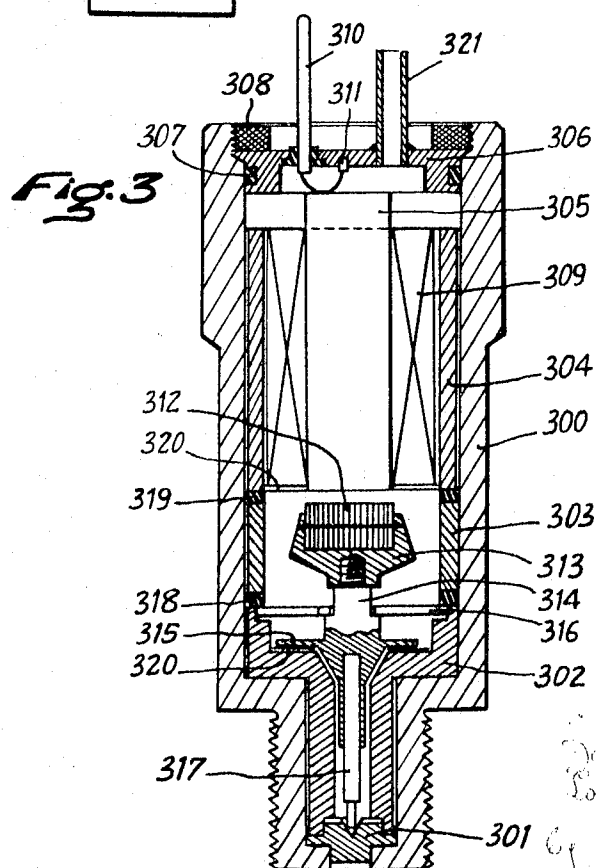
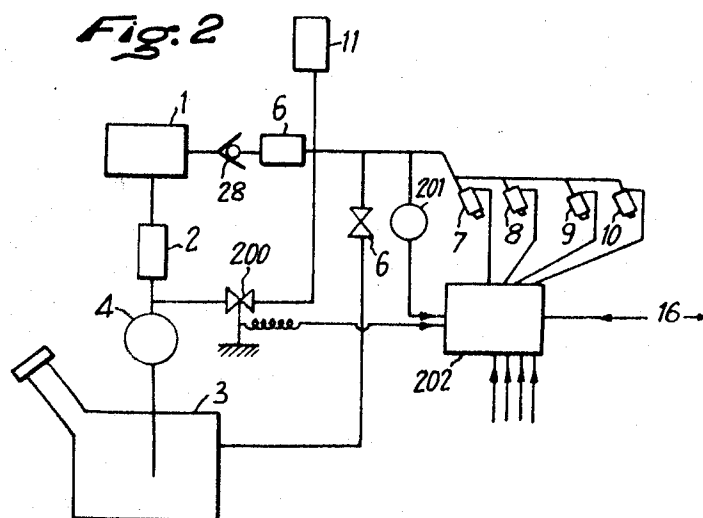
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3,456,628

HIGH-SPEED FUEL INJECTION SYSTEM

Filed April 11, 1967

18 Sheets-Sheet 2



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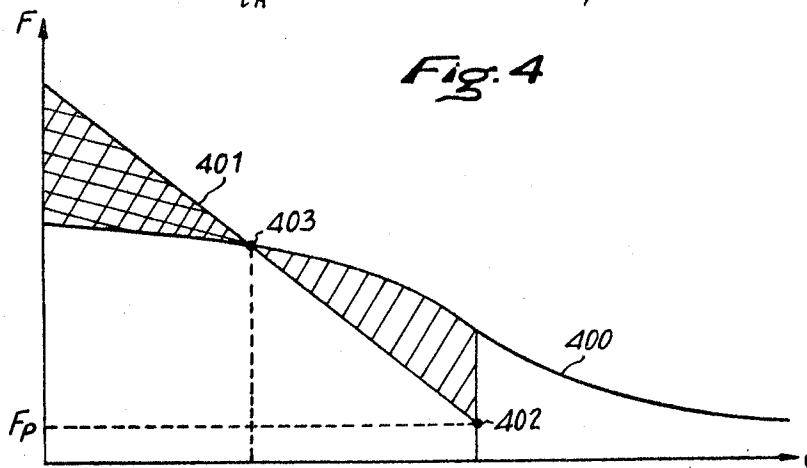
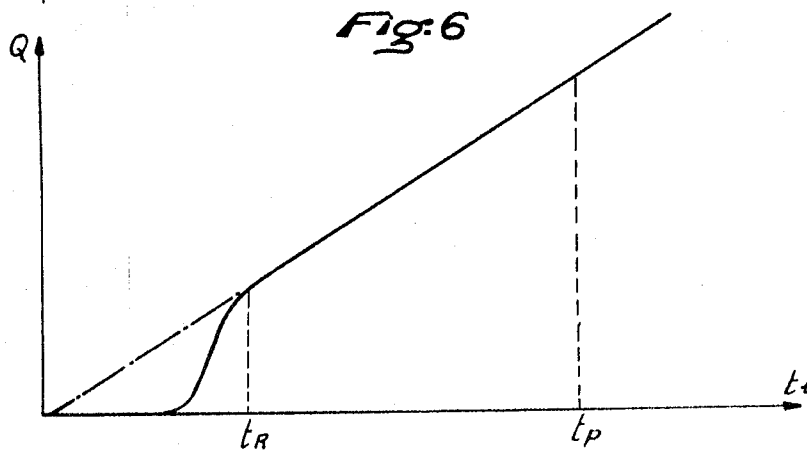
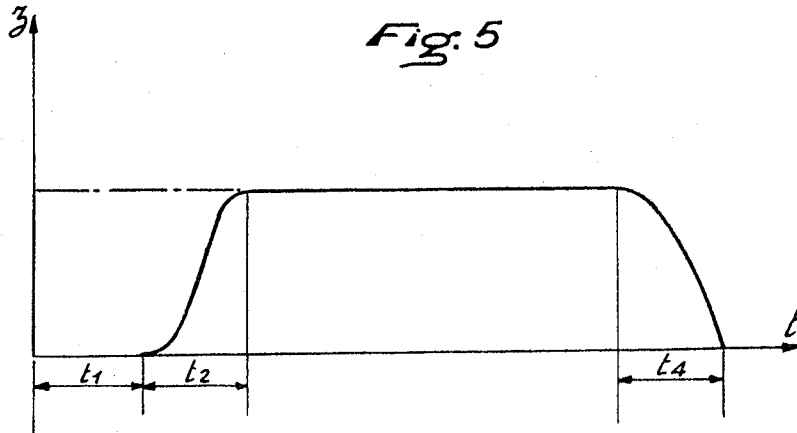
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HIGH-SPEED FUEL INJECTION SYSTEM

Filed April 11, 1967

18 Sheets-Sheet 3



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3,456,628

HIGH-SPEED FUEL INJECTION SYSTEM

Filed April 11, 1967

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Fig. 7

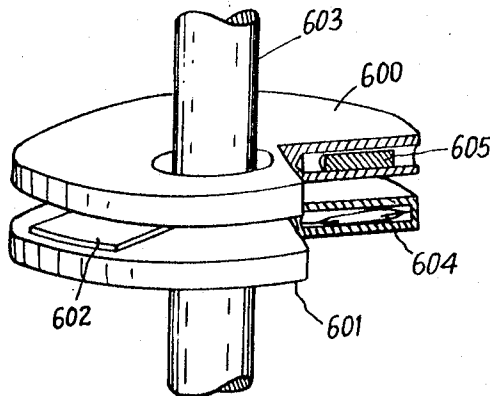


Fig. 9

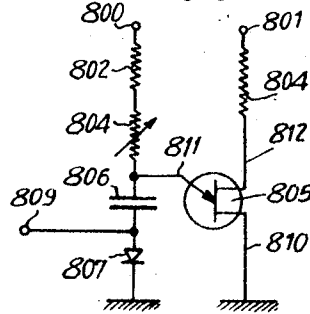


Fig. 10

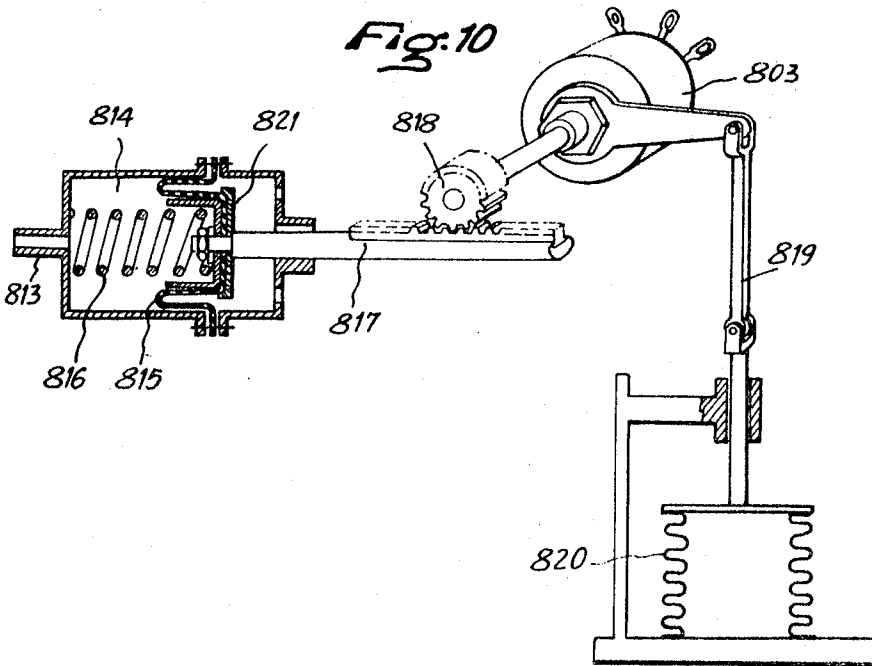
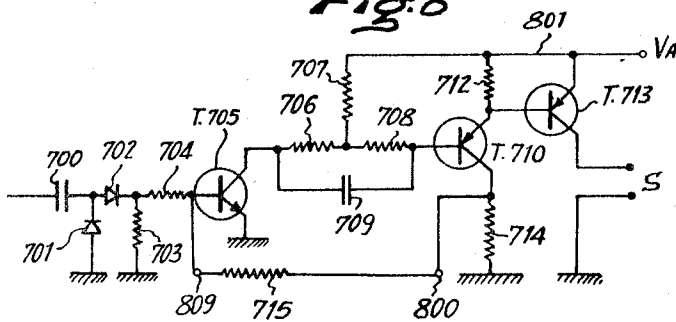


Fig. 8



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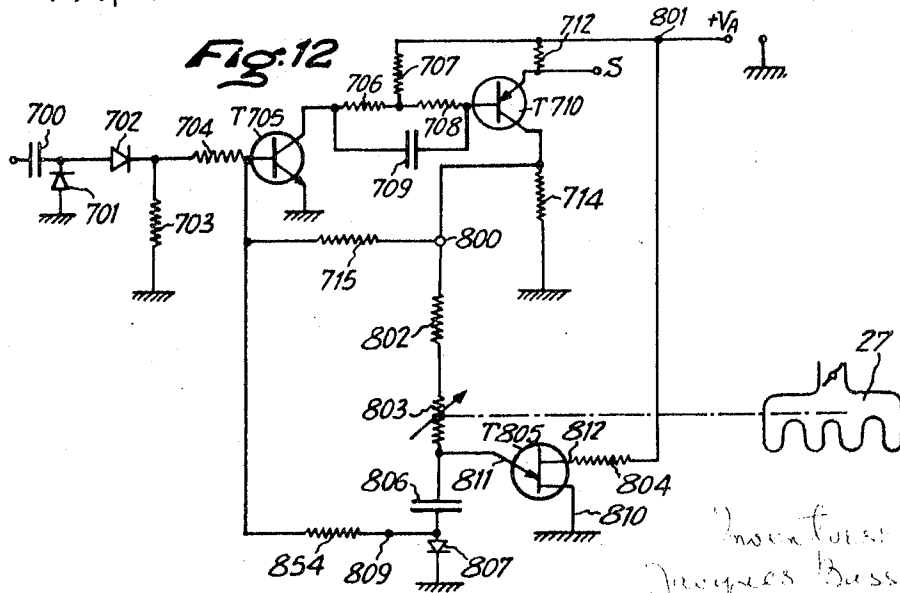
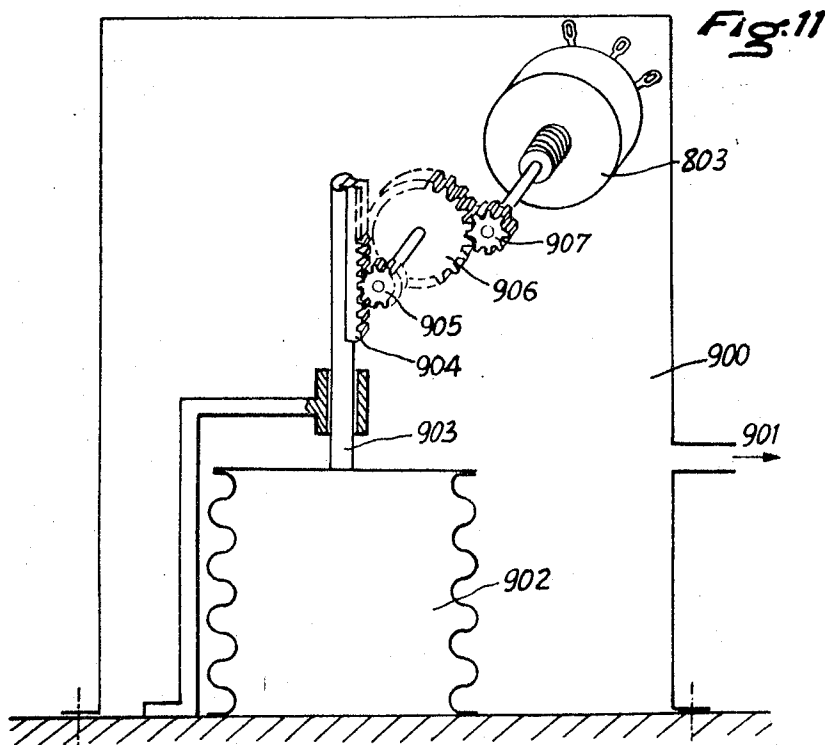
J. BASSOT ET AL

3,456,628

HIGH-SPEED FUEL INJECTION SYSTEM

Filed April 11, 1967

18 Sheets-Sheet 5



Inventors:
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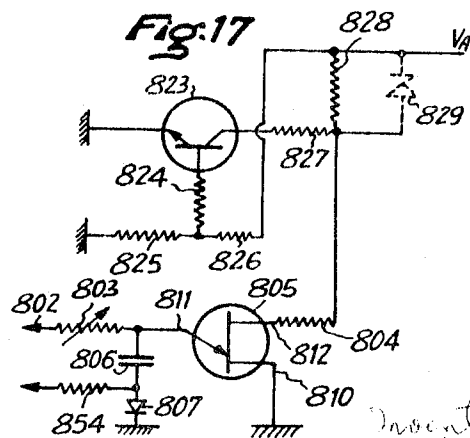
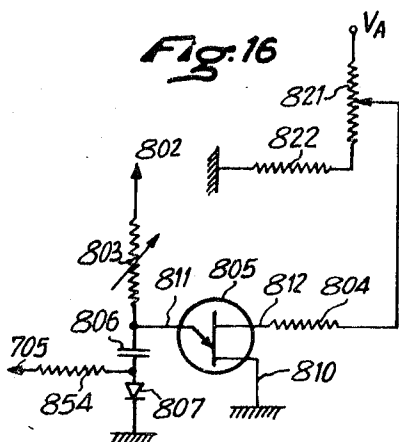
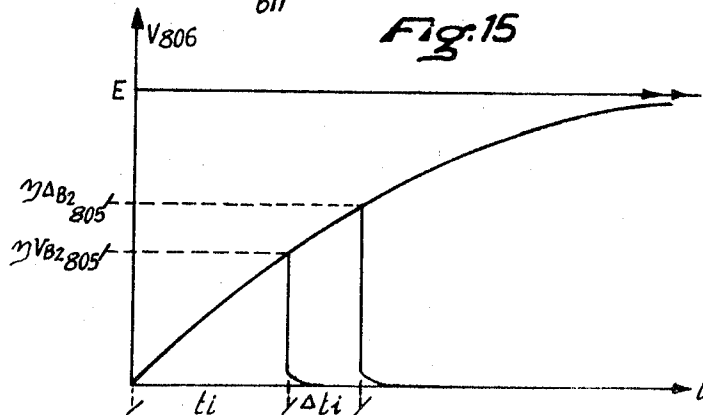
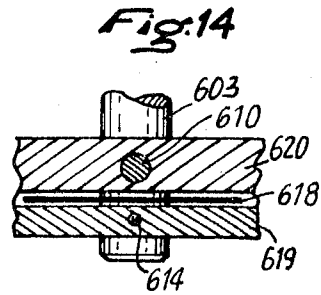
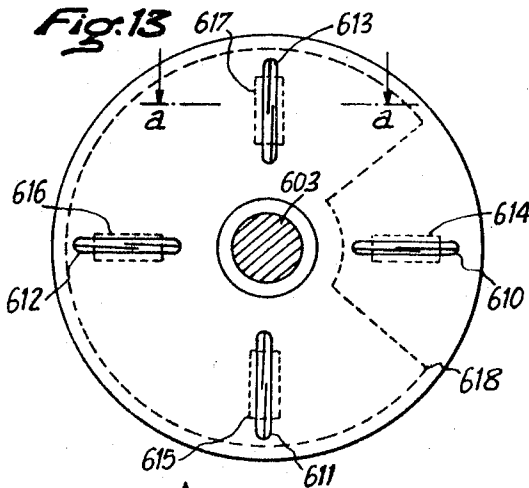
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3,456,628

HIGH-SPEED FUEL INJECTION SYSTEM

Filed April 11, 1967

18 Sheets-Sheet C



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Fig. 18

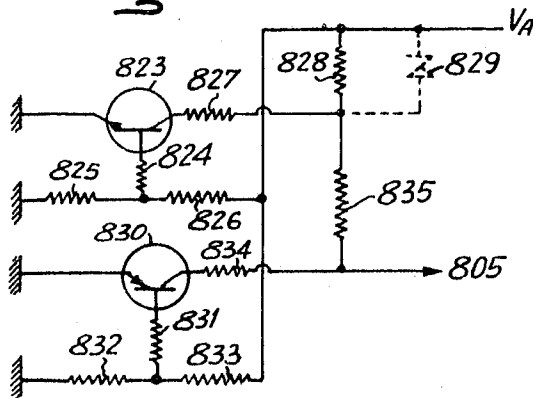


Fig. 19

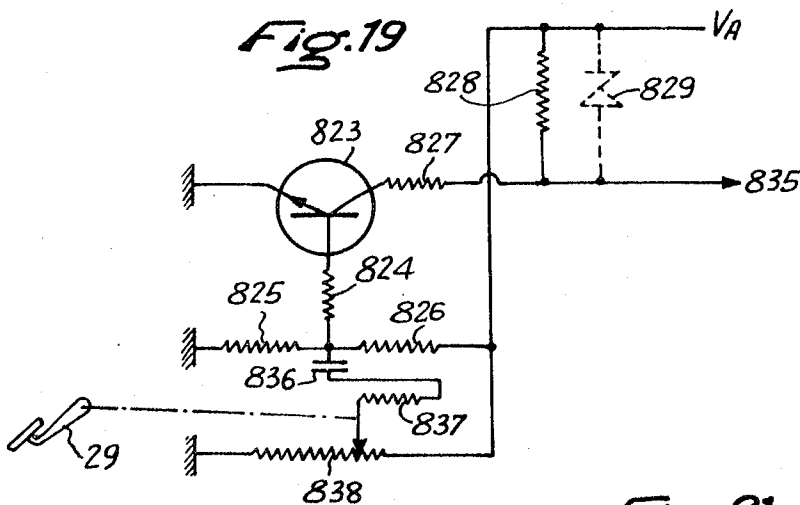


Fig. 20

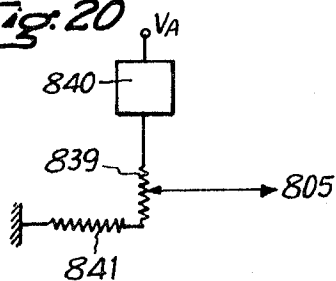
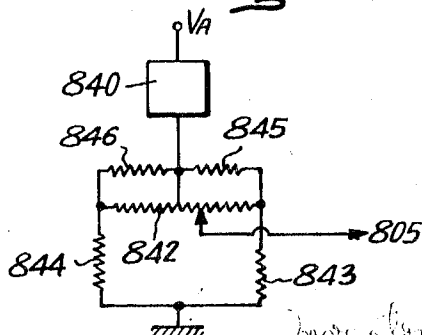


Fig. 21



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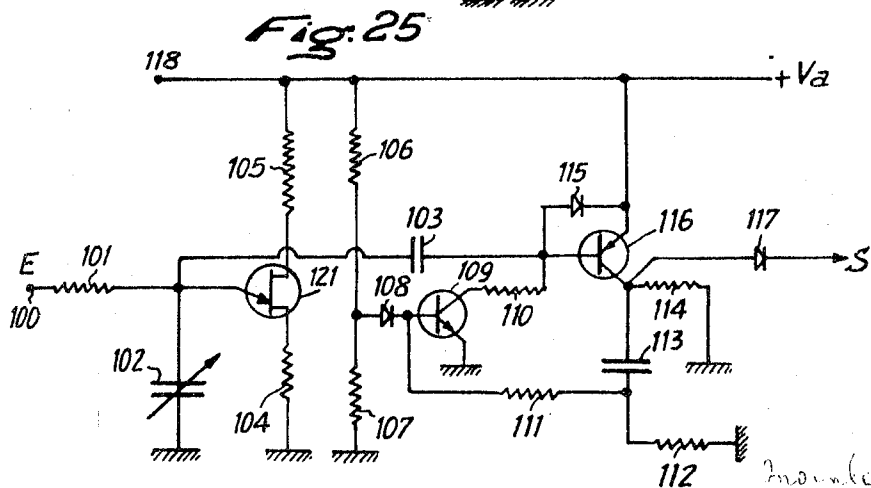
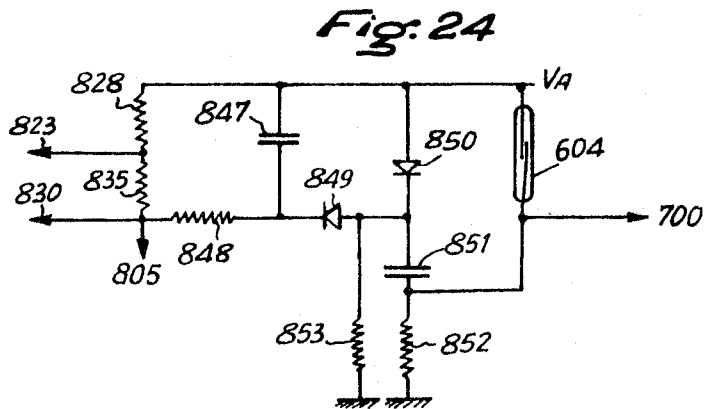
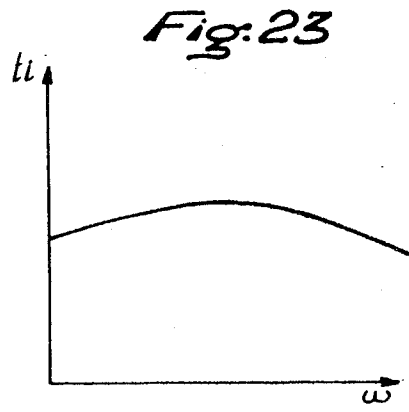
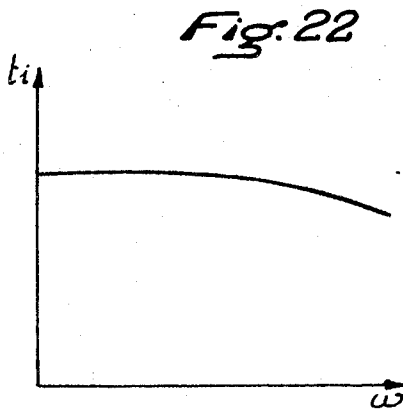
J. BASSOT ET AL

3,456,628

HIGH-SPEED FUEL INJECTION SYSTEM

Filed April 11, 1967

18 Sheets-Sheet 8



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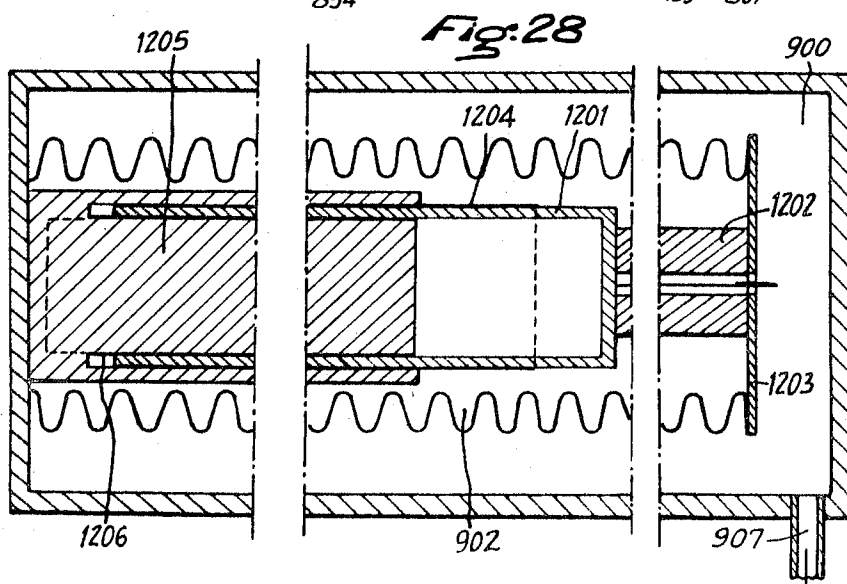
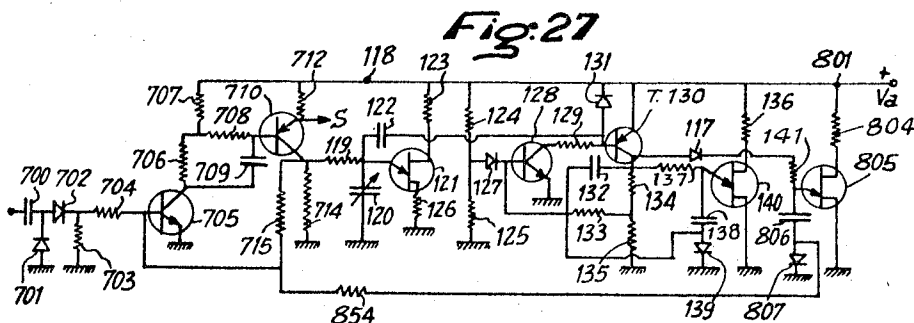
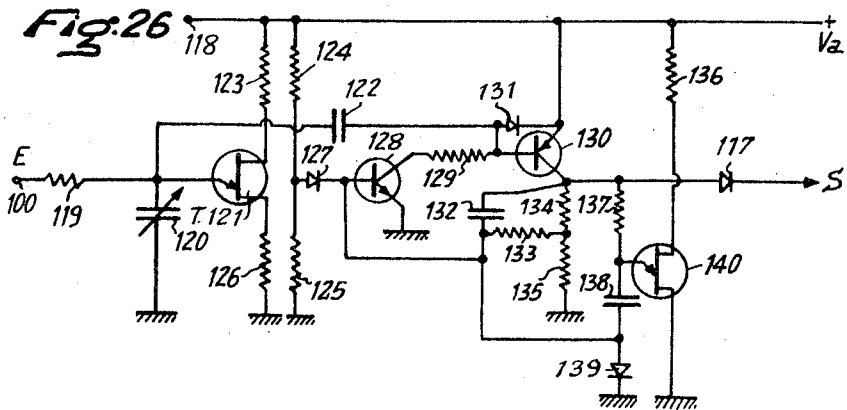
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HIGH-SPEED FUEL INJECTION SYSTEM

Filed April 11, 1967

18 Sheets-Sheet 9



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HIGH-SPEED FUEL INJECTION SYSTEM

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Fig. 29

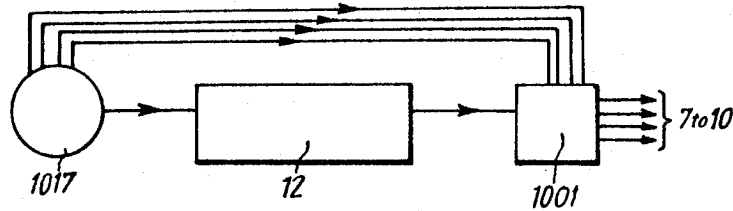


Fig. 30

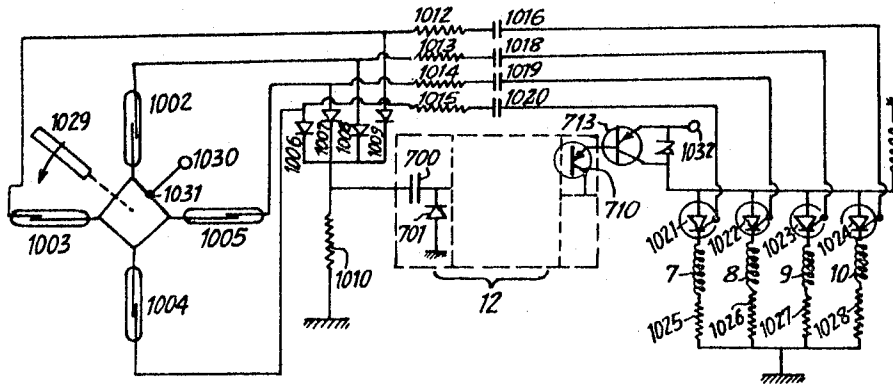


Fig. 31

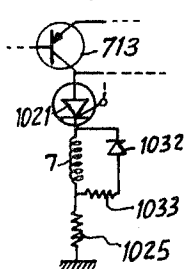


Fig. 32

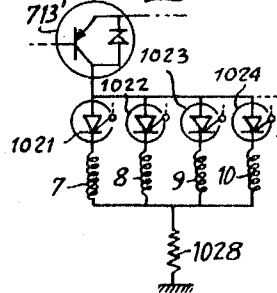
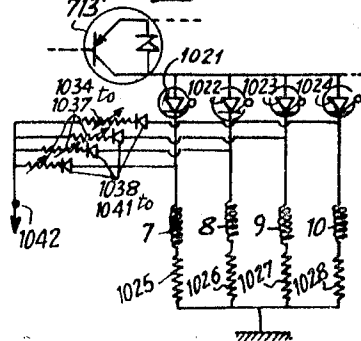


Fig. 33



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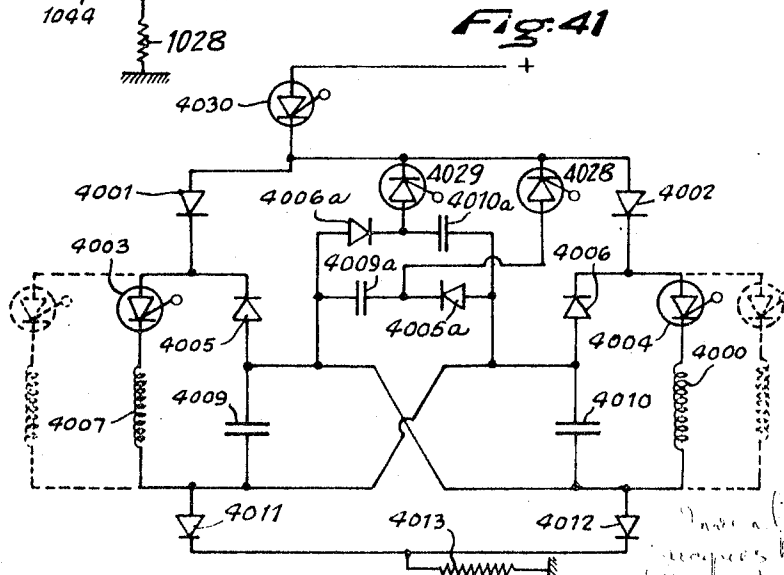
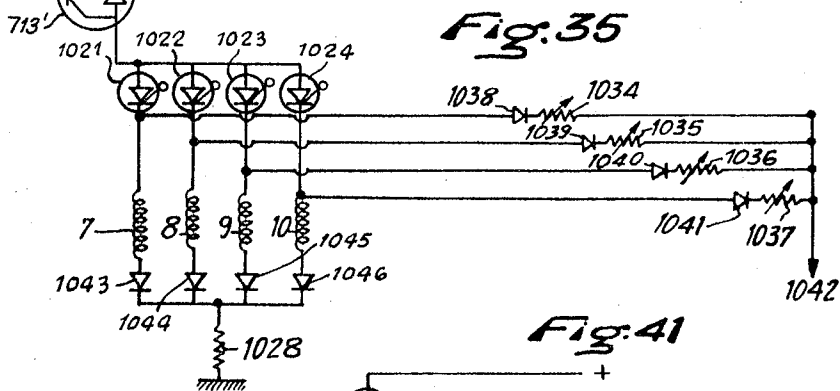
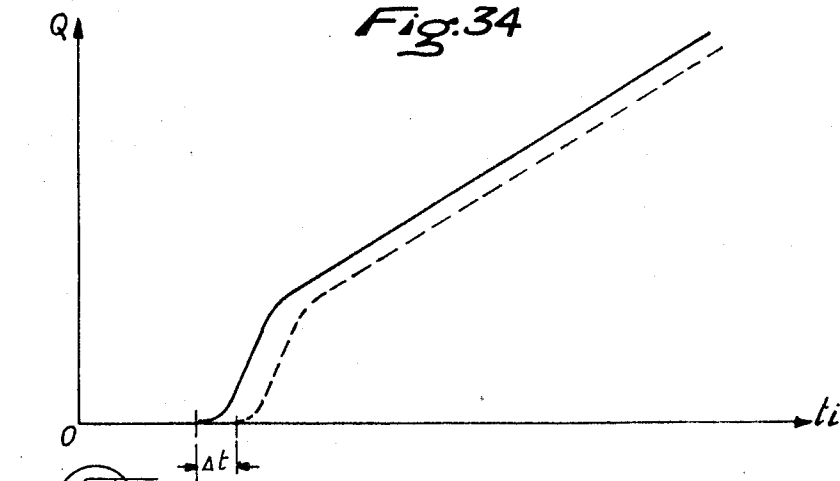
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3,456,628

HIGH-SPEED FUEL INJECTION SYSTEM

Filed April 11, 1967

18 Sheets-Sheet 11



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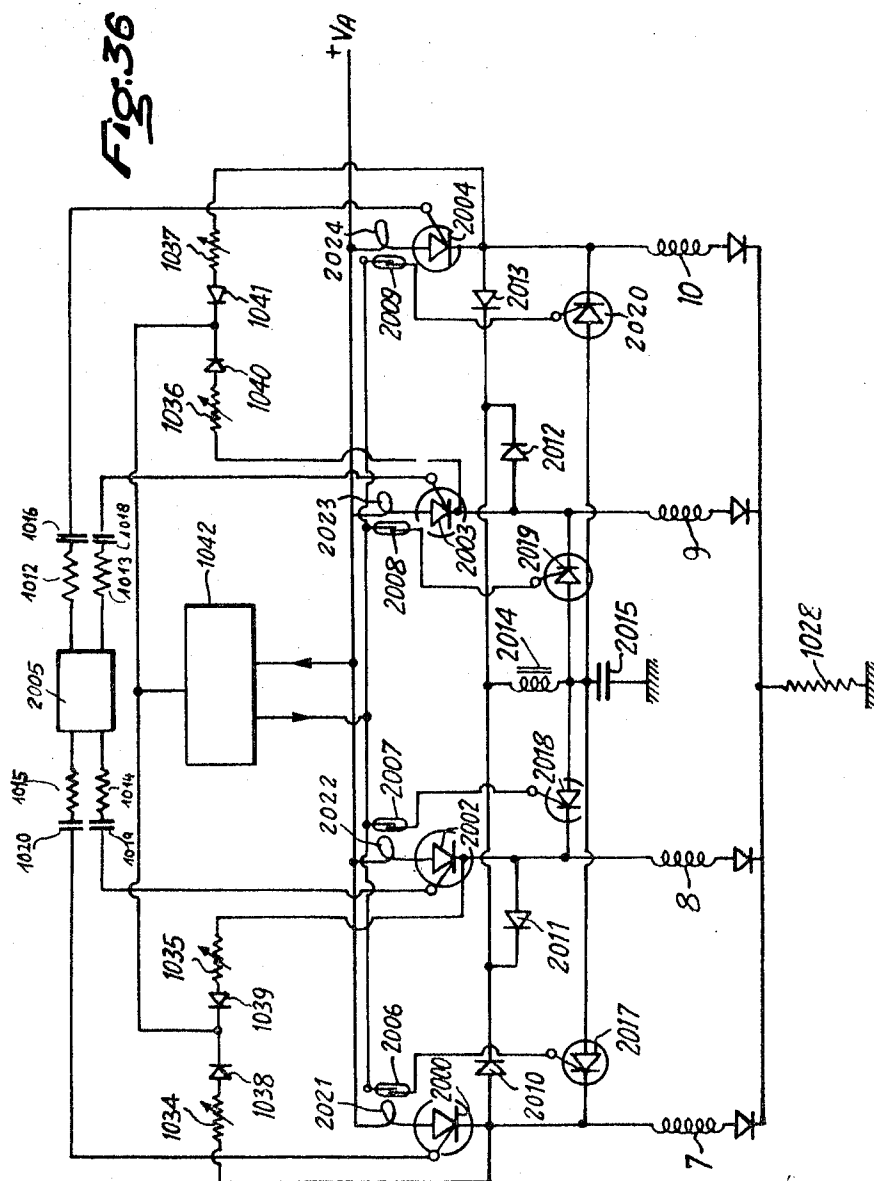
J. BASSOT ET AL

3,456,628

HIGH-SPEED FUEL INJECTION SYSTEM

Filed April 11, 1967

18 Sheets-Sheet 12



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HIGH-SPEED FUEL INJECTION SYSTEM

Filed April 11, 1967

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Fig. 37

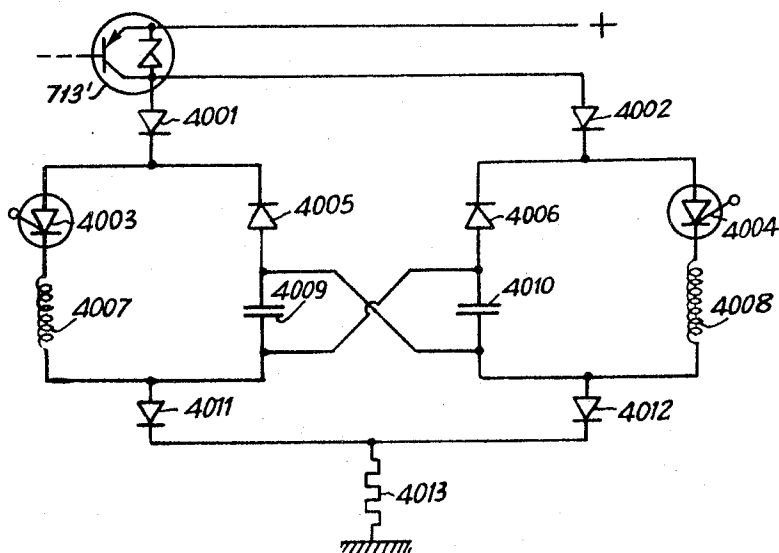
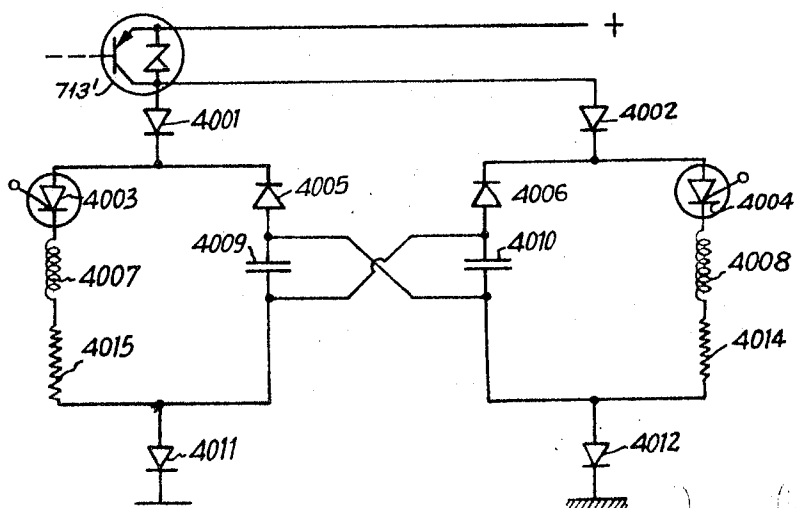


Fig. 38



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HIGH-SPEED FUEL INJECTION SYSTEM

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Fig. 39

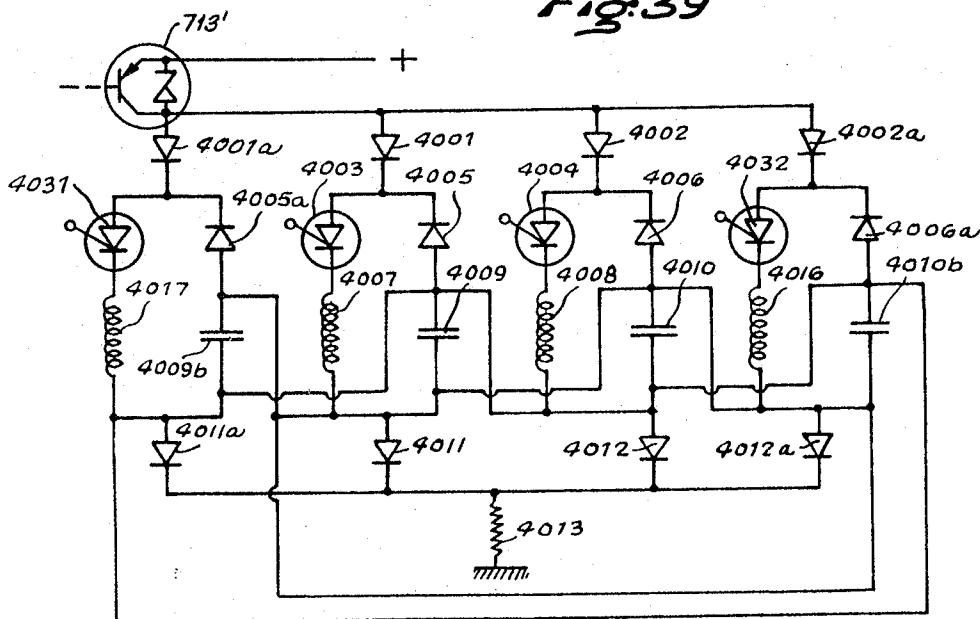
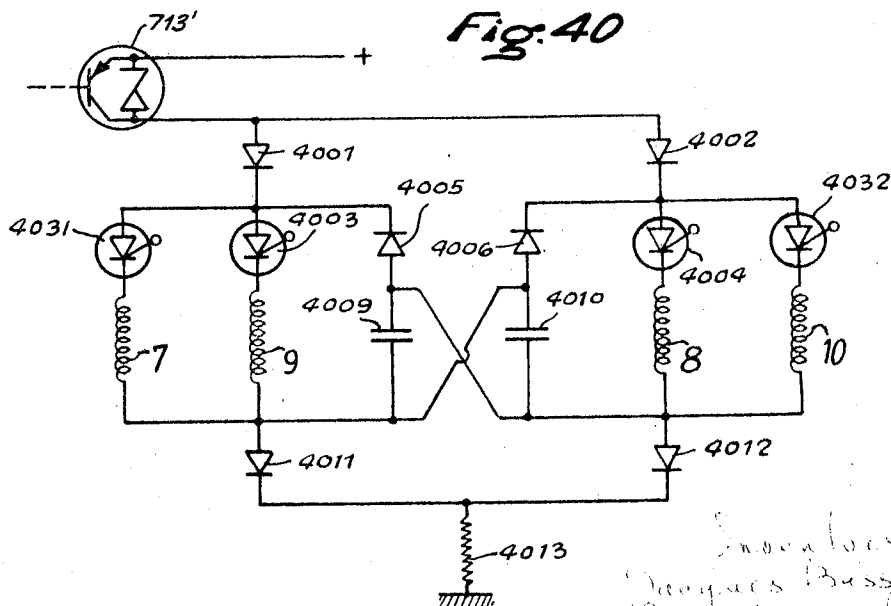


Fig. 40



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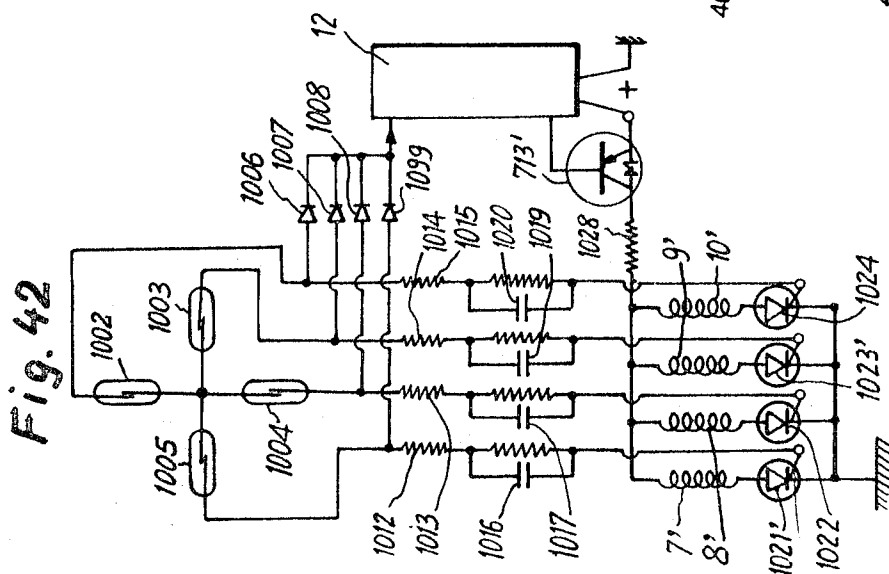
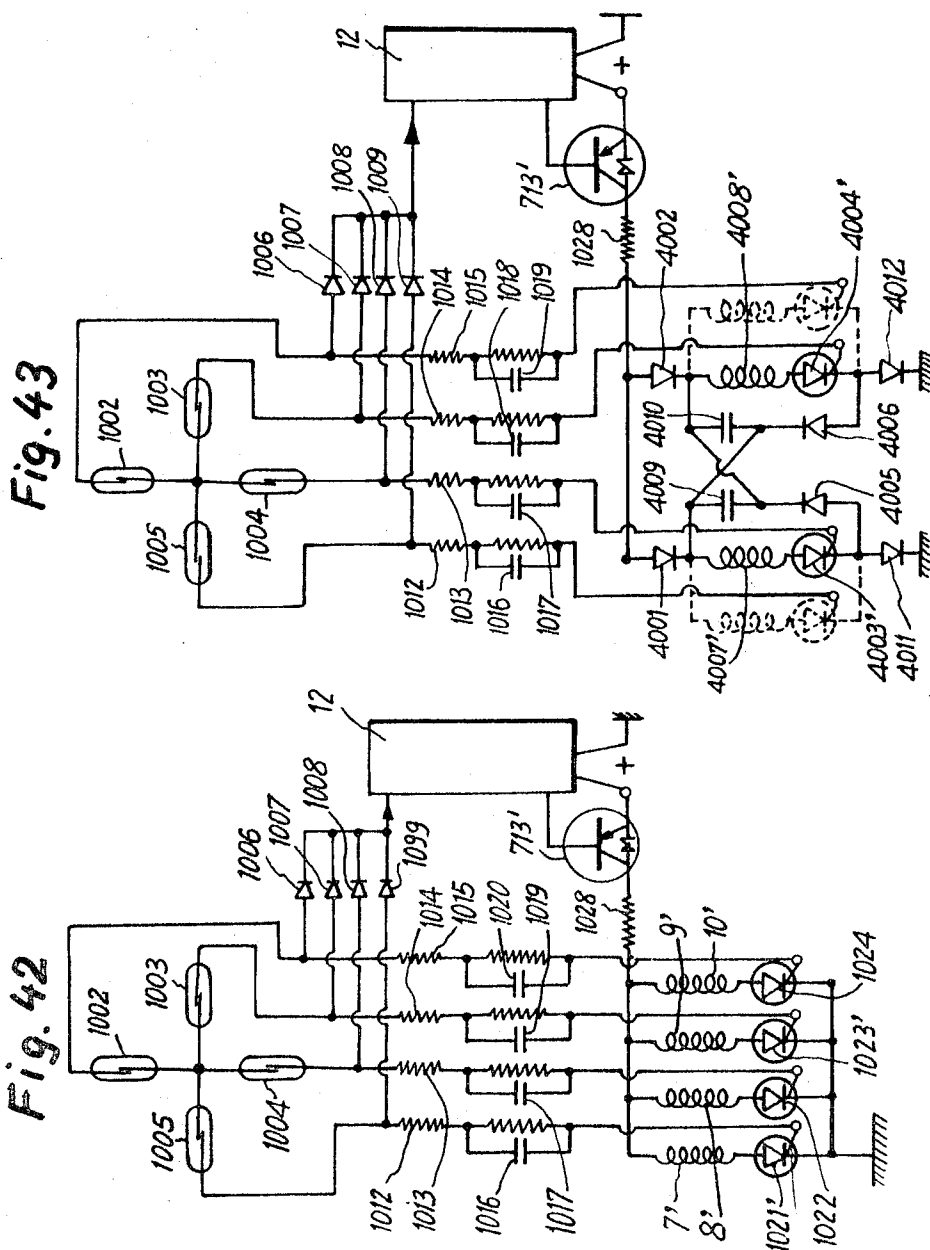
J. BASSOT ET AL

3,456,628

HIGH-SPEED FUEL INJECTION SYSTEM

Filed April 11, 1967

18 Sheets-Sheet 15



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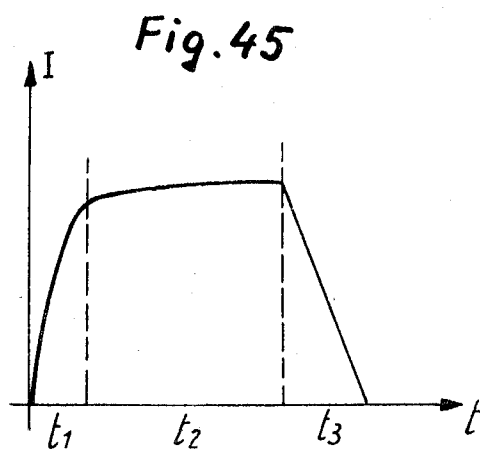
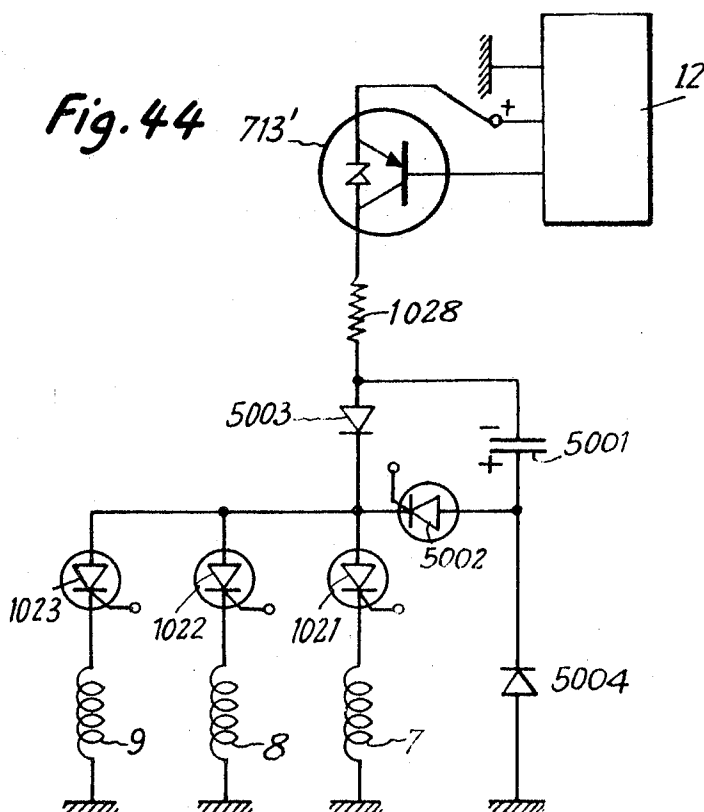
J. BASSOT ET AL

3,456,628

HIGH-SPEED FUEL INJECTION SYSTEM

Filed April 11, 1967

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J. BASSOT ET AL

3,456,628

HIGH-SPEED FUEL INJECTION SYSTEM

Filed April 11, 1967

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Fig. 46

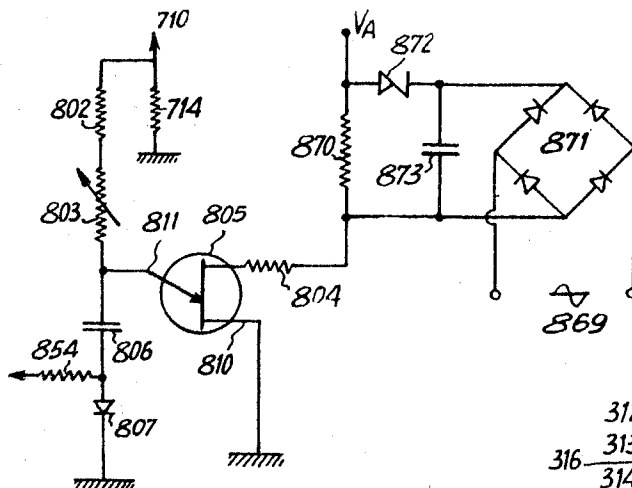


Fig. 48

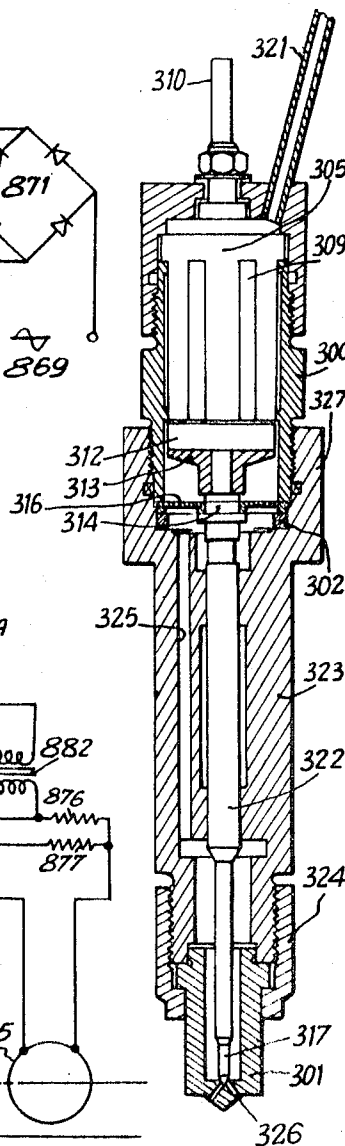
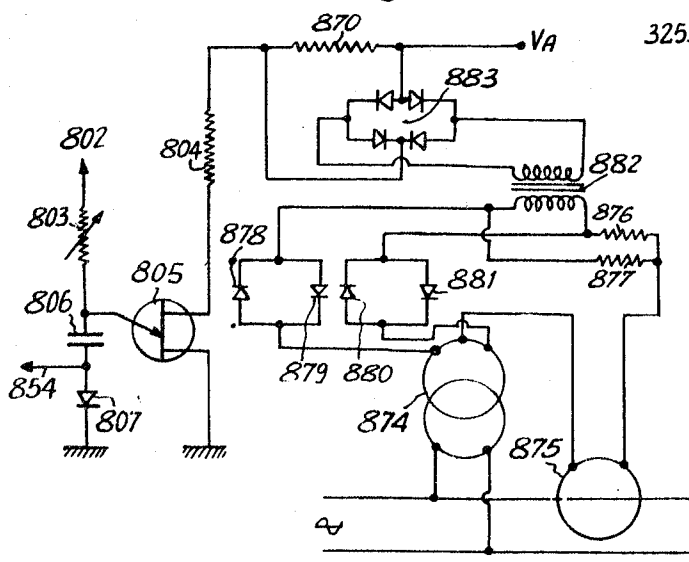


Fig. 47



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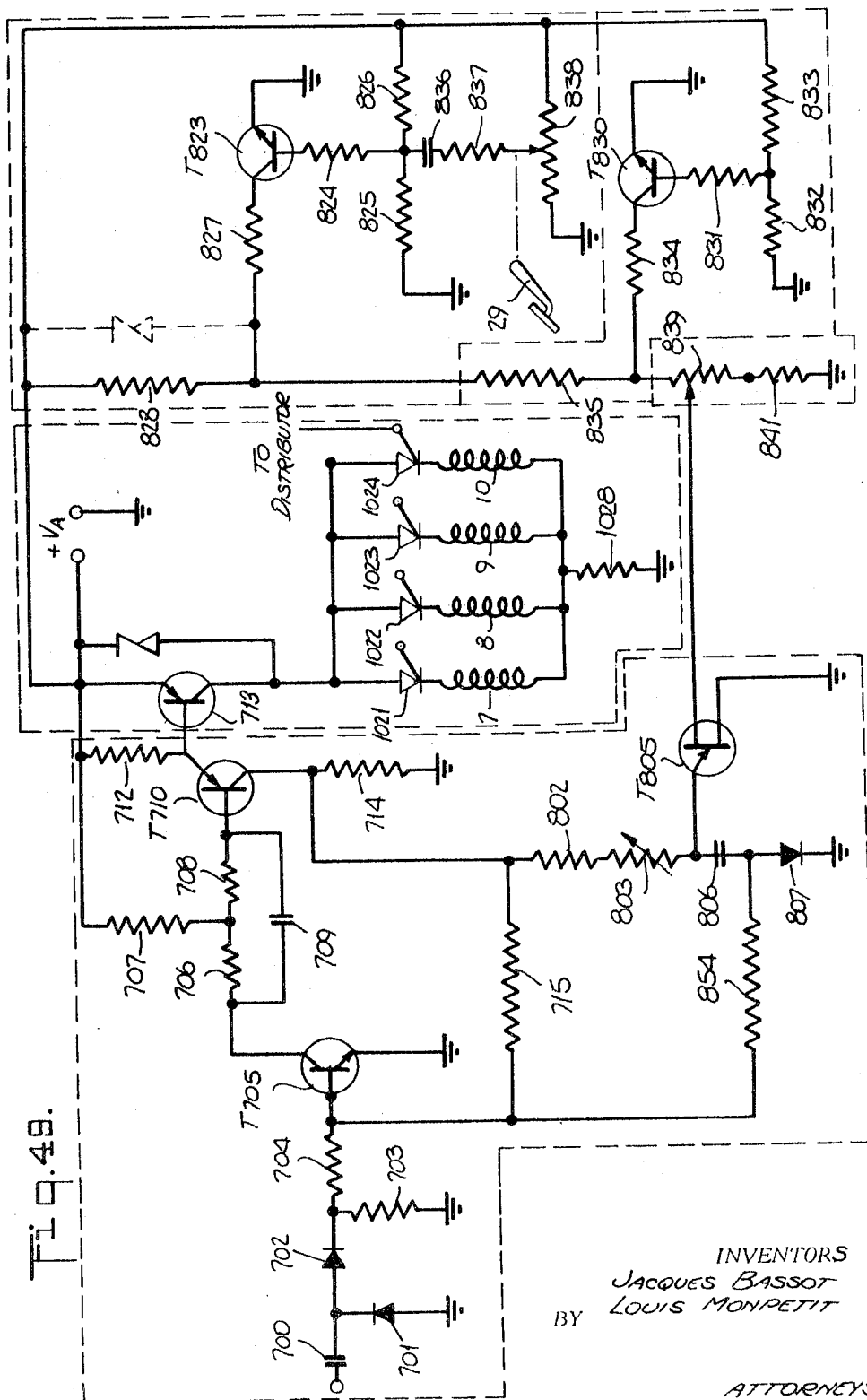
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HIGH-SPEED FUEL INJECTION SYSTEM

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HIGH-SPEED FUEL INJECTION SYSTEM

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Filed Apr. 11, 1967, Ser. No. 630,035

Claims priority, application France, Apr. 13, 1966, 57,392

Int. Cl. F02m 51/06; F02b 3/06

U.S. Cl. 123—32

33 Claims 10

ABSTRACT OF THE DISCLOSURE

Construction of high speed injectors, a special type switch mechanism for synchronizing the operation of the injectors to the angular position of a motor shaft, a uni-junction transistor time delay circuit whose base and emitter voltages are varied in response to variations in different parameters, rapid switching bistable control circuits, which control the injection period in one state, damping circuits for the injector, circuits for transferring the electromagnetic energy liberated by current interruption in one injector coil to the next injector coil to be activated, and circuits for regulating a motor driving a generator to correspond to the voltage, current or power output of the latter.

Background of the invention

The present invention relates to fuel injection systems, and in particular to fuel injection systems with electronic controls and the injectors used with said electronic controls.

It is known that use of fuel injection systems instead of carburetors for motors with controlled ignition results in a certain number of advantages which are based on the greater possibilities for regulation and for adaptation to the particular type of motor. It is thus possible to lower the fuel consumption, to increase the power, and above all to reduce the percentage of unburned matter in the exhaust gas, especially the carbon monoxide. This is of great importance in cities, where the air pollution reaches serious proportions. However, the use of conventional injection pumps as are known for diesel motors would lead to a very high price since these devices are extremely precise with very tight tolerances.

Attempts have been made to reduce these inconveniences by electronic control systems using monostable multivibrators for electromagnetic injectors. But these devices again present a certain number of difficulties as, for example, a very high price and a relatively sluggish operation. This is because the electromagnetic injectors only allow a very low injection pressure and their response time to electric signals is so long that it is impossible to provide one injector for each cylinder in either director indirect injection. On the contrary, it is necessary to provide only one injector for several cylinders, which injects during a period which corresponds to the quantity of fuel required for all the cylinders. Obviously with such a system one loses almost all the advantages of the injection system as compared to carburetors.

Summary of the invention

The object of this invention is to provide a high speed fuel injection system capable of having one controlled injector for each cylinder.

The system comprises high speed electromagnetic injectors of a special construction which inject fuel into the respective corresponding cylinders for a time duration corresponding to the duration of an injection control signal. Distributing means for synchronizing the time of

operation of each of said high speed injectors to a corresponding predetermined angular position of a motor shaft generate injection starting signals corresponding to each of said angular positions. These injection starting signals also serve as inputs to variable delay means, which generate end of injection signals after a time delay varying as a function of one or more motor or ambient parameters. Bistable control means, which switch from a first to a second state upon receipt of the injection starting signals, and back to the first state upon receipt of the end of injection signals, generate said injection control signals determining the length of the injection period while in said second state. These injection control signals are then coupled to the high speed injectors.

The novel features which are considered as characteristic for the invention are set forth in particular in the appended claims. The invention itself, however, both as to its construction and its method of operation, together with additional objects and advantages thereof, will be best understood from the following description of specific embodiments when read in connection with the accompanying drawings.

FIG. 1 is an overall diagram of the fuel injection system;

FIG. 2 is a more detailed diagram of the injection system;

FIG. 3 is a sectional view of an injector to be used in this injection system;

FIG. 4 is a curve of the operating characteristics of the injector shown in FIG. 3;

FIG. 5 is a curve showing the opening of the injector pictured in FIG. 3 as a function of time;

FIG. 6 is a curve showing the fuel quantity injected as a function of time with an injector according to FIG. 3;

FIG. 7 is a diagram showing a switching mechanism used with the injection device;

FIG. 8 is an electrical diagram showing the bistable circuit controlling the injection;

FIG. 9 is a circuit diagram of the delay element of the injection system;

FIG. 10 is a diagram showing a mechanism for obtaining regulation as a function of pressure in the inlet tubes;

FIG. 11 is another embodiment of this regulating device;

FIG. 12 is an electrical diagram showing the electronic bistable circuit and the delay element;

FIG. 13 is a diagram showing a distributor used with the injection system;

FIG. 14 is a sectional view of the distributor shown in FIG. 13;

FIG. 15 is a curve showing the duration of the injection as a function of a regulating voltage;

FIG. 16 is an electronic diagram of a manual device for enriching the fuel mixture when the engine is cold, connected with the delay element;

FIG. 17 is an electronic diagram for an automatic device for enriching the fuel mixture when the engine is cold, connected with the delay element;

FIG. 18 is an electronic diagram of an automatic device for enriching the fuel mixture when the engine is cold, combined with a device for enriching the fuel mixture as a function of the inlet air temperature;

FIG. 19 is an electronic diagram of a device connected to the gas pedal for allowing temporary enrichment of the fuel mixture;

FIG. 20 is an electronic diagram of a device for correcting the duration of the injection as a function of the rotational speed of the motor;

FIG. 21 is another embodiment of a device for correcting the duration of the injection as a function of the rotational speed of the motor;

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FIG. 22 shows a curve showing the duration of injection as a function of the speed of rotation with the device shown in FIG. 20;

FIG. 23 is a curve showing the duration of injection as a function of motor speed with the device shown in FIG. 21;

FIG. 24 shows another embodiment of a device for correcting the duration of injection as a function of motor speed;

FIG. 25 is an electronic diagram showing a relaxation oscillator combined with a bistable circuit;

FIG. 26 is an electronic diagram of a circuit according to FIG. 25 combined with the delay element;

FIG. 27 is a general electronic diagram utilizing a relaxation oscillator as a regulating element;

FIG. 28 is a sectional view of a capacitor having a capacity which varies as a function of the manifold pressure;

FIG. 29 is a block diagram showing an electronic distributing arrangement device;

FIG. 30 is a circuit diagram of an arrangement according to FIG. 29;

FIG. 31 is a diagram showing an electronic circuit for protection of the power transistor;

FIG. 32 is another embodiment of the circuit shown in FIG. 31;

FIG. 33 is an electronic diagram for an arrangement permitting individual adjustment of the duration of injection;

FIG. 34 is a curve of the quantity of fuel injected, as a function of time, with an arrangement according to FIG. 33;

FIG. 35 is another embodiment of an electronic device permitting individual adjustment of the duration of injection;

FIG. 36 is a general diagram of an injection device using thyatrons in the bistable circuit controlling the duration of the injection period;

FIG. 37 is a first arrangement for the recovery of magnetic energy;

FIG. 38 is a second arrangement for the recovery of magnetic energy;

FIG. 39 is a third arrangement for the recovery of magnetic energy;

FIG. 40 is a fourth arrangement for the recovery of magnetic energy;

FIG. 41 is a fifth arrangement for the recovery of magnetic energy;

FIG. 42 shows an arrangement for preventing over-voltages due to interruption of the injection control coil current;

FIG. 43 is the arrangement of FIG. 42, combined with an arrangement for the recovery of magnetic energy;

FIG. 44 shows an alternate method for recovery of magnetic energy;

FIG. 45 shows the current in the injector coil as a function of time, for the circuit of FIG. 44;

FIG. 46 is a circuit for varying the injection period of a diesel engine as a function of the output voltage of an alternator driven by the engine;

FIG. 47 is a diagram of the circuit for varying the injection period as a function of the power delivered by an alternator driven by the diesel engine;

FIG. 48 is a diagram of an injector designed for use in a diesel engine; and

FIG. 49 is a schematic diagram illustrating the interconnection of the circuits illustrated in FIGS. 12, 17, 18, 19, 20 and 32, providing one example of how the injection period for each injector may be controlled as a function of a plurality of motor parameters.

Description of the preferred embodiments

Referring first to FIG. 1, a pump 1, driven as described below, has an intake by way of a filter 2 either directly from a fuel tank 3 or by way of a feed pump 4, and pumps the fuel by way of filter 5 towards the electro-

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magnetic injectors numbered 7 to 10. The circuit has a pressure regulating discharge valve 6 and if necessary a mechanical or pneumatic back pressure accumulator 11.

The electrical and electronic circuitry is fed by a source of energy, generally the storage battery 13, which itself is connected in a conventional manner to a generator 14 by way of a conventional regulator 15. The power may be connected to the electronic circuitry by switch 16. This switch may be operated independently or it may be connected to the switch furnishing the power for the motor ignition. The control means 12, receives information regarding the angular position of the motor from a device 17 and transmits orders in the form of current pulses, to the injector 7 to 10 by way of the distributor 18, which itself is made dependent on the angular position of the motor by the device 19.

Devices 17 and 18 thus constitute distributing means for synchronizing the time of operation of each of the high speed injectors to a corresponding predetermined angular position of the crank shaft. The control device 12 delivers current pulses which have a fixed amplitude and a width varying linearly with the manifold pressure through the distributing means 18 according to a signal furnished by a device 20. The manifold pressure is hereinafter called the fundamental regulatory parameter.

It should be noted that the particular parameters used for regulation in the embodiment shown are used purely as illustrative examples and are not intended to be limiting on the system, since the system is capable of accommodating many other parameters also.

The current pulses furnished by the device 12 undergo, by way of the devices 21 to 26, corrections based on:

(a) The local atmospheric pressure transmitted by device 21, eventually incorporated into device 20.

(b) The motor temperature transmitted by device 22.

(c) The temperature of the inlet air transmitted by device 23.

(d) The speed of depression of the pedal controlling the opening of the butterfly valve, transmitted by device 24. This device plays the role of the acceleration pump in a conventional system having a carburetor.

(e) The value of the coefficient of the rate of introduction of air to the motor, a value which depends on the speed of the motor and on the shape of the manifold. This correction is transmitted by the device 25.

(f) The angular lead or lag of the injection which is transmitted by the device 26.

As was stated above the fuel pressure is delivered by the pump 1 which acts as a simple liquid compressor and has no part in determining quantities to be furnished. This pressure exists only at the pump and not in the injectors themselves, which can operate under several hundred bars (a bar is the international unit of pressure) of pressure. For economic reasons the operating pressure of the order of ten bars for indirect injectors and of the order of thirty bars in direct injections are used. In any case the pumps used are of conventional type as for example gear pumps.

Valve 6 and the accumulator 11 used in conjunction with piston or gear pumps permit a substantially constant injection pressure to be maintained. The pump may be driven either by the motor itself or by an electric auxiliary motor.

In a preferred embodiment, the pump 1 is a gear pump driven by an electric motor and the necessity for the accumulator 11 is eliminated. If the electric motor is used it may be energized automatically by a switch connected to the system which furnishes the voltage for the ignition system.

However, if the pump is driven directly from the motor itself, the accumulator 11 is generally necessary. The valve 6 which regulates the pressure may be of a classical pressure regulating type or may be an electrically controlled valve.

In the latter case a valve having a construction similar

to that of the injectors described below is preferably, although not necessarily, used.

If a pump directly driven by the motor is used, the pressure in the feed pipes of the injectors may drop during a long idle period due to leakage at the valves 6, 28 even though the injectors 7 to 10 are perfectly liquid tight. In this case, if one wishes to avoid waiting until the pressure has risen sufficiently, when restarting the engine, it is possible to interpose an electric valve 200 (FIG. 2) between feed pump 4 and the injectors 7 to 10. This electric valve is controlled by a pressure gauge 201, which by means of a relay box 202, changes the electric input to the injectors 7 to 10 from the normal electrical system to a separate voltage source.

The injection system shown in FIGS. 1 and 2 utilizes electromagnetic injectors having a particular embodiment described below.

The injector shown in FIG. 3 consists of a housing 300, at the lower internal extremity of which is mounted a needle valve 301 which provides a tight seal. This needle valve 301 is mounted in the housing by means of a threaded collar 308 and comprises the nozzle housing, 302; a bracing member, 303; the electrical enclosure, 304; the magnetic circuit 305; and the cover 306 having a seal 307.

The current enters one of the ends of the coil 309 by the isolating terminal 310, the other terminal being connected to ground by the immersed terminal 311. In certain embodiments the terminal 311 may be a jack which permits the isolation of both ends of the winding from ground. The laminated magnetic circuit 305 is formed in an E shape. The three lower pole faces are opposite a magnetic armature 312 which is housed in a retainer 313, and mounted on intermediary member 314. A disc 315 is attached to the lower part of the piece 314, which has a shoulder supporting an elastic membrane at its upper part. Complete closure is assured by plunger 317 connected to member 314. At rest, in the absence of fluid pressure, tight closure is assured by a supporting pressure obtained from spacer 318 which preloads the membrane 316. A spacer 319 permits easy establishment of a predetermined air gap. Lamina 320, made of plastic material known under the name of Mylar, act as dampers by hydraulic throttling and thus prevent oscillations on opening and rebounds on closing. The fuel intake takes place through the tube 321 connected to the cover 306. It is evident that with this type of design the injector cannot stick no matter what fuel is injected.

The embodiment of the injector as described above results in the following characteristics:

The ampere turns furnished to the magnetic circuit by the winding 309 are sufficient to saturate the circuit magnetically at least in the central branch. As a result the force exerted by the winding of 309 on the armature 312 as a function of the air gap has the shape of the curve 400 in FIG. 4. If at rest the position and the force resulting from the preloading are shown at the point marked 402, and if the straight line 401 is the line representing the elastic reaction of the membrane 316, then the equilibrium point of the movable part of the injector is shown by the point 403. The distance between the rest and the equilibrium position of the plunger are determined by the difference between the abscissas of points 402 and 403. To avoid having the armatures 312 strike the stationary magnetic circuit, it is sufficient to calculate the various elements in such a way that the doubly hatched surface of FIG. 4 is equal to or greater than the singly hatched surface. Furthermore the travel of the piston is determined as the minimum travel for which the throttling under the center (in the open position) is negligible as compared to the throttling in the needle valve.

The injector is thus characterized by a magnetic circuit which has only the necessary air spaces and which thus for a given number of ampere turns attains very high values of magnetic induction and through large sur-

faces of attraction. These two characteristics together result in a high attractive force and thus permit one to obtain frequencies of the order of 1 kilohertz with the movable parts.

Therefore a perfectly linear response curve for the injector is obtainable. As was described above, the thin lamina, made of Mylar (320, FIG. 3) having a total thickness slightly less than that of the residual air gap are disposed between the movable part and the fixed pole pieces of the magnetic circuit, such that the travel of the movable parts is limited by severe hydraulic breaking with energy dissipation when the equilibrium position is approached. In the same way, again referring to FIG. 3, sheets of Mylar are disposed between the disc 315 and the nozzle 302 to avoid rebounds on closure.

The characteristic curve of the piston movement as a function of time is shown in FIG. 5 and that of the flow in FIG. 6. For an injector as described above the time duration of t_1 is approximately 400 microseconds, t_2 is of the order of 300 microseconds and t_4 is of the order of 400 microseconds. The total time of opening is substantially equal to the duration of the control current pulse (injection control signal), but displaced from it by approximately 400 microseconds.

The flow as a function of the duration of the control current pulse (injection control signal) therefore becomes rigorously linear starting with a very short duration of electrical pulse. The injection system will therefore function between the duration (t_r , FIG. 6) corresponding to no-load operation and the duration t_p corresponding to full power operation of the motor. It will be noted on FIG. 6 that for a slight diminution of the duration of the current pulse (the injection control signal) under the value t_r , the quantity injected becomes zero. This characteristic results in lowering of the percentage of carbon monoxide and unburned matter to almost zero during periods of abrupt deceleration of a vehicle (motor-braking). During this particular period the amount of carbon monoxide and unburned matter normally ejected by a vehicle using a carburetor is particularly great.

A device 17 (FIG. 1) delivers a pulse at the moment the motor passes through a certain number of positions determined in advance, for example at the opening of each of the inlet valves.

In a preferred embodiment the device 17 is a system independent of the ignition control system, with switches having magnetizable flexible lamina. This system has the advantage of transmitting signals which may be used directly by the control system 12 and also permits the regulation of the advance or retardation of the fuel injection independent of the advance of the ignition.

FIG. 7 shows a view of the device. A fixed non-magnetic disc 601 carries one or more switches of the type mentioned above, such as 604, mounted in a cylindrical opening. A second stationary disc 600 similarly carries one or several permanent magnets such as 605 opposite of the switches 604. In the absence of a magnetic screen the switches are closed due to the magnetic field of the magnets. Magnetizable sheets 602, connected so as to move with the shaft of a motor, as for example the crank shaft, allow a magnetic screen to be placed periodically between the members 604 and 605. By proper choice of the number of switches and sheets one may therefore obtain a signal for each cycle of each cylinder.

Finally, the turning member is furnished with an advancement device of known type operating under centrifugal force.

The current pulse, or injection control signal, delivered by the control means has a duration which is linear with respect to the fundamental parameter of motor operation, and is modified by other correction parameters.

According to this invention a bistable control circuit of intermediate power level is used. The circuit is switched from a first state to a second state by the injection starting

signal generated by device 17, and is flipped back by an end of injection signal whose spacing in time from the first signal is determined by information furnished by devices 20 to 26. Both commands are furnished in the form of switching voltages which, in case of an embodiment using transistors, insure a very rapid communication.

The bistable circuit is shown in FIG. 8. The transistor controlling the injector or injectors, 713 (terminals S) is not strictly speaking a part of the bistable circuit.

Starting from a rest condition, an injection starting signal, in form of a positive pulse, furnished by device 17 is transmitted to the binary circuit, by the capacitor 700, which will later discharge through diode 701. The pulse is transmitted to the base of NPN transistor 705 by diode 702 and resistor 704. This voltage injection starting pulse causes very rapid switching of the transistor, which in turn causes the switching of PNP transistor 710 by way of resistances 706 and 707 and capacitor 709. This in turn causes control transistor 713 to become saturated.

The bistable circuit is maintained in this second state, during which injection takes place, by feeding back a saturation base current for transistor 705 from the terminal of resistor 714 by means of resistor 715. The resistances 703, 707 and 712 maintain the proper voltages at the bases of the transistors and avoid extraneous flipping due to charge effects.

The bistable element is returned to a blocked state by a negative pulse on the base of transistor 705.

The circuit which controls the duration of the injection, FIG. 9, is supplied with a voltage E at terminal 800 and with a voltage V_{B2} at terminal 801.

The voltage source E charges a capacitor 806 through resistor 802, a potentiometer connected as a rheostat 803, and diode 807.

Transistor 805 is a double base or unijunction transistor. Its first base 810, is connected to ground. The voltage V_{B2} at terminal 801 is supplied to the second base, 812, through resistor 804. At rest the diode formed by the emitter 811 and base 1, 810, of transistor 805, is non-conductive. However, it is rapidly energized when the voltage at 811 attains a predetermined value:

$$V_p = \eta V_{B2}$$

where η is the base-emitter coefficient of transistor 805.

Energization takes place at a time t such that:

$$E(1 - e^{-t/RC}) = V_p = \eta V_{B2}$$

where R = the sum of resistors 802 + 803 and C is the value of capacitor 806. Thus:

$$t = RC \ln(E/E - \eta V_{B2})$$

When transistor 805 is energized, the voltage at terminal 809 changes from a zero (ground) value to:

$$-V_p$$

thus polarizing diode 807 in the reverse direction. This negative pulse is used to switch the bistable circuit back to the blocked (or first) state.

The circuit shown in FIG. 9, which is extremely simple is the variable delay means which determine the duration of the injection period. The duration, t , of the injection thus varies linearly with the value R or C .

The fundamental parameter constituting the criterion for the motor regulation is, as mentioned above, a parameter varying linearly with the amount of air admitted to the cylinders, or, which is the same thing, the pressure P in the manifold for a given air temperature. In a first embodiment of this invention the pressure P affects the value R of the potentiometer 803 according to the system shown in FIG. 10.

A pipe is connected to the manifold 27 (FIG. 1) at a point below the butterfly valve and is connected to the entrance 813 of a pressure chamber 814, which is sealed by an elastic member 815. The displacement of piston 821

is dependent on the pressure in chamber 814 and on the spring pressure exerted by spring 816. The movement of the piston causes pinion gear 818 to turn as a function of the motion of rack gear 817. Gearing 818 is in turn connected to the potentiometer 803.

If P is the absolute pressure in the pipes and P_0 the local atmospheric pressure:

$$R = R_m P / P_0$$

where R is the resistance as a function of the absolute pressure P in the manifold and the local atmospheric pressure P_0 and R_m is the maximum value of the variable resistor used.

For small variations in P_0 :

$$\Delta R / R (=) - \Delta P_0 / P_0$$

To make the system independent of these small changes in atmospheric pressure the body of the potentiometer is connected to a vacuum chamber 820 by leverage 819. However, this correction is not rigorous except for a given value of P .

Therefore, a preferred embodiment of the invention is the device shown in FIG. 11.

A liquid-tight housing 900 is connected to the inlet tube 27 by a pipe connected at the orifice 901. The only things passing through the walls of the housing are the electrical conductors of the potentiometer 803 and these too are liquid-tight.

The absolute pressure in the pipes acts on a vacuum membrane 902 which is connected by a rack gear 904 and a gearing 905, 906 and 907 to the axis of the potentiometer 803. Thus:

$$R = R_m \cdot P$$

Of course the particular form of the member 902 and the gearing may be modified. FIG. 11 is only given as an illustrative example.

The electronic control system 12 therefore becomes that shown in FIG. 12. Transistor 713 (FIG. 8) is omitted here.

As was described above, the variable delay means which determine the duration of the injection period is put into operation at the time of the switching of the bistable element by the injection starting pulse derived from device 17 (FIG. 1). After a time proportional to the pressure P the end of the injection signal, namely a negative pulse, is transmitted by resistor 854 to the base of the transistor 705.

The system as shown above has a very great temperature stability. The principal variation is caused by variations in V_p ; thus the control is calculated to yield:

$$V_p = \eta V_A$$

Thus the derivative, for voltage-controlled transistors 705, 710 and 713, can only be due to the variations of η less than $\pm 0.001\%$ per degree.

The change with temperature per degree is less than .01% even if the transistors 705, 710 and 713 are germanium. The change with temperature is even less if silicon transistors are used. However their use is not generally justified at the present time because of the higher price.

Since the duration of the injection period varies only with the ratio of E/V_{B2} the system also has a high stability with respect to voltage changes.

FIGS. 13 and 14 show a simple embodiment of distributing means 18 (FIG. 1), using a switch having elastic thin lamina if the speed of the motor permits it. In practice the device 18 and device 17 are combined and their movable parts are connected to a shaft of the motor, for example the crankshaft.

As shown in FIGS. 13 and 14 such a distributor has four power switches in the case of a four cylinder motor. These switches have elastic magnetizable lamina 610 to 613 lodged in the cylindrical cavities of a stationary non-magnetic disc 619. Opposite this disc, and a certain distance removed from it, is a second stationary disc 620 in

which small permanent magnets 614 to 617 are mounted opposite to each switching lamina 610 to 613, thus assuring the closing of the switches in the absence of a magnetic screen between the two discs. The movable part of the distributor consists of a magnetic disc 618 having a cutout sector, thus assuring that each of the switches 610 to 613 is closed consecutively for a period exceeding the maximum duration of injection.

The armature of the device 17 is displaced with respect to the sector of the distributor 18 by such an angle that the switch (610 for example) is closed before the injection signal delivered by it has been transmitted to the control circuit 12.

In this type of operation the distributor itself does not affect the electric switching at all either in opening or in closing. Furthermore the switches 610 to 613 are thus able to reach a stable state after the transients due to rebounds on closing. In addition to the fundamental parameter determining the injection period, namely the pressure in manifold 27, it is necessary to provide other corrections to assure the good functioning of the motor namely:

(a) An enriched fuel mixture for starting with a cold engine.

(b) A correction as a function of the inlet air temperature.

(c) A supplementary injection in case of rapid acceleration.

(d) A correction depending on the rate of air admission to the motor, which depends on the rotational speed of the motor.

To facilitate understanding of the arrangement for enriching the fuel mixture for starting with a cold motor, the curve of FIG. 15 may be consulted, showing the variation of injection duration with regulating voltage. The duration of injection is given by:

$$t_i = RC1n(E - \eta V_{B2})$$

Therefore if V_{B2} is increased for starting with a cold motor, t_i will increase.

Enrichment of the mixture when starting with a cold motor is obtained as shown in FIG. 16. A potentiometer 821 and a fixed resistance 822 form a voltage divider for the base 2 of transistor 805. Under normal operation, the movable slider is at the junction point of the resistors 821 and 822. In case of starting up a cold engine, the movable arm moves up along the resistor 821, which causes an increase in the voltage V_{B2} . Thus a manual control of enrichment is readily furnished.

In another embodiment, this enrichment may be regulated automatically with or without additional manual regulation.

FIG. 17 shows the automatic control for this. A voltage divider is formed by resistances 828, 827, and the transistor 823. The voltage at the base of the latter is determined by resistors 824, 825 and 826. Voltage V_{B2} of transistor 805 is thus a function of the collector current of transistor 823. Here the temperature effect of a silicon transistor capable of sustaining relatively high temperatures is used. This transistor, enclosed in a capsule filled with oil, is inserted in the block of the motor. When the motor warms up, the current in the collector of transistor 823 increases and voltage V_{B2} diminishes, thus diminishing the richness of the mixture.

This system is extremely stable and viable, since transistor 823 is in intimate contact with the water. To limit the enrichment effect to start with a given water temperature, for example 70° C., a Zener diode 829 may be connected across the terminals of resistors 828. More simply, resistors 824, 825 and 826 may be chosen such that transistor 823 is saturated for the chosen water temperature. In another embodiment, additional enrichment may be obtained by insertion of a resistance in series with resistor 803.

For the correction as a function of air temperature the circuit shown in FIG. 18 may be used, which is analogous to that of the correction with respect to the water temperature and operates in the same manner. Elements 831, 832, 833, 834 and 835 are so chosen that under normal operation a correction of the duration of injection of the order of .2 to .3% per degree is obtained, which value can be adjusted to the particular motor used. The air temperature is sensed by transistor 830 in exactly the same way as the water temperature is sensed by transistor 823 as described above.

The device for causing an enriched mixture in case of rapid acceleration is shown in FIG. 19. This circuit comprises a capacitor 836, a resistor 837, and a potentiometer 838 connected as shown in FIG. 19.

The slider arm of potentiometer 838 is connected to the accelerator pedal 29 or the axis of the butterfly valve. At the time of the acceleration the wiper of 838 is displaced toward the left in FIG. 19, thus causing a decrease in the base current of transistor 823 during a variable time period dependent on the time constant of the circuit 826, 836, 837 and 838. This in turn causes the collector current of transistor 823 to decrease, resulting eventually in the desaturation of transistor 823 if this device for enrichment when starting the cold motor has been used, or otherwise in breakdown of the Zener diode 829, resulting in a temporary increase in the voltage V_{B2} of transistor 805 and therefore in a temporary enrichment of the mixture. The operation is varied as a function of the speed of depression of the pedal.

It should be noted that the response time is less than the speed of penetration of the air and that therefore there is no sudden drop in rapid acceleration.

The device for correction as a function rate of admission of air to the motor is necessary because aerodynamic effects in the inlet pipes and, for certain motors, the valve effects in the exhaust and inlet valves generally lead to a decrease in the rate of air intake to the motor at high speed. Furthermore, because of a resonance effect in the tubing, there usually exists a preferred intake mode, whether this is desired or not.

FIGS. 20 and 21 show two possible solutions, each using a potentiometer having a driven wiper arm. The arm may be driven by a known type tachometric device over the whole speed range or only after a certain threshold value is exceeded.

In FIG. 20 the potentiometer 839 is of the standard type. In FIG. 21 the potentiometer 842 has a center tap. FIGS. 22 and 23 show the correction curves for the injection time t_i as a function of the rotation of speed omega of the motor.

By use of the addition of resistances 843, 844, 845 and 846 almost any desired shape may be obtained. Box 840 symbolizes the corrections discussed above. However the correction arrangement for motor speed is not static.

A completely static embodiment of the arrangement is shown in the device pictured in FIG. 24.

When the switch having the elastic lamina (604) FIG. 7 is open, capacitor 851 may charge through diode 850 and resistance 852:

$$V_{851} = V_A (1 - e^{-\alpha/\omega t_1})$$

where V_{851} is the voltage at capacitor 851; V_A is the supply voltage of the circuit, α (alpha) is the angle of rotation in degrees, and ω (omega) is the rotational speed in degrees per second, while t_1 is defined hereinbelow. At the moment at which switch 604 closes, causing the beginning of the injection period, the juncture point of 851, 850, 849 and 853 rapidly changes to a voltage $V_A + V_{851}$. Capacitor 851 starts to charge capacitor 847, and finally discharges through resistor 853. Capacitor 847 discharges according to an exponential law over members 848, 835 and 828 thus producing a change in V_{B2} (805). This in turn produces a change in the injection period. By proper coordination of the various components, all

the correction curves of the type shown in FIG. 22 or 23 may be obtained, since, for a given control pulse:

$$\Delta t_1 = \frac{1 - e^{-\frac{\alpha}{\omega t_2}}}{1 - B e^{-\frac{\alpha}{\omega t_2}}}$$

where Δt_1 is the variation in injection time obtained and t_1 , t_2 , and B are defined hereinbelow.

$$t_1 = C_{851} \cdot R_{852}$$

$$t_2 = C_{847} (R_{848} + R_{828} + R_{835})$$

$$B = \frac{C_{847}}{C_{847} + C_{851}}$$

The complete injection arrangement described above has, in a first embodiment, a regulatory device, comprising a potentiometer whose wiper arm is controlled by a pressure sensitive arrangement.

Another embodiment is possible which uses the same basic elements, namely the bistable circuit associated with a unijunction transistor delay or calculating element. The pressure in the inlet tubing of the motor may be translated into an electrical signal by means of a small variable condenser, having a low capacity (maximum value being of the order of a nanofarad).

As was discussed above, the end of the injection period takes place when the voltage value at the emitter of a unijunction transistor (805 FIG. 9) exceeds a certain value. In another embodiment, the charge on the condenser 806 (FIG. 9) is determined not by variable resistance 803 (FIG. 9), but by a succession of electric pulses having a fixed peak value and a constant duration. These pulses are furnished by a relaxation oscillator whose frequency is determined by a variable condenser whose value varies linearly at each moment with the value of the fundamental parameter of regulation: namely the manifold pressure of the motor. The intermediate frequency of the relaxation oscillators of the order of 10^5 Hz.

FIG. 25 is one embodiment of such an oscillator.

The voltage for the oscillator is furnished by the supply voltage of the injection system at terminal 118. Furthermore a positive voltage is applied at terminal 100 at the beginning of the injection period.

When both of these voltages are applied at the beginning of the injection period the relaxation oscillator, consisting of the unijunction transistor 121, resistor 101 and capacitor 102, begins to oscillate. The oscillation period is proportional to the value of the resistance 101 and of the capacity of capacitor 102. A negative pulse is conducted by capacitor 103 to the base of transistor 116 for each oscillation. This pulse causes the monostable element consisting of the complementary transistors 109 and 116 to be switched to the state where both transistors are saturated. The element remains in this state until the condenser 113 is charged sufficiently so that the base current of transistor 109 is sufficiently small to switch the element back into the state where both transistors are blocked. It is understood that the value of the components must be so chosen that the period in which the monostable element is in the saturated condition is less than the smallest relaxation period. Use of monostable element with complementary transistors is not to be taken as limitative and is simply given as an example.

The rectangular pulses, whose frequency varies with the pressure in the pipes and which appear across resistor 114 charge capacitor 806 of the injection system (FIG. 9) by way of diode 117. In this case the components 802 and 803 in the same figure are omitted.

Therefore the injection period is proportional to the value of resistor R101 and capacitor 102.

This arrangement may cause a certain temperature dependency, particularly if the transistors used are germanium type transistors. This is why a preferred embodiment according to this invention is shown in FIG. 26.

In this embodiment the oscillator no longer consists of a monostable element associated with a unijunction transistor, but of a bistable element requiring two switching voltages. One of these is furnished by a first relaxation oscillator using a first unijunction transistor while the other is furnished by a second relaxation oscillator using a second unijunction transistor. The supply voltages for this arrangement are furnished in a manner analogous to the arrangement of FIG. 25 and the system interacts with the control system for the injection in a manner analogous to the figures shown in FIG. 25 by way of diode 117. The bistable element consists of transistors 128 and 130 and the first relaxation oscillator consists of resistor 119, variable capacitor 120 and unijunction transistor 121. Capacitor 120 is charged from the voltage E via resistor 119. When the voltage on capacitor 120 reaches a value such that V_{120} equals V_{B2} , it discharges rapidly via resistor 126 through unijunction transistor 121 which is now conductive. Resistor 123 serves to limit the peak value of current. Negative pulses are transmitted at each discharge of capacitor 120 to the base of transistor 130 via capacitor 122. Capacitor 122 charges via diode 131, causing transistor 130 to become conductive. The conduction of transistor 130 causes switching of transistor 128 by way of resistances 133, 134 and capacitor 132. The base of transistor 128 is maintained at a positive voltage level while the base of transistor 130 is maintained at a negative potential by way of resistor 129. The second relaxation oscillator is comprised of resistors 136, 137, capacitor 138, diode 139 and unijunction transistor 140. The second relaxation oscillator starts oscillating at the time the bistable element is switched and delivers a negative pulse to the base of transistor 128 when capacitor 138 has charged to a value $V_{138} = \eta V_{B2}$ (140).

In this manner a succession of rectangular pulses appears at S transmitted via the diode 117 and these pulses charge, in a step-by-step fashion, the capacitor 806 in the timer circuit of FIG. 9 as described hereinabove. The arrangement of FIG. 26 is as stable with respect to temperature as the general arrangement of FIG. 12.

FIG. 27 illustrates the combination of the circuit of FIG. 26 with the bistable multivibrator of FIG. 8 and the time delay circuit of FIG. 9. The succession of pulses received via diode 117 from the circuit of FIG. 26 as described above, serves to charge capacitor 806 and the operation of the circuit is precisely the same from that point on as described above in connection with FIGS. 8 and 9. It is easily shown that the control pulse duration at the injector is proportional to $R_{119} \times C_{120} \times R_{141} \times C_{806}$. As was said before the fundamental correction parameter, namely the pressure in the inlet tubes varies the capacitance of C120 which is a very small capacitor. C120 may be a variable rotatable capacitor commercially available and driven in a similar fashion as the potentiometer 803 shown in FIGS. 10 and 11. This capacitor may also take the form shown in FIG. 28, consisting of one or several concentric cylinders having small play between them. A liquid-tight enclosure 900 is connected to the admission pipe 27 by a pipe connected to the orifice 901. Only the wires furnishing the electrical connection for condenser 120 need pass through the enclosure and these too must be liquid-tight. The condenser is housed in a vacuum membrane 902. The movable cylindrical part 1201 is connected by a shaft 1202 to the cover 1203 of the vacuum membrane 902 and therefore follows its movement. The cylinder 1201 has a Teflon covering 1204 and moves with a small tolerance relative to the corresponding stationary part 1205 which also has a Teflon covering 1206. If a greater capacity is desired further concentric cylinders may be provided.

In case the pressure in the tubes is measured relative to atmospheric pressure, corrections must then be made for variations in this quantity. This may be accomplished in a rigorous fashion by varying R119 by means of a vacuum capsule.

Corrections with air temperature may be made simply and rigorously by using a resistor having a positive temperature coefficient.

It should also be noted that the injection period may be varied by small variations of the capacitor C120 and C138 which are themselves of low capacity. Under one important characteristic of the invention any type of correction may be made very easily by, for example, putting an auxiliary variable capacitor across the terminals of C138 or C120. Variations in the capacity of this auxiliary capacitor may then be made proportional to the opening of the butterfly valve, for example, or proportional to the speed of rotation of the motor. Also, capacitors designed with a technique similar to that of printed circuits may be used.

The control pulses may be transmitted to the different injectors from the output S of transistor 710 (FIG. 12) by a rotating distributor connected to the motor and carrying the switches having the elastic membranes, thus connecting the base of each transistor 713 (FIG. 8) with the emitter of transistor 710.

At this level the distribution current is of the order of 1 ampere and this distributor necessitates use of as many power transistors with Zener diode protection as there are injectors. The mechanical assembly for the distributor should also include the device 17 which gives information on the angular position of the motor.

FIG. 29 shows a preferred embodiment of the distributor.

The device 17 (FIG. 1) which has been slightly changed and is therefore called 1017, sends signals both to the control assembly 12 (FIG. 1) which is also furnished with all the correction arrangements which have already been described, and to a completely static distributor assembly 1001 as shown in FIG. 29. This distributor distributes the control current pulses to all the injectors. In case of this particular example there are 4, corresponding to 4 cylinders, and they are numbered 7 to 10.

FIG. 30 shows the electrical schematic diagram. The control device 12 includes the main bistable circuitry, the unijunction transistor delay device, and the various correction devices described above. The return to the normal state of the bistable element is controlled mainly by the pressure existing in the tubes, either by use of a potentiometer or by use of a variable condenser.

In an example of a motor having four cylinders, the device 1017, includes four stationary switches of the type described above numbered 1002 to 1005. As shown in FIG. 30 the closure of the switches is effected by a permanent magnet 1029 which is capable of turning and is connected to the cam shaft of the motor. Of course the turning member could also be constituted as was mentioned above by a simple magnetic screen which periodically is placed between each membrane and a stationary magnet placed opposite said membrane.

For each closure of switch 1002 to 1005 a positive rectangular signal is produced which is in turn transmitted by the circuit including diodes 1006 to 1009, the resistance 1010, and the input circuit of the control device 12 (component 700 and 701) to produce the switching of the bistable control circuit. Switches 1002 to 1005 are connected to the positive main circuit supply at their common point 1031.

The signals are transmitted independently by the circuits 1012, 1016; 1013, 1018; 1014, 1019; 1015, 1020; to the control electrodes of the thyristors 1021 to 1024, each thyristor being connected on the one hand to a given switch and on the other hand to the corresponding injector (7 to 10).

Interruption of the current in the thyristors and their de-energization are assured by the blockage of transistor 713.

The latter is protected against overvoltages at the time of current cutoff by a Zener diode. Generally the assem-

bly of the transistor and the Zener diode are put together into one housing and the resultant over all circuitry is designated by the name "ignistor" hereinafter designated by the reference character 713'. FIG. 31 shows an alternate mode for protection of the transistor. This consists of placing a diode 1032 and a resistance 1033 in parallel with the injector.

The governing equation, if a protective diode is used to limit the rate of change of current in the injector coil, is:

$$L \frac{di}{dt} + I \frac{dL}{dt} = R_{1033} \cdot I$$

For the case of a Zener diode:

$$L \frac{dI}{dt} + I \frac{dL}{dt} + R_{1025} I = V_z$$

L being the inductance of the injector coil, and V_z being the voltage at the Zener diode.

All of these protective devices are designed to limit the rate of current decrease to a predetermined value. Thus there is also provided electrical damping to limit the velocity of descent of the movable part of the injector thus avoiding possible rebounds. This particular characteristic of having the electrical damping of the piston movement vary as a function of dL/dt is an interesting feature of this invention. Of course, it is also possible to replace the resistors 1025 to 1028 by a single resistance 1028 as shown in FIG. 32.

FIG. 49 illustrates how the circuit of FIG. 32, in one embodiment of the invention, may be combined with the circuits of FIGS. 12, 17, 18, 19 and 20. The portion of the circuit enclosed by the dotted lines at the left of FIG. 49 represents the circuit of FIG. 12; the central portion enclosed by the dotted lines represents the circuit of FIG. 32; the portion of the circuit enclosed by the dotted lines at the upper ring of FIG. 49 represents a combination of the circuits of FIGS. 17 and 19; the portion of the circuit enclosed by the dotted lines immediately below the last described portion represents the circuit of FIG. 18; and the portion of the circuit enclosed by the dotted lines immediately to the left of the last described portion represents the circuit of FIG. 20.

The operation of the circuit of FIG. 49 is briefly as follows: A magnetic switching device which rotates with the crankshaft of the motor, of the type illustrated in FIG. 30 or of the type illustrated in FIGS. 13 and 14, delivers a positive pulse at a predetermined position of the crankshaft to capacitor 700 and at the same time delivers such a positive pulse to the control electrode of one of the thyristors 1021, 1022, 1023 or 1024, causing one of said thyristors to become conductive. The particular thyristor which is thus rendered conductive is determined by the distributor which selects the particular injection coil 7, 8, 9 or 10 which is to be energized. The positive pulse applied to the capacitor 700 is transmitted to the base of transistor 705 causing that transistor to become conductive and placing the bistable multivibrator, comprising transistors 705 and 710, in its first state. The conduction of transistor 705 also causes power transistor 713 to conduct which in turn causes a flow of current through transistor 713, conductive thyristor 1024 and injection coil 7, for example. The flow of current through coil 7 will continue so long as the bistable multivibrator is in its first state, i.e. with transistor 705 conducting. When the bistable multivibrator is switched to its second state, transistor 705 cut off and transistor 710 conducting power transistor 713 will be rendered non-conductive and the flow of current through coil 7 will cease.

As explained above in connection with FIG. 12, the bistable multivibrator will remain in its first state for a period of time determined by the separate variable time delay circuit including variable resistor 803, condenser 806 and unijunction transistor 805. Transistor 705 will

be rendered non-conductive and transistor 710 will commence conducting when the voltage at the collector of unijunction transistor 805, i.e. the voltage on the condenser 806, is equal to the voltage at the second base (V_{B2}) of the unijunction transistor 805.

The voltage at the emitter of transistor 805 is determined by the time constant of the circuit consisting of resistors 802 and 803 and the capacitor 806. As described above, resistor 803 is varied in accordance with manifold pressure. The voltage appearing at the second base of unijunction transistor 805 is determined by a plurality of other motor parameters and is effected by the combination of the circuits separately described above in FIGS. 17, 18, 19 and 20, comprising the righthand portion of FIG. 49. This voltage is a resultant of the voltage drops in resistors 828, 835 and 839. The voltage drop in 828 is determined by the collector current in transistor 823 which is a function of the engine temperature and includes a correction for engine acceleration in response to the depression of accelerator pedal 29. The voltage drop in resistor 835 is determined by the collector current in transistor 830 which is a function of air temperature. The voltage drop in resistor 839 is determined by the position of its movable wiper arm, which is a function of engine speed and may be driven by any known tachometric device.

Thus, the duration of injection current in each of the injector coils 7, 8, 9 and 10 is precisely determined as a function of the manifold pressure as well as a number of other motor parameters. The above-described cycle of operation is, of course, repeated for each of the injector coils.

The injectors as well as their response curves, namely the quantity of fuel injected as a function of the duration of the control current pulse, (FIGS. 4 and 6) were described above. The slope of the linear portion of the curve $Y(t)$ can be reproduced exactly without need for great mechanical precision in the manufacture of the injector. Actually the slope depends only on the size of the orifice of the needle point valve. However the transient portion from 0 to t_R (FIG. 6) necessitates very great precision in the elastic membranes and its elastic characteristic to be perfectly repeatable from one injector to the next. By means of an electrical device it is possible to decrease the need for the tight tolerances and consequently to lower the price of the injectors, as well as eventually to take into account a dissimilarity in the air inlet in the various cylinders which may occur even if the tubular inlet pipes are well designed. If a certain variation of the characteristics of the membrane is assumed, the response curves of the injector will vary as shown in FIGS. 34. The curves are parallel to one another but displaced by a constant value Δt . Here Δt is the maximum admissible dispersion. Therefore it becomes obvious that to inject equal quantities of fuel into an injector having characteristics displaced to the right hand side of FIG. 34 by an amount t_1 , its fuel injection would have to take place during a period t_1 longer than that of the injector whose characteristics are shown on the left side of FIG. 34.

As has been shown previously the duration of the injection period is proportional either to resistors R802 and R803 in conjunction with C806 (FIG. 12) namely $(R802 + R803) C806$ for the case of the control by potentiometer or, proportional to $R_{119} \times R_{141} \times C_{120} \times C_{806}$. (FIG. 27) for the case of control by variable condenser. In the chosen embodiments R803 or C120 has been chosen to be proportional to the pressure in the inlet tubes. Therefore, if an additional resistance, regulated by each injector is added either to resistors 802, 803 or to resistor R119, it would become possible to correct the injection periods for each injector to compensate accurately for the dispersion due to membrane characteristics resulting from the manufacture of the injector.

The circuit showing these additional variable resistors is shown in FIGS. 33 and 35. As shown in FIG. 35, and

also in FIG. 33, where each injector coil has a separate associated resistor, a circuit consisting of a diode (1038 to 1041) in series with a variable resistance (1034 to 1037) is inserted at the cathode of each thyristor the resistors 1034 to 1037 are individually adjusted in accordance with the measurement of current flow through each of the injectors, before the injectors and variable resistors are inserted in the fuel injection system. The other ends of these series circuits are tied together at a terminal 1042. This terminal 1042 is connected to resistor 802 or 803, which are no longer fed by transistor 710, in the case of a correction by means of potentiometer, and to point 118 in case the regulation is achieved by the variable condenser.

If the arrangement of FIG. 35 is used, isolating diodes 1042 to 1045 are required to decouple the circuits from one another.

Finally FIG. 36 shows a complete diagram of the regulation system having the correction element, and utilizing only thyristors and a unijunction transistor, and the correction arrangements.

Thyristors 2000 to 2004 (representing the case of a four-cylinder motor as an example) are energized by a pulse coming from the distributor 2005 similar to that already described. Each thyristor, once energized, controls the closing of one of the switches 2006 to 2009 by current flowing through one of the inductive loops 2021-2024. Furthermore a unijunction transistor constituting variable delay means 1042 (or an oscillating circuit of regulation by variable condenser is used) is energized upon energization of the thyristors. The delay means 1042 after a time interval equal to the duration of the injection, sends an end of injection signal or control pulse to the gate of another thyristor (2017 to 2020) which cuts off the first thyristor by discharging a capacitor 2015 at its terminals. The capacitor has previously been charged to a higher voltage than the supply voltage in the oscillating circuit formed by it and the inductor 2014 energized through one of the diodes 2010 to 2013. The embodiment of FIG. 36 thus contains a bistable multivibrator, constituted by each of the pairs of thyristors 2000-2017, 2002-2018, 2003-2019, 2004-2020, for each injector.

It is also possible, without departing from the body of the invention, to furnish a particular arrangement of the control elements of the injector to permit a cycle of "energy recuperation" which would increase the speed of response of the injectors.

As was described above the injectors are opened by an injection control signal (voltage) furnished by transistors, or ignistors, or thyristors. There exists a time delay between the moment the voltage is applied and the moment the injector opens. This delay is caused partly by the mechanical time constant of the injector and partly by the delay in the current flow in the electric circuit of the injector because of the coefficient of self induction of the latter.

Moreover, at the moment the injector is closed, the magnetic energy which was stored in its magnetic circuit is dissipated to the exterior in the Joule effect.

Therefore a procedure is proposed which consists in transferring the magnetic energy which is emitted by one injector at the moment of its closing to another injector at the moment at which the second injector opens, in such a manner as to decrease considerably the opening time in the latter. For a multicylinder motor this system may of course be extended by transferring the energy from one cylinder to the next in a ring-type arrangement.

To simplify the explanation, FIG. 37 shows an embodiment for the case of two injectors, FIG. 38 is a variation of this embodiment, FIG. 39 is an extension of the system to a four cylinder motor. The extension of the system to a greater number of cylinders can readily be deduced from the last diagram.

Each of the injectors 4007 and 4008 is energized in-

dependently by an ignistor 713' through a diode 4001 or 4002, respectively connected to a thyristor 4003 or 4004, a diode 4011 or 4012 and a resistance 4013 while a circuit comprising a diode (4005 or 4006) and a capacitor (4009 or 4010) is connected in parallel with the thyristor-injector branch of each circuit.

The operation is described starting with the moment the injector 4007 is opened. The voltage at its terminals is practically zero. At the moment of cutoff by ignistor 713' there appears across the terminals of 4007 a voltage due to the stored magnetic energy. This is transformed into potential energy by charging the two capacitors 4009 and 4010, which are connected in parallel, through the diode 4005. The diode 4005 and the cut-off of the thyristor 4003 blocks the oscillation of the circuit constituted by the inductance of 4007 and the capacity 4009 at the end of a quarter cycle.

The two capacitors 4009 and 4010 are now charged to a high voltage. This voltage is positive at the connection with 4011 and negative at the connection with 4012. This is a stable state.

At the moment of the following injection, that is the conduction of thyristor 4004, and of saturation of ignistor 713', a voltage equal to the supply voltage appears between the anode of the diode 4002 and the cathode of 4012, while a voltage equal to the voltage across the capacitors appears between their other electrodes.

At the moment that thyristor 4004 is energized, capacitors 4009 and 4010 discharge in a quarter of a cycle into the winding of the injector 4008 until they are fully discharged. However, when the value of the condenser voltage reaches the value of the supply voltage a steady-state current is established in the circuit, thus causing an ultra rapid opening of the injector 4008. When this injector is closed the capacitors are recharged and speed the opening of the injectors 4007 by an identical process.

FIG. 38 shows another version, wherein the resistance 4013 is divided into two resistances 4014 and 4015. However the operation of energy transfer of the first embodiment is superior.

FIG. 39 shows an embodiment for a four-cylinder motor. This arrangement is preferable to that which would consist simply of combining the two arrangements for a two-cylinder motor. Particularly with this arrangement, the value of storage capacity to be used stays the same for a given type of injector, independent of the number of cylinders. The value of capacitance is simply divided into as many elements as there are cylinders.

Of course, in every case, the establishment of the steady state current takes place especially quickly if the transient current resulting from the capacitor discharge is permitted to attain the saturation value of the magnetic circuit during the opening. It is obvious that this arrangement is symmetrical for any number of cylinders provided there is no ignition advance. A circuit taking advantage of the symmetry is shown in FIG. 40. The operation of the circuit is identical to that described in relationship to FIG. 37. Coils 7, 8, 9 and 10 are energized in order. The same total value of storage capacity is used, but a certain number of diodes is saved. This system may of course be extended to any even number of cylinders.

The characteristics of the circuit may be exploited further, (FIG. 41) by replacing the ignistor with a simple thyristor and using the inductance of the injector coils to cause its extinction. Furthermore, the binary symmetry allows use of only two thyristors for initiating the end of the injection period, independent of the number of cylinders. The arrangement is shown in FIG. 41. Thyristor 4029 controls the extinction of the main thyristor 4030 when an injector in the odd group is activated, and thyristor 4028 performs the same function for the injectors in the even group. It should be noted that each time that capacitor 4009, for example, charges, capacitor 4009a is also charged via diode 4005a. At the next cycle, when thyristor 4029 is fired, the positive voltage on capacitor

4009a appears at the cathode of thyristor 4030 and extinguishes it. This cycle will repeat itself for the firing of the even number injectors.

An improved circuit for avoiding overvoltages across the switches serving to control the ignition of the thyristors is shown in FIG. 42. This shows the same circuit as FIG. 30 except that the thyristors 1021, 1022, 1023 and 1024 have the cathode connected directly to ground, and the anode connected to one end of the respective injector coils 7, 8, 9 and 10. The other end of the injector coil is connected jointly to resistor 1028 which in turn is connected to the ignistor 713'. The advantage of this circuit is as follows. Upon interruption of the current in the injector coils 7 to 10, a high voltage appears across these coils. In FIG. 30 the cathodes of the thyristors are not tied to ground, and the gate-cathode junction is conductive, permitting a high negative voltage to be transmitted to the switches having the elastic lamina. If the end of the injection takes place before the opening of the corresponding switch, this switch is submitted to an unnecessary transient voltage. Furthermore, if the closing of an injector and the opening of the associated switch happen to coincide, breakdown voltages may appear across the switch causing the delay element to produce stray pulses. These difficulties are avoided by the arrangement of FIG. 41, where, as mentioned above, the cathodes of all the thyristors are connected to ground. A corresponding arrangement for a circuit wherein transfer of energy takes place from one injector to the next as described above is shown in FIG. 43.

The circuits illustrated in FIGS. 39-41 above for transferring energy from one injector coil to the next have several disadvantages. First of all, they are only applicable to motors having an even number of cylinders. Secondly, a relatively high number of diodes is necessary and it is also necessary to have at least two capacitors if one wishes to charge the capacitors in the same direction each time, thus permitting use of a relatively cheap component. These difficulties are avoided by the circuit shown in FIG. 44. The power injection control signal is furnished by ignistor 713' from a direct current source through a resistor 1028 connected to the anode of diode 5003. The cathode of diode 5003 is connected to three series circuits each consisting of a thyristor in series with one of the injection coils. The other terminal of each of these series circuits is connected to ground. Connected to the juncture of diode 5003 and these three series circuits is the cathode of a thyristor 5002, whose anode is connected to the cathode of a diode 5004 and also by means of capacitance 5001 to the anode of the diode 5003. The anode of diode 5004 is connected to ground. In some of these designs the value of resistor 1028 may be zero. Current furnished by the ignistor 713' is conducted to a chosen injector coil 7, 8 or 9 by a short voltage pulse (injection starting signal) applied to the gate of the corresponding thyristor 1023, 1022 or 1021. For this first operating cycle thyristor 5002 does not serve any particular function. When the current through the particular coil is interrupted at a time determined by control means 12, the magnetic energy contained in the particular coil is transferred as potential energy to the capacitor 5001 which is charged in the direction shown in FIG. 44. Capacitor 5001 remains charged until the following injection takes place. Thyristor 5002 is energized simultaneously with the next following thyristor corresponding to the next chosen injector. Since diode 5003 is blocked by the voltage on the capacitor 5001, current for the coil is supplied by the discharge current of capacitor 5001. Current may still be furnished to the selected coil by ignistor 713' after the capacitor is discharged and thyristor 5002 is again non-conducting. The operating cycle described above is then repeated. FIG. 45 shows the current through any one of the injector coils as a function of time.

The injection system which is the subject of the present invention may also be applied to injectors operating under

much higher pressures (several hundred bars) for use in diesel motors. In particular, two types of diesel motors would profit from an electromechanical injection system under electronic control, namely, free piston motors and two stroke engines. In the case of free piston motors the injection must be made at the time when the speed of the moving parts is practically zero. That is, approximately at the dead point. Therefore an independent injection system is particularly advantageous. For this type of application the pump is driven by an electric motor as was discussed further above (see FIG. 1). The injector, of a size to conform with the particular motor, is constructed along the lines of the injector described above. Experimental models have functioned up to 350 bars.

Voltage, current, or power regulation may be accomplished for a dynamo driven by an engine by control of the base 2 of transistor 805 (FIG. 46). Potentiometer 803 is adjusted for the necessary fuel quantity for full load functioning. Voltage regulation consists of diminishing the quantity of fuel injected when the load decreases. In the case of a free piston motor coupled directly to an alternator having a rectangular hysteresis loop, the alternating voltage produced by the generator is applied to a resistance 870, after rectification by a diode bridge 871 and a capacitor 873, and after passing a threshold value set by Zener diode 872. Resistance 870 is in the base circuit of unijunction transistor 805. When the voltage produced by the alternator exceeds the threshold voltage of Zener diode 872, the current in resistor 870 effectively diminishes the voltage appearing at the base of transistor 805 and therefore the quantity of fuel injected.

Current regulation may be accomplished in an analogous manner.

Power regulation is accomplished by starting with potentiometer 803 set to correspond to a no load power. The circuit used for power regulation is shown in FIG. 47. A transformer 874, having a center tapped secondary, applies a voltage proportional to the output voltage of the alternator to two pairs of diodes, each pair being connected in parallel and in opposite polarity, namely diodes 878 and 879 and diodes 880 and 881 respectively. A current transformer 875 delivers a voltage proportional to the current furnished by the alternator to the other terminals of the respective diode pairs by means of the identical resistors 876 and 877. The diodes are point contact diodes used in the parabolic region. This causes the voltage appearing at the primary of transformer 882 to be proportional to the power developed by the alternator, even when the power factor is different from 1, since, if the value r of resistors 876 and 877 is large compared to the diode resistance, the voltage across the primary of transformer 882 is:

$$4\lambda r k k' U I$$

Where λ equals the parabolic coefficient of diodes 878, 879, 880 and 881; r equals the value of resistors 876 and 877; k equals the no-load transformation ratio of transformer 874; k' equals the voltage to current ratio of current transformer 875; U equals the voltage delivered by the alternator; and I equals the current delivered by the alternator.

λ =parabolic coefficient of diodes.

k, k' =transformation ratio of voltage and current transformers.

U, I =voltage and current of the group in vector value.

The secondary voltage of transformer 882 is applied across the terminals of resistor 870 as shown in FIG. 47, in such a way that the fuel injection is increased when the power demand increases.

Finally, using conventional methods, one may convert the frequency of the alternator to an electrical current and by applying this to resistor 870, obtain a frequency regulation.

For high speed diesel motors, particularly two-stroke engines, the rotational velocity is limited among other

factors by the speed attainable in mechanical injection devices under high pressure.

The system according to this invention is not subject to this limitation. The system is like that of free piston machines. However, the injector itself in practice requires a special design to conform with the requirements of present day motor assemblies. The injector is shown in FIG. 48.

The upper part of this injector is analogous to that of the injector shown in FIG. 3. The lower part consists of a tubular member 323 which acts as a guide to the shaft 322 which is integral the membrane 316 and the armature 312. At the lower end of the shaft 322 is the needle valve 317 which controls the opening and the closing of the injection orifices 326 which are situated at the lower extremity of member 301. Said piece 301 is connected with the tubular part 323 by means of the hollow member 324. The electrical assembly of the injector is screwed into the member 323 at the location of a shoulder 327 where the injector assembly is finally connected to the cylinder assembly.

The electronic control assembly of these injectors obviously has many components in common with the control assembly of internal combustion engines described above. These are:

A high-pressure injection system,

A switching assembly 17 furnishing pulses depending on the angular position of the motor,

A system for controlling the duration of the injection, 12,

A distributor 18-19.

On the other hand, the control of the motor is accomplished by regulating the quantity of fuel injected. This operation is accomplished directly by action on the wiper arm of potentiometer 803 of FIG. 12, which in the case of that figure, is connected first to move as a function of the pressure in the inlet tubing.

While the invention has been illustrated and described as embodied in a high speed injection system for internal combustion or diesel engines, it is not intended to be limited to the details shown, since various modifications and structural changes may be made without departing in any way from the spirit of the present invention.

Without further analysis, the foregoing will so fully reveal the gist of the present invention that others can by applying current knowledge readily adapt it for various applications without omitting features that, from the standpoint of prior art, fairly constitute essential characteristics of the generic or specific aspects of this invention and, therefore, such adaptations should and are intended to be comprehended within the meaning and range of equivalence of the following claims.

What is claimed as new and desired to be protected by Letters Patent is set forth in the appended claims.

We claim:

1. A high speed injection system for internal combustion or diesel engines having a motor shaft and one or more cylinders, comprising, in combination, high speed electromagnetic injectors, one for each cylinder, each having an injector coil, responsive to an injection control signal and adapted to inject fuel into the corresponding cylinder for the duration of said injection control signal; distributing means for synchronizing the time of operation of each of said high speed injectors to a corresponding predetermined angular position of said motor shaft and for generating injection starting signals corresponding to each of said predetermined angular positions; variable delay means responsive to said injection starting signals and adapted to generate end of injection signals after a time delay varying as a function of one or more parameters; at least one bistable control means adapted to switch from a first state to a second state upon receipt of said injection starting signals, and adapted to switch back to said first state upon receipt of said end of injection signal for generating said injection control sig-

nals while in said second state; and coupling means for coupling said injection control signals to said high speed electromagnetic injectors.

2. A system as set forth in claim 1 wherein said bistable control means comprises a bistable multivibrator.

3. A system as set forth in claim 1 wherein said variable delay means comprises means having a first and a second terminal, adapted to generate said end of injection signal when the signal at said first terminal is equal to the signal at said second terminal.

4. A system as set forth in claim 3 wherein said variable delay means comprises a unijunction transistor having an emitter and a base, adapted to generate said end of injection signal when the voltage at said emitter is equal to the voltage at said base.

5. A system as set forth in claim 3 also comprising means for varying the voltage of said first terminal of said variable delay means as a function of the manifold pressure of said engine.

6. A system as set forth in claim 5 wherein said means for varying the voltage at said first terminal of said variable delay means as a function of the pressure in said inlet tubing of said engine comprise variable capacitance means having a capacity adapted to vary with the pressure in said inlet tubing; means for generating constant amplitude pulses at a frequency corresponding to the valve of said variable capacitor; and means for storing said pulses in such a manner that the voltage at said first terminal increases with time as a function of the frequency of said constant amplitude pulses.

7. A system as set forth in claim 5 wherein said means for varying the voltage at said one terminal as a function of the manifold pressure comprises a variable resistor; and means for varying the value of said variable resistor as a function of said manifold pressure.

8. A system as set forth in claim 3 also comprising means for varying said voltage at said second terminal as a function of a plurality of motor parameters.

9. A system as set forth in claim 6 wherein said means for generating constant amplitude pulses at a frequency proportional to said variable capacitance comprise relaxation oscillator means having a frequency proportional to said variable capacitance and adapted to generate relaxation pulses; monostable switching means adapted to assume the unstable state upon receipt of said relaxation pulses, adapted to return to the stable state during a time period less than the smallest relaxation period, and adapted to generate monostable switching output pulses while in said unstable state; and means for conducting said monostable switching output pulses to said terminal of said variable delay means.

10. A circuit as set forth in claim 6 wherein said means for generating pulses at a frequency proportional to said variable capacitance comprise relaxation oscillator means adapted to generate relaxation oscillator pulses at a frequency corresponding to said variable capacitance; additional delay means responsive to said relaxation oscillator pulses and adapted to generate delay pulses after a predetermined time delay not exceeding the smallest period of said relaxation oscillator; bistable switching means adapted to be switched to a first switching state by said relaxation oscillator pulses and adapted to be switched to a second switching state by said time delay pulses, and further adapted to generate a bistable switching output pulse while in said first state; and means for conducting said bistable switching output pulse to said first terminal of said delay means.

11. A system as set forth in claim 10 wherein said relaxation oscillator and said bistable switching means comprise resistors and capacitors arranged in such a manner that the injection control pulse duration is proportional to the product of a resistance and a capacitor multiplied by a second resistor capacitor product, thus permitting the duration of the injection period to be varied as a function of the pressure in the inlet tubing, while permit-

ting the instantaneous duration of the injection period to vary as a function of operating parameters of the motor.

12. A system as set forth in claim 11 also comprising a feed pump for pumping said engine fuel to said injectors; and means for varying the capacitance of one of said capacitors as a function of the feed pump pressure.

13. A system as set forth in claim 3 also comprising manually operable variable voltage divider means, connected in such a manner as to effect variation of the voltage at said second terminal for changing the injection period to obtain an enrichment of the mixture when a cold motor is started.

14. A system as set forth in claim 3 also comprising voltage divider means having a temperature sensitive element immersed in the cooling water of the motor; and means for connecting said voltage divider to a terminal of said variable delay means in such a fashion that the voltage at said terminal decreases with increasing temperature of the cooling water, thus varying the fuel injection period as a function of cooling water temperature.

15. A system as set forth in claim 14 also comprising a threshold member connected between said voltage divider and said terminal in such a manner as to limit the start of the injection period increase to a predetermined water temperature.

16. A system as set forth in claim 14 wherein said temperature sensitive element is a silicon transistor.

17. A system as set forth in claim 16 also comprising circuitry associated with said silicon transistor and adapted to cause said silicon transistor to be saturated at a predetermined temperature.

18. A system as set forth in claim 3 also comprising voltage divider means having a sliding arm; means for attaching said sliding arm to the acceleration pedal of said engine; time constant means associated with said voltage divider means; and means for connecting said time constant means to one of said terminals of said variable delay means in such a manner as to obtain an enrichment of the fuel mixture at the time of an acceleration.

19. A system as set forth in claim 3 also comprising tachometric means for changing the voltage at a terminal of said variable delay means as a function of the motor speed.

20. A system as set forth in claim 19 wherein said tachometric means comprises a potentiometer having a slider arm, and a slider arm output terminal connected to said variable delay means terminal; and a tachometer responsive to the speed of the motor and adapted to drive said slider arm.

21. A system as set forth in claim 19 wherein said tachometric means comprise a potentiometer having a center tap and a slider arm; a tachometer driving the slider arm of said potentiometer; and a bridge circuit connected across the terminals of said potentiometer in such a manner that varying said bridge element permits adjustment of the curve of correction as a function of motor speed to a predetermined characteristic.

22. A system as set forth in claim 3 also comprising stationary means for varying the voltage at said second terminal as a function of the engine speed, said means comprising capacitive means; means for charging said capacitive means for the duration of time between injection starting pulses; and means for coupling said capacitive means to said second terminal in such a manner that the voltage at said second terminal will vary as a predetermined function of the speed of rotation of the motor.

23. A system as set forth in claim 1 wherein said high speed electromagnetic injectors comprise an injector housing having fuel injector openings at the lower extremity and an internal shoulder; an E-shaped laminated magnetic member mounted within said housing; an injector control coil wound upon said magnetic member; a magnetic armature opposite said E-shaped magnetic member adapted to saturate at least the center branch of said E-shaped mag-

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netic member; a needle valve adapted to move with said magnetic armature and adapted to close said injector openings when in the closed position; a shaft connecting said needle valve and said magnetic armature; elastic means connected between said housing and said shaft in such a manner as to return said needle valve to the closed position; a disc carried by said shaft; and damping means interposed between said disc and said internal shoulder of said housing, as well as between said magnetic armature and said stationary magnetic circuit, in such a manner that dampening by hydraulic throttling occurs at the time of the opening and the closing of said injectors.

24. A system as set forth in claim 1 also comprising means for limiting the rate of change of current in said injector control coils, thus achieving electrical damping in said injectors.

25. A system as set forth in claim 24 wherein said means for limiting the rate of change of current in said injector coils comprise resistors in parallel with said injector coils.

26. A system as set forth in claim 23 also comprising means for individually adjusting the end of the injection period for each injector, in such a manner as to compensate for variations resulting from manufacturing tolerances for each injector.

27. A system as set forth in claim 1, having one bistable control means for each injector, each of said bistable control means comprising a bistable control element responsive to the corresponding one of said injection starting signal, adapted to furnish current to said injector coil for a time period starting with receipt of said injection starting signal and ending with receipt of a cut-off signal; means for generating a cut-off signal; a bistable cut-off element responsive to said end of injection signal and adapted to connect said cut-off signal generating means to said control element upon receipt of said end of injection signal.

28. A system as set forth in claim 27 wherein said bistable elements comprise thyristors.

29. A system as set forth in claim 1 also comprising means for transferring the magnetic energy liberated upon cut-off of the current in an injector control coil at the end of an injection period to the injector control coil receiving the subsequent injection control signal.

30. A system as set forth in claim 29 wherein said means for transferring the magnetic energy comprises at least one transfer capacitor adapted to be charged upon cut-off of the current in an injector coil and adapted to

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be discharged when the flow of current in the subsequent injector coil commences.

31. A system as set forth in claim 30 also comprising switching means adapted to assume the conductive state upon receipt of said injection starting signals, interposed between said transfer capacitor and said injector coils; first transfer rectifier means adapted to permit the charging of said capacitor upon current cut-off in said injector coils; and second transfer rectifier means adapted to prevent charging of said capacitor in the opposite direction.

32. A system as set forth in claim 1 wherein said engine drives an alternator having an alternator output voltage, said alternator output voltage constituting said parameter for varying said time delay; said system also comprising means for rectifying said alternator output voltage; and means for applying said alternator voltage to said variable delay means in such a manner that said time delay decreases when said alternator output voltage increases.

33. A system as set forth in claim 1 also comprising an alternator driven by said engine, said alternator furnishing alternator output power, said alternator output power constituting said parameter for varying said time delay of said variable delay means; said system also comprising means for generating a voltage proportional to the alternator output voltage; means for generating a second voltage proportional to the output alternator current; means for combining said first and second voltages in such a manner as to create a voltage proportional to the alternator output power; and means for applying said signal proportional to said alternator output power to said variable delay means in such a manner as to cause said time delay to be varied as a function of said alternator output power.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,456,628 Dated July 22, 1969

Inventor(s) Jacques Bassot et al.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 9, line 37, the equation should appear as shown below:

$$t_i = RC \ln \left(\frac{E}{E - \eta V_{B2}} \right)$$

Column 10, line 61, the equation should appear as shown below:

$$V_{851} = V_A (1 - e^{\alpha/\omega t_1})$$

Column 19, cancel lines 61-64.

Signed and sealed this 1st day of December 1970.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents