United States Patent [19]

Bassot et al.

[11] **3,822,678**

[45] **July 9, 1974**

[54] **HIGH SPEED FUEL INJECTION SYSTEM**

[75] Inventors: **Jacques Bassot**, Paris; **Louis Monpetit**, L'Etang La Ville (Seine et Oise), both of France

[73] Assignee: **Societe Des Procedes Modernes D'Injection Sopromi**, Les Mureaux, France

[22] Filed: **May 1, 1972**

[21] Appl. No.: **249,275**

Related U.S. Application Data

[60] Continuation of Ser. No. 871,670, Nov. 10, 1969, Pat. No. 3,710,763, which is a continuation of Ser. No. 816,767, April 16, 1969, abandoned, which is a division of Ser. No. 630,035, April 11, 1967, Pat. No. 3,456,628.

[30] **Foreign Application Priority Data**

Apr. 13, 1966	France	66.57392
Dec. 2, 1966	France	66.85951
Dec. 9, 1966	France	66.86830

[52] **U.S. Cl.** ..... **123/32 EA**, 123/119 R

[51] **Int. Cl.** **F02m 51/00**

[58] **Field of Search** .... 123/32 EA, 119 R; 317/151, 317/DIG. 5

[56] **References Cited**

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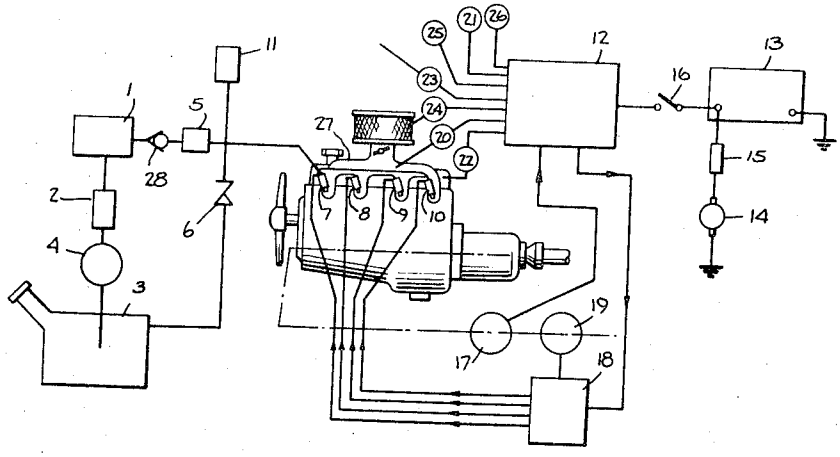
Primary Examiner—Laurence M. Goodridge

Attorney, Agent, or Firm—Kenyon & Kenyon Reilly Carr & Chapin

[57] **ABSTRACT**

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 unijunction 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.

6 Claims, 34 Drawing Figures



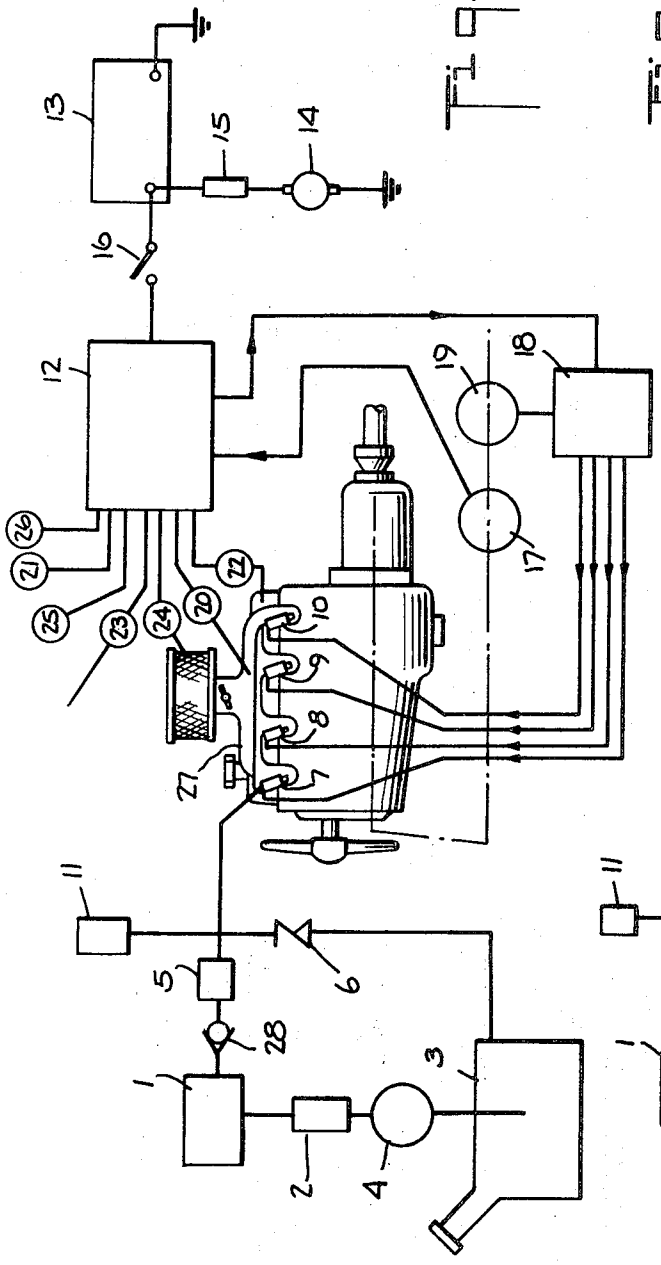


Fig. 1.

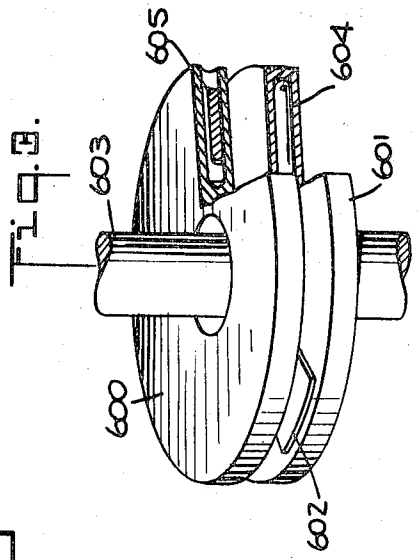


Fig. 3.

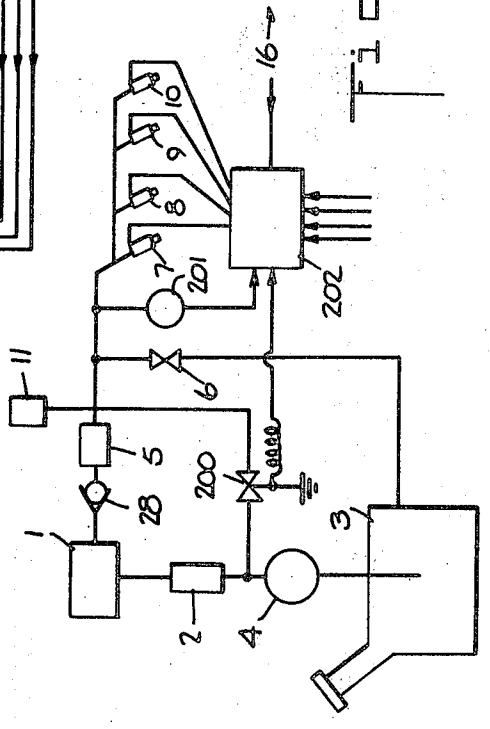


Fig. 2.

Fig. 4.

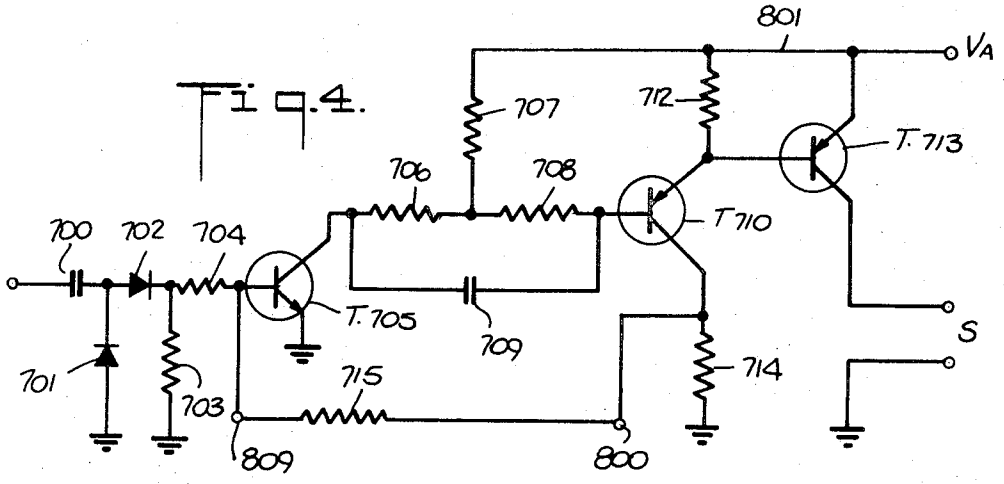


Fig. 5.

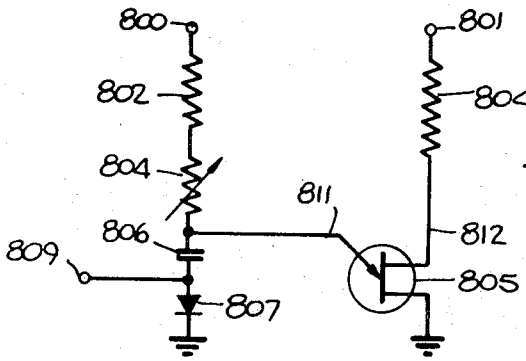


Fig. 6

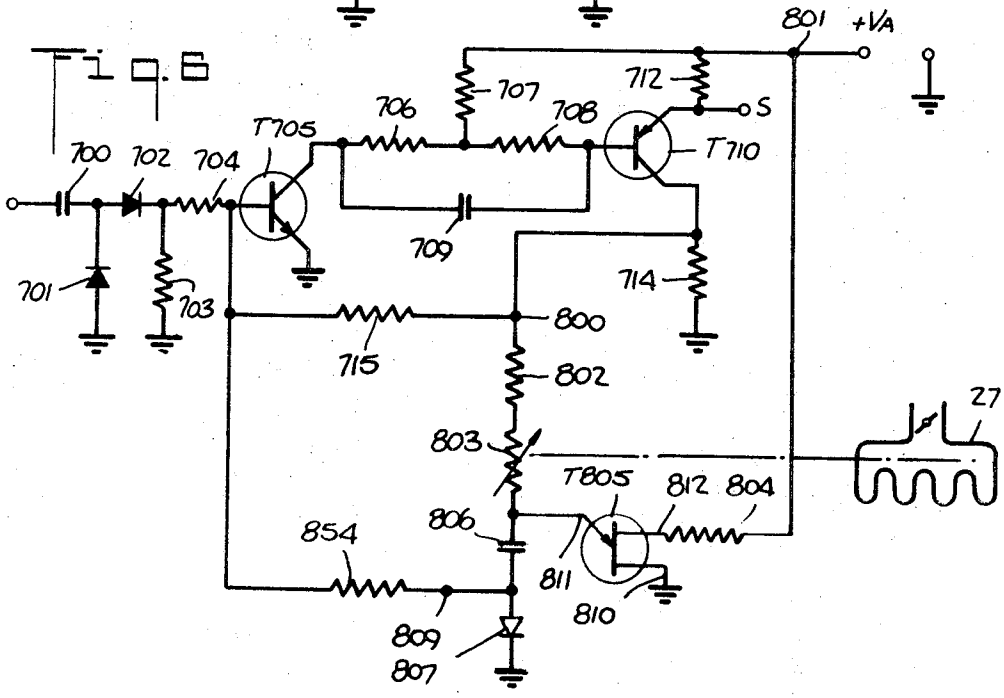


Fig. 7.

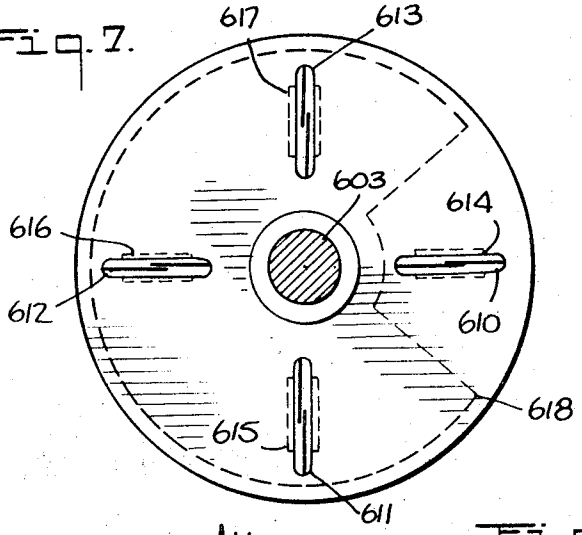


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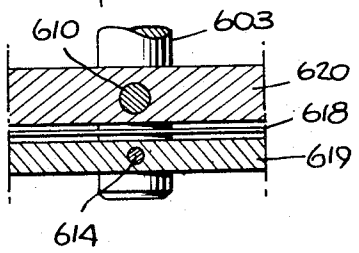


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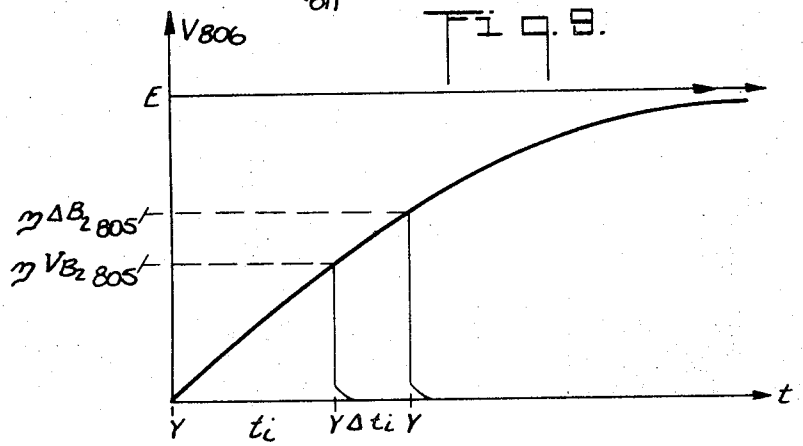
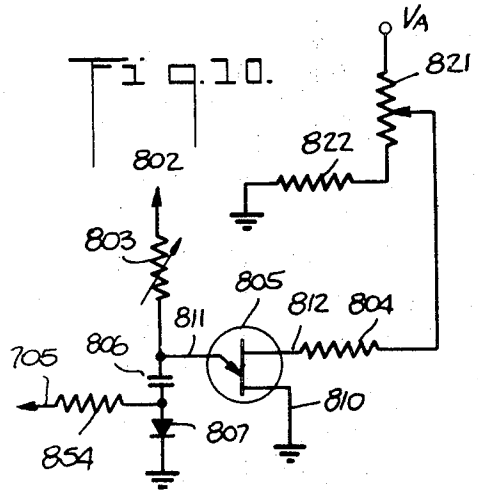


Fig. 10.



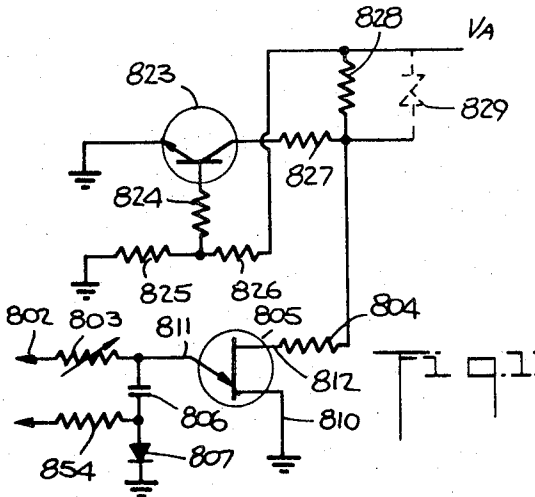


Fig. 11.

Fig.12.

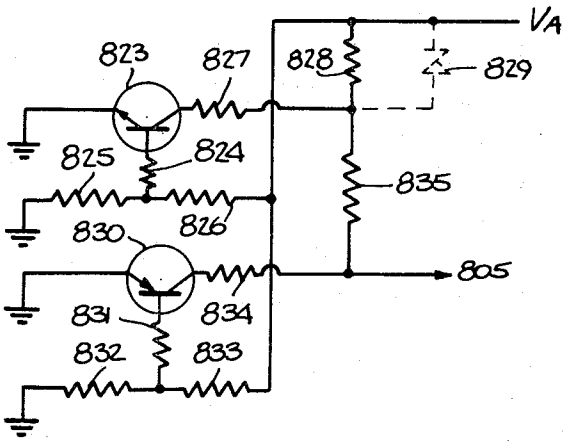


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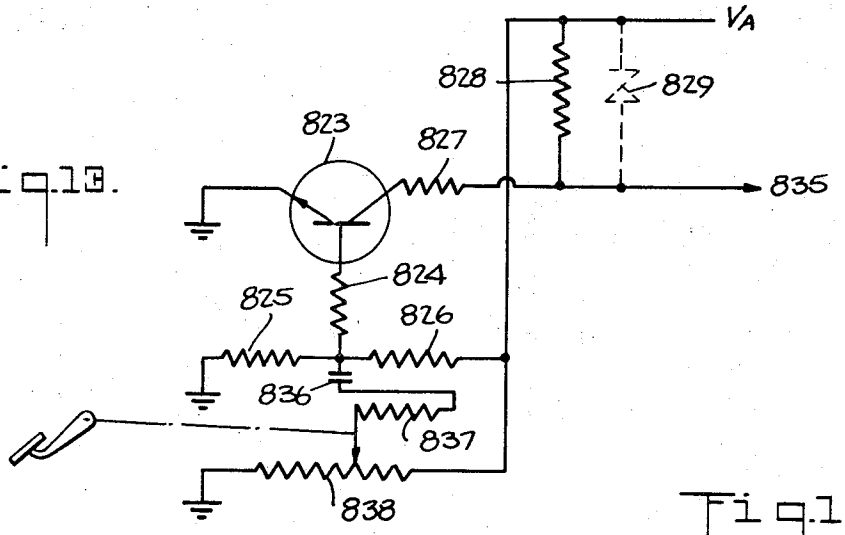
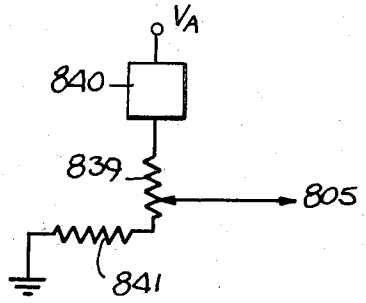


Fig.15.



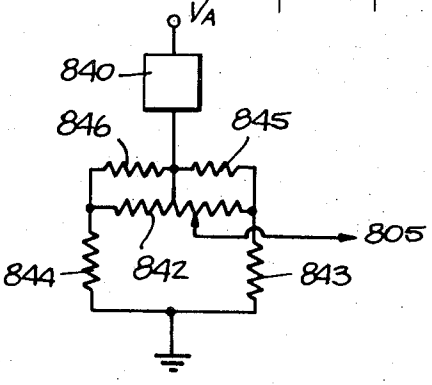


Fig.14.

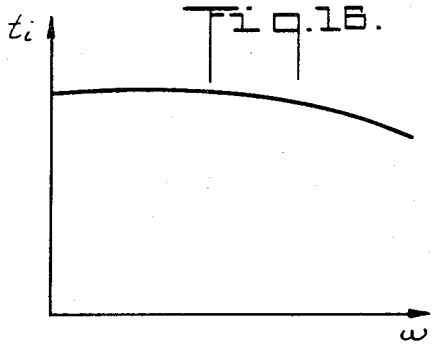


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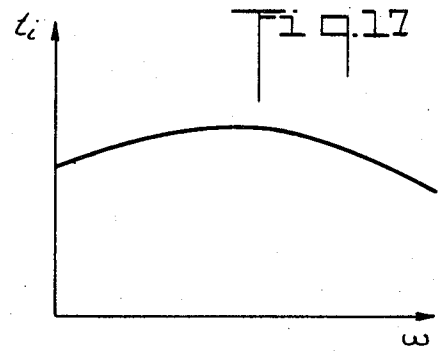


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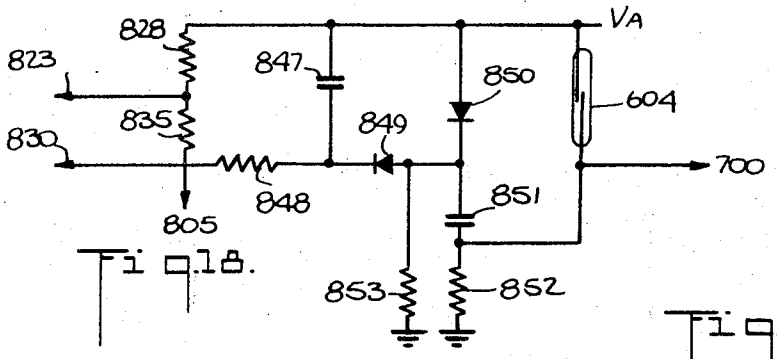
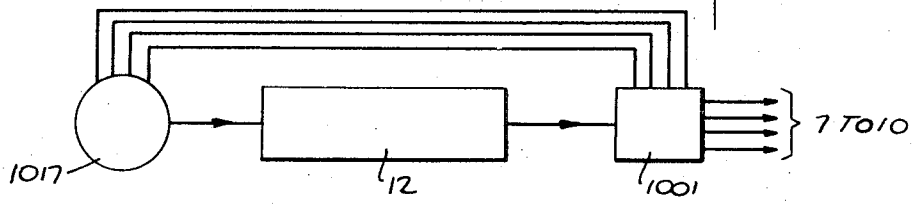


Fig. 18.

Fig. 19.



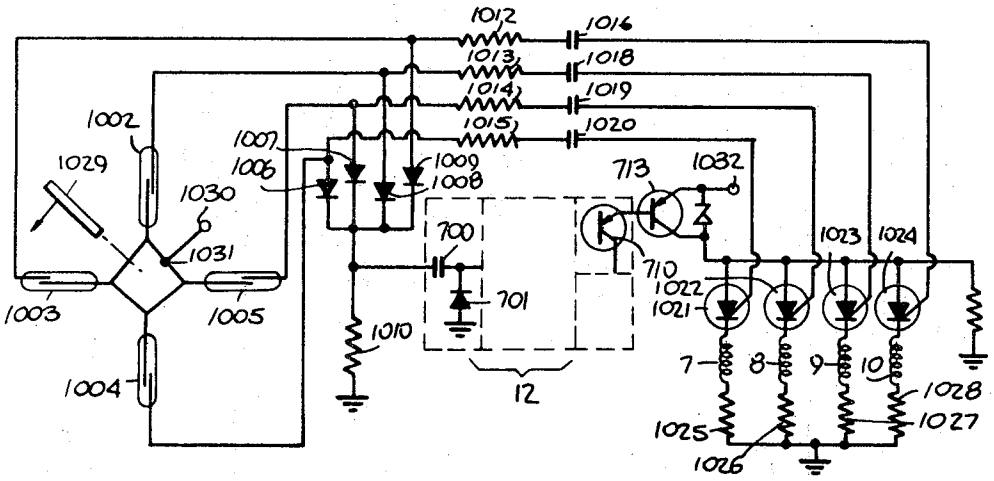


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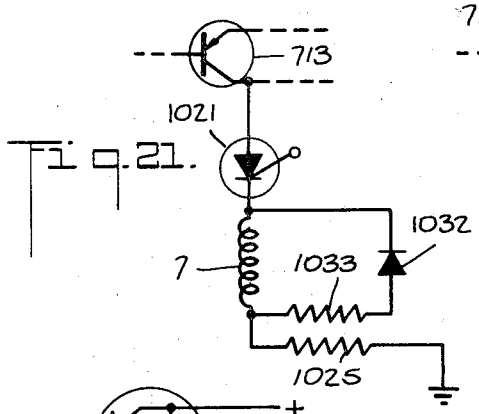


Fig. 21.

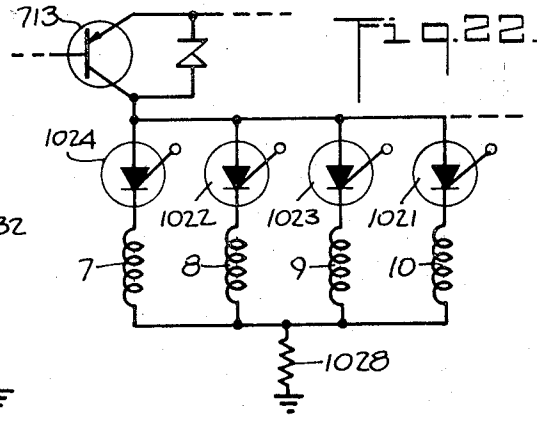


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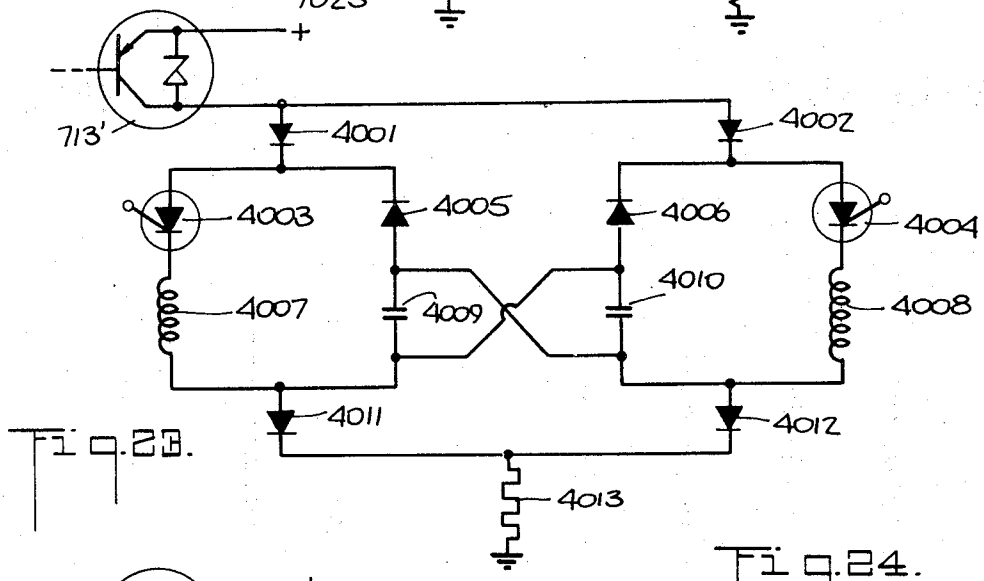


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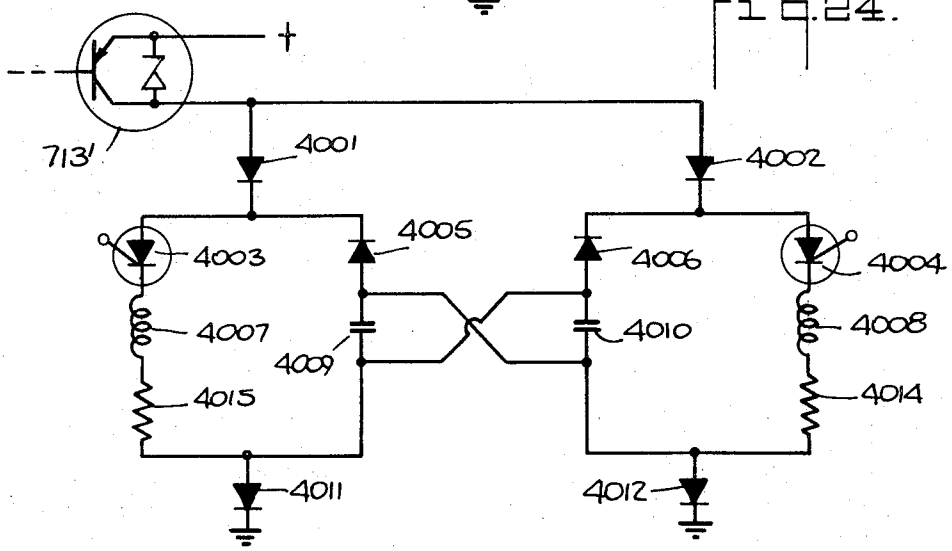


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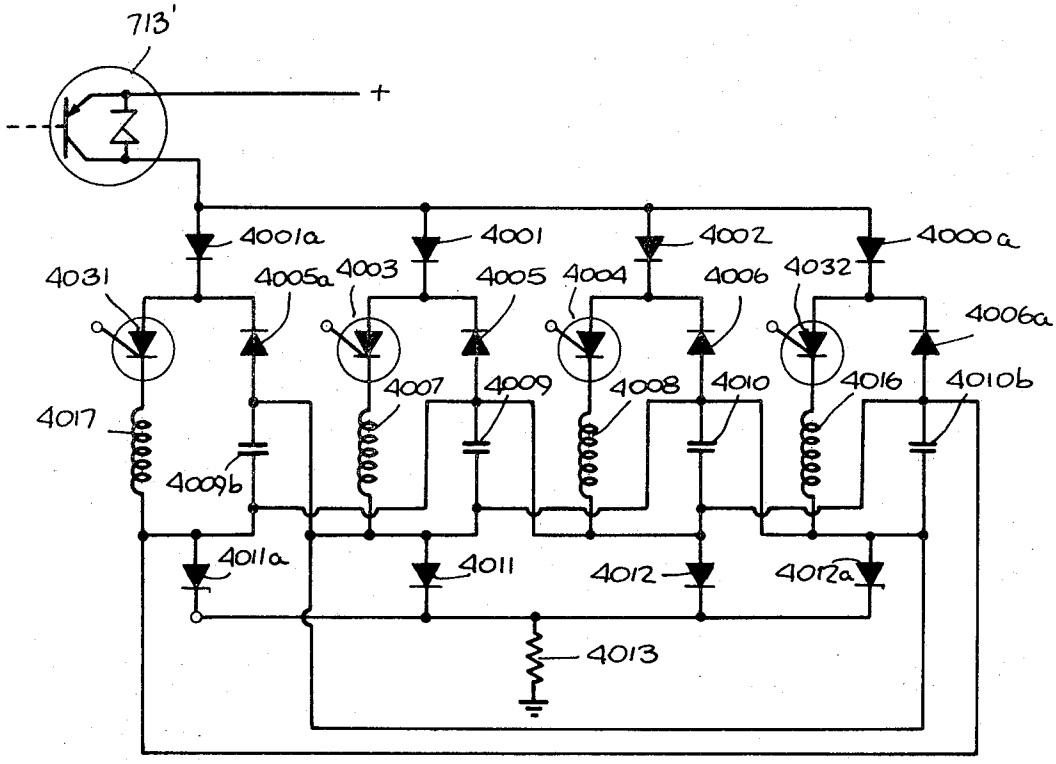
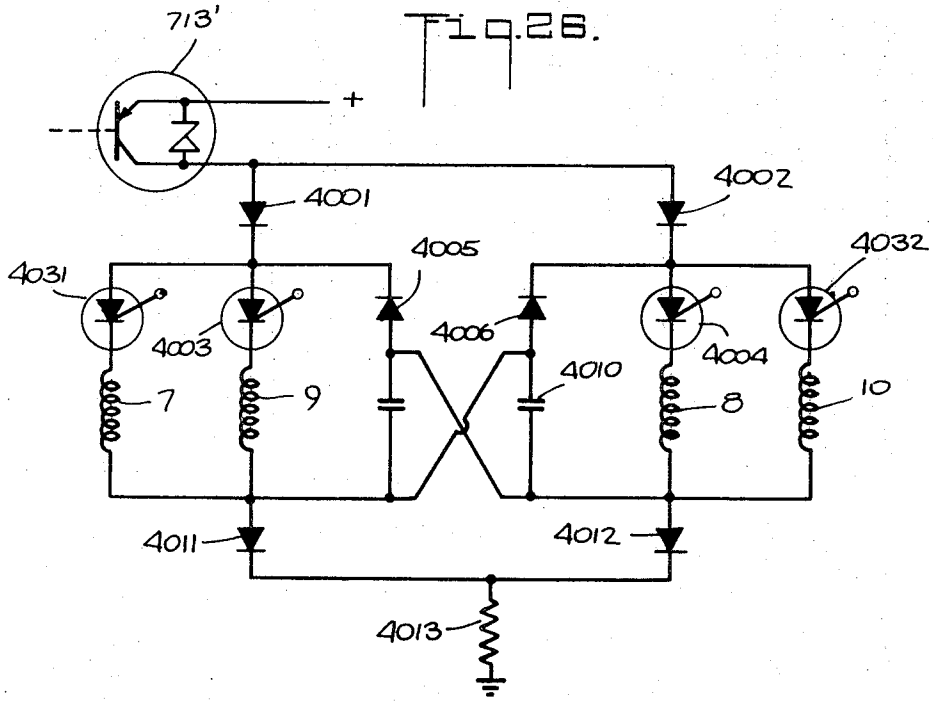

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Fig.25.

Fig.26.


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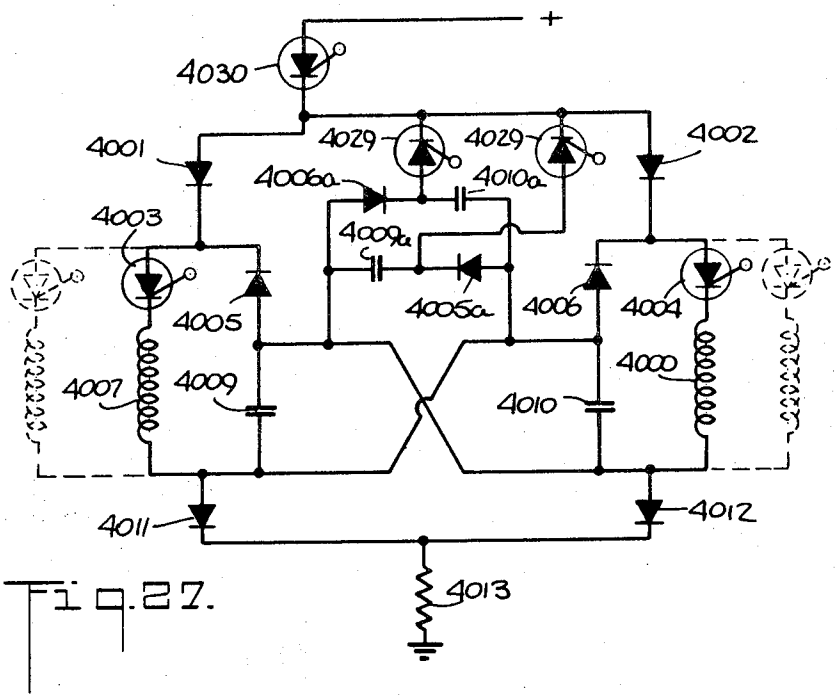


Fig. 27.

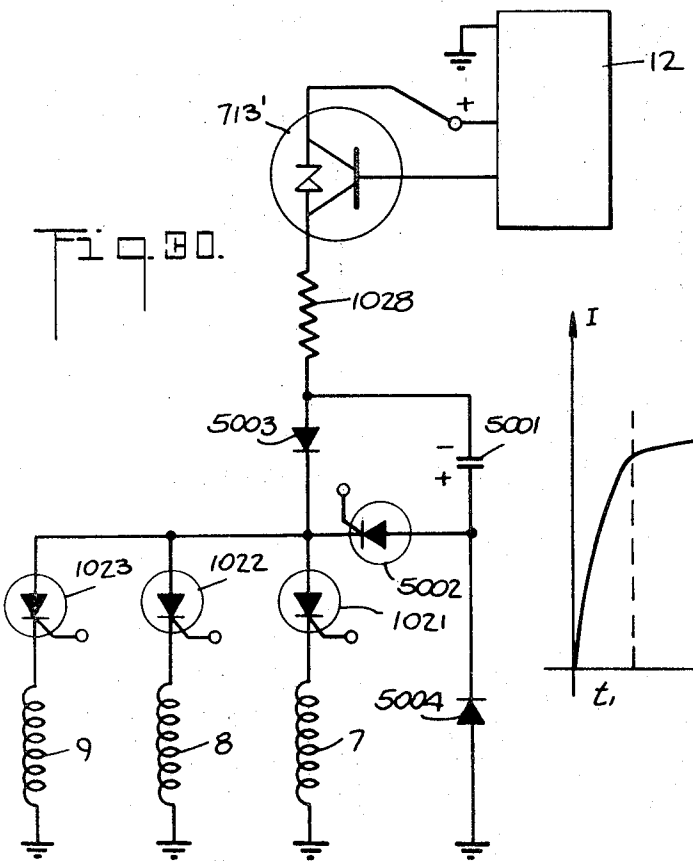


Fig. 30.

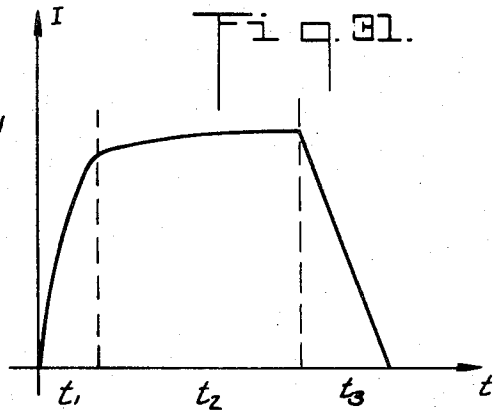


Fig. 31.

Fig. 2B.

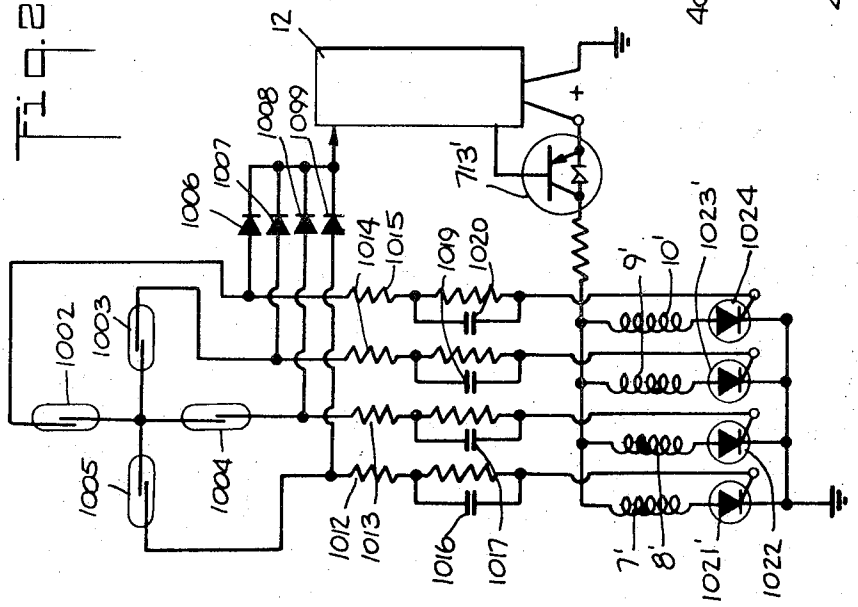
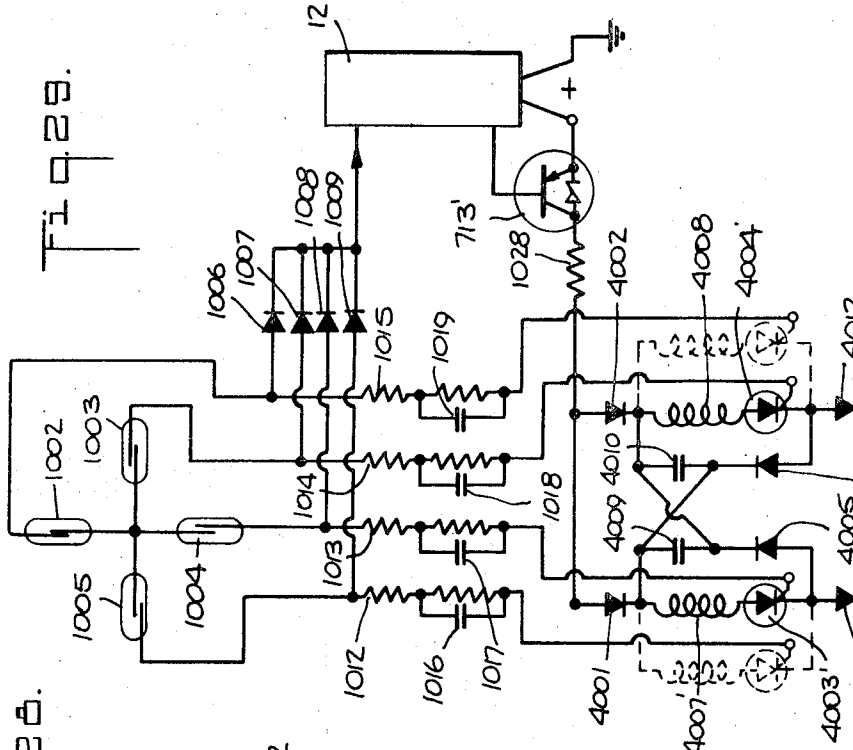

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Fig. 2B.


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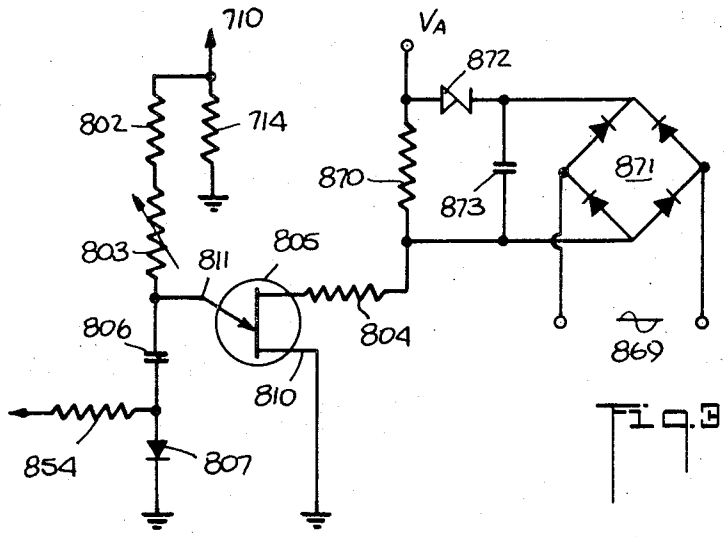
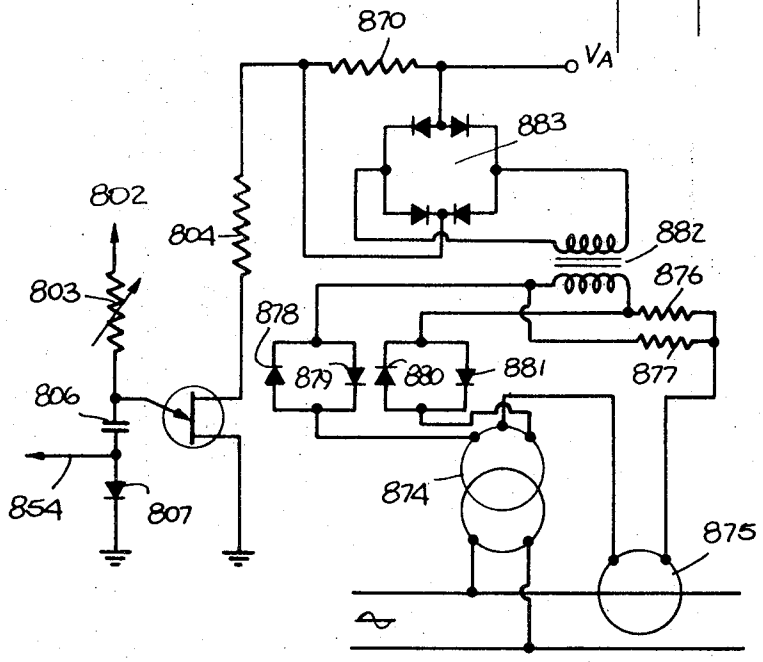

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Fig. 32.

Fig. 33.


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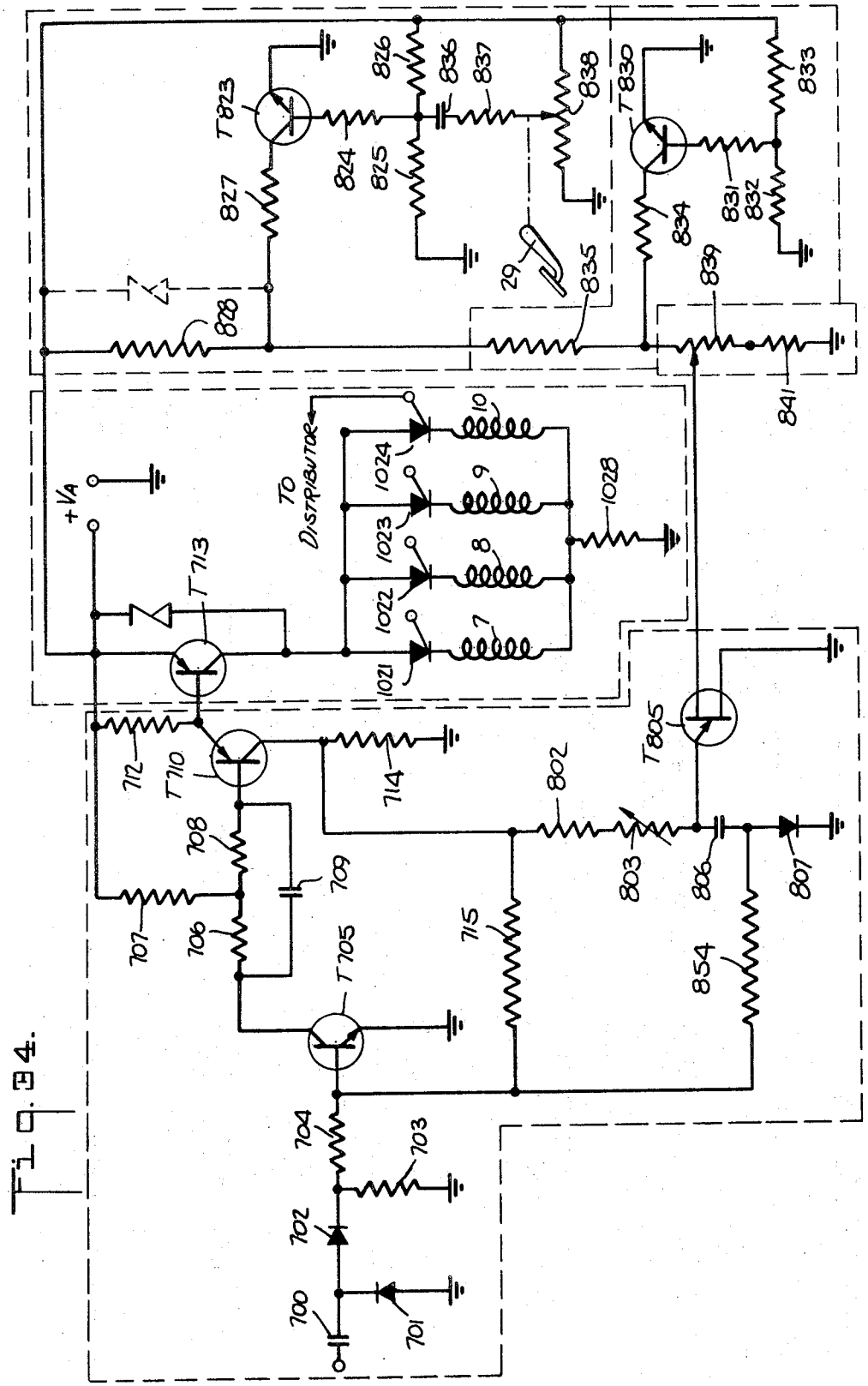

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FIG. 84.

HIGH SPEED FUEL INJECTION SYSTEM

This is a continuation of application Ser. No. 871,670, filed Nov. 10, 1969, now U.S. Pat. No. 3,710,763 issued on Jan. 16, 1973, which is a continuation of Ser. No. 816,767 filed Apr. 16, 1969 and now abandoned, which in turn is a division of application Ser. No. 630,035 filed Apr. 11, 1967 for "HIGH-SPEED FUEL INJECTION SYSTEM", now U.S. Pat. No. 3,456,628 issued July 22, 1969 in the name of the present applicants.

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 diffuculties 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 direct or 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 diagram showing a switching mechanism used with the injection device;

FIG. 4 is an electrical diagram showing the bistable circuit controlling the injection;

FIG. 5 is a circuit diagram of the delay element of the injection system;

FIG. 6 is an electrical diagram showing the electronic bistable circuit and the delay element;

FIG. 7 is a diagram showing a distributor used with the injection system;

FIG. 8 is a sectional view of the distributor shown in FIG. 7;

FIG. 9 is a curve showing the duration of the injection as a function of a regulating voltage;

FIG. 10 is an electronic diagram of a manual device for enriching the fuel mixture when the engine is cold, connected with the delay element;

FIG. 11 is an electronic diagram for an automatic device for enriching the fuel mixture when the engine is cold, connected with the delay element;

FIG. 12 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. 13 is an electronic diagram of a device connected to the gas pedal for allowing temporary enrichment of the fuel mixture;

FIG. 14 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. 15 is another embodiment of a device for correcting the duration of the injection as a function of the rotational speed of the motor;

FIG. 16 shows a curve showing the duration of injection as a function of the speed of rotation with the device shown in FIG. 14;

FIG. 17 is a curve showing the duration of injection as a function of motor speed with the device shown in FIG. 15;

FIG. 18 shows another embodiment of a device for correcting the duration of injection as a function of motor speed;

FIG. 19 is a block diagram showing an electronic distributing arrangement device;

FIG. 20 is a circuit diagram of an arrangement according to FIG. 19;

FIG. 21 is a diagram showing an electronic circuit for protection of the power transistor;

FIG. 22 is another embodiment of the circuit shown in FIG. 21;

FIG. 23 is a first arrangement for the recovery of magnetic energy;

FIG. 24 is a second arrangement for the recovery of magnetic energy;

FIG. 25 is a third arrangement for the recovery of magnetic energy;

FIG. 26 is a fourth arrangement for the recovery of magnetic energy;

FIG. 27 is a fifth arrangement for the recovery of magnetic energy;

FIG. 28 shows an arrangement for preventing over voltages due to interruption of the injector control coil current;

FIG. 29 is the arrangement of FIG. 28, combined with an arrangement for the recovery of magnetic energy;

FIG. 30 shows an alternate method for recovery of magnetic energy;

FIG. 31 shows the current in the injector coil as a function of time, for the circuit of FIG. 30;

FIG. 32 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. 33 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; and

FIG. 34 is a schematic diagram illustrating the interconnection of the circuits illustrated in FIGS. 6, 11, 12, 13, 14 and 22, 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 electromagnetic 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 curcuitry 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 curcuitry 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 of pressure (a bar is the international unit 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.

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.

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. **3** 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 commutation.

The bistable circuit is shown in FIG. **4.** 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. **5,** 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:

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

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

Energization takes place at a time t such that:

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

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:

$$-Vp$$

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. **5,** 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 electronic control system **12** therefore becomes that shown in FIG. **6.** Transistor **713** (FIG. **4**) 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 Vp; thus the control is calculated to yield:

$$Vp = \eta V_A$$

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 percent per degree.

The change with temperature per degree is less than 0.01 percent 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. **7** and **8** 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 crank shaft.

As shown in FIGS. **7** and **8** 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. **9** may be consulted, showing the variation of injection duration with regulating voltage. The duration of injection is given by:

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

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. **10.** 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. **11** 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 resistor **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. **12** 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 0.2 to 0.3 percent 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. **13.** This circuit comprises a capacitor **836,** a resistor **837,** and a potentiometer **838** connected as shown in FIG. **13.**

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. **13,** 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. **14** and **15** 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. **14** the potentiometer **839** is of the standard type. In FIG. **15** the potentiometer **842** has a center tap. FIGS. **16** and **17** 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. **18.**

When the switch having the elastic lamina (**604**) FIG. **3** 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 FIGS. **16** or **17** may be obtained, since, for a given control pulse:

$$\Delta t_i = \frac{1 - e^{\frac{-\alpha}{wt_1}}}{1 - Be^{\frac{-\alpha}{wt_2}}}$$

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

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

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

$$B = (C_{847} \cdot)/C_{847} + C_{851})$$

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.

FIG. **19** 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. **19.** 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. **20** 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. **20** 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 assembly of the transistor and the Zener diode are put together into one housing and the resultant overall circuitry is designated by the name "ignistor" hereinafter designated by the reference character **713'**. FIG. **21** 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.

Of course, it is also possible to replace the resistors **1025** to **1028** by a single resistance **1028** as shown in FIG. **22.**

FIG. **34** illustrates how the circuit of FIG. **22,** in one embodiment of the invention, may be combined with the circuits of FIGS. **6, 11, 12, 13** and **14.** The portion of the circuit enclosed by the dotted lines at the left of FIG. **34** represents the circuit of FIG. **6**; the central portion enclosed by the dotted lines represents the circuit of FIG. **22**; the portion of the circuit enclosed by the dotted lines at the upper right of FIG. **34** represents a combination of the circuits of FIGS. **11** and **13**; the portion of the circuit enclosed by the dotted lines immediately below the last described portion represents the circuit of FIG. **12**; 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. **14.**

The operation of the circuit of FIG. **34** is briefly as follows: A magnetic switching device which rotates with the crankshaft of the motor, of the type illustrated in FIG. **20** or of the type illustrated in FIGS. **7** and **8,** 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. **6,** 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. **11, 12, 13** and **14,** comprising the right-hand portion of FIG. **34.** 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.

As was described above, the injectors are opened by an injection control signal. 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. **23** shows an embodiment for the case of two injectors, FIG. **24** is a variation of this embodiment, FIG. **25** 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 independently 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 cutoff of the thyristor **4003** blocks the oscillation of the circuit constituted by the inductance of **4007** and the capacitance **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 cyle 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. **24** 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. **25** 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. **26.** The operation of the circuit is identical to that described in relationship to FIG. **23.** 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. 27) 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. **27.** 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 **4009***a* is also charged via diode **4005***a*. At the next cycle, when thyristor **4029** is fired, the positive voltage on capacitor **4009***a* 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. **28.** This shows the same circuit as FIG. **20** 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. **20** 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. **27,** 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. **29.**

The circuits illustrated in FIGS. **25–27** 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. **30.** 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. **30.** 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. **31** 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 the 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. **32**). 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. **33.** 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-lead 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. The secondary voltage of transformer **882** is applied across the terminals of resistor **870** as shown in FIG. **33,** 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.

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.

1. In a fuel injection system for internal combustion engines of the type including at least one electromagnetic fuel injector, each injector having an injector solenoid; a source of voltage; and switching means for connecting the source of voltage to said at least one injector solenoid in response to periodic injector control signals for supplying at least a portion of injector current pulses from the voltage source to the injector solenoid for activating the associated electro-magnetic fuel injector to inject fuel for the duration of the injector control signals, the improvement for recovery of electrical energy to aid in rapidly energizing the next solenoid to be actuated comprising:

a. capacitive electrical energy storage means having one side adapted to be connected to one side of each of said injector solenoids and the other side adapted to be connected to the voltage source;

b. first current flow control means connected to the other side of each injector solenoid and the one side of the capacitive storage means for permitting current generated in said injector solenoid upon cutoff of one of the injector control signals which serves to energize said injector to flow in a first direction into the capacitive storage means for storage therein and for preventing current flow from the capacitive storage means through said injector solenoid in a direction opposite to the first direction;

c. first triggering means connected between said one side of the capacitive storage means and one side of an injector solenoid to be energized by a subsequent injector current pulse for conducting the energy stored in the capacitive storage means to the winding of said subsequently energized injector solenoid in response to the initiation of the corresponding subsequent injector control signal, whereby said injector solenoid receiving the subsequent injector current pulse is rapidly energized by the energy stored in the capacitive storage means; and

d. second current flow control means connected between the other side of the capacitive storage means and said one side of said one injector solenoid for permitting current flow in said first direction from the connection between the capacitive storage means and the voltage source to said one injector solenoid but for preventing a short circuit discharge current flowing in the opposite direction from the capacitive storage means when the first triggering means is conductive.

2. The system of claim **1** including at least two electromagnetic fuel injectors and their associated injector solenoids wherein the system further comprises:

a. second triggering means connected in series with said one injector solenoid and said voltage source for conducting injector current pulses to said one injector solenoid in response to the initiation of selected ones of said injector control signals and

b. third triggering means connected in series with a second one of the injector solenoids and said voltage source for conducting injector current pulses to said second injector solenoid in response to the initiation of selected others of said injector control signals alternating with said selected ones, the series circuit including the the second solenoid and the third triggering means being connected in parallel with the series circuit including the one solenoid and the second triggering means, and both series circuits are connected to the capacitive storage means and the first triggering means.

3. The system of claim **2** wherein said first current flow control means and said second current flow control means comprise first and second unidirectional current control devices, respectively.

4. The system of claim **3** wherein said first, second, and third triggering means comprise first, second, and third thyristors, respectively.

5. The system of claim **1** wherein said first triggering means is also connected to a point which is between the voltage source and said subsequently energized injector

solenoid, said first triggering means applying at least a portion of the subsequent injector current pulse to the winding of said subsequently energized injector solenoid, the portion of the subsequent injector current pulse including the stored energy from the at least one capacitive storage means and said first triggering means applying the portion of the subsequent injector current pulse in response to the corresponding subsequent injector control signal.

6. In a method for controlling fuel delivery to internal combustion engines having one or more electromagnetic fuel injectors, each injector being activated by an associated solenoid energized from a source of voltage in response to periodic injector control signals, including the steps of connecting one solenoid to the source of voltage through a switching means activated in response to the initiation of one of the injector control signals to supply a current pulse in a predetermined direction through the one solenoid to activate the associated injector and disconnecting the said one solenoid from the source of voltage at the termination of the one injector control signal for regulating the quantity of fuel injected in accordance with the duration of the one injector control signal, the improved method of rapidly energizing a subsequently energized solenoid comprising the additional steps of:

a. conducting in the predetermined direction the self-induced current generated in said one solenoid upon termination of the injector control signal through a path from the one solenoid through a first current control means to one side of a capacitive storage means;

b. preventing the reverse flow of current from the one side of the capacitive storage means through the current control means to said one solenoid; and

c. connecting the one side of said capacitive storage means to one side of a subsequently energized solenoid through a triggering means actuated in response to the initiation of a subsequent injector control signal;

d. connecting the other side of said capacitive storage means to the other side of the subsequently energized solenoid through a series path that includes the source of voltage and the switching means, the switching means being activated in response to initiation of the subsequent injector control signal simultaneously with the actuation of the triggering means, whereby the charged capacitive storage means and the source of voltage are connected in series across the subsequent solenoid so that said subsequent solenoid is rapidly energized by a flow of current in the predetermined direction.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,822,678 Dated July 9, 1974

Inventor(s) Jacques Bassot and Louis Monpetit

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

Column 3, Line 46, change "cur" to --cir--.

Column 16, line 52, delete second "the".

Column 18, line 2, before "injector" insert --one--.

Signed and sealed this 24th day of September 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

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