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W. F. GUNKEL

2,970,246

SOLENOID ACTUATING CIRCUIT

Filed Feb. 15, 1957

2 Sheets-Sheet 1

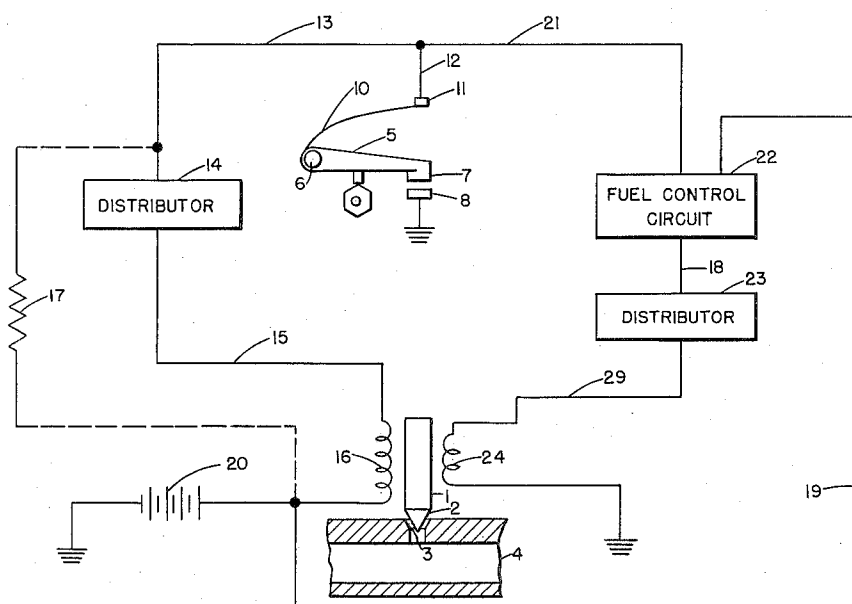
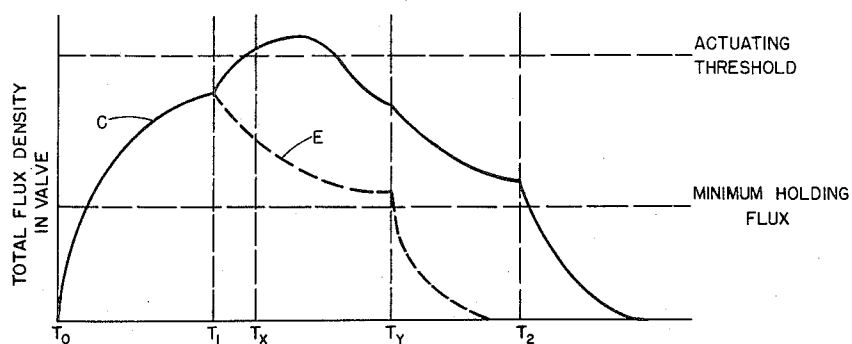


FIG. 1



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FIG. 2

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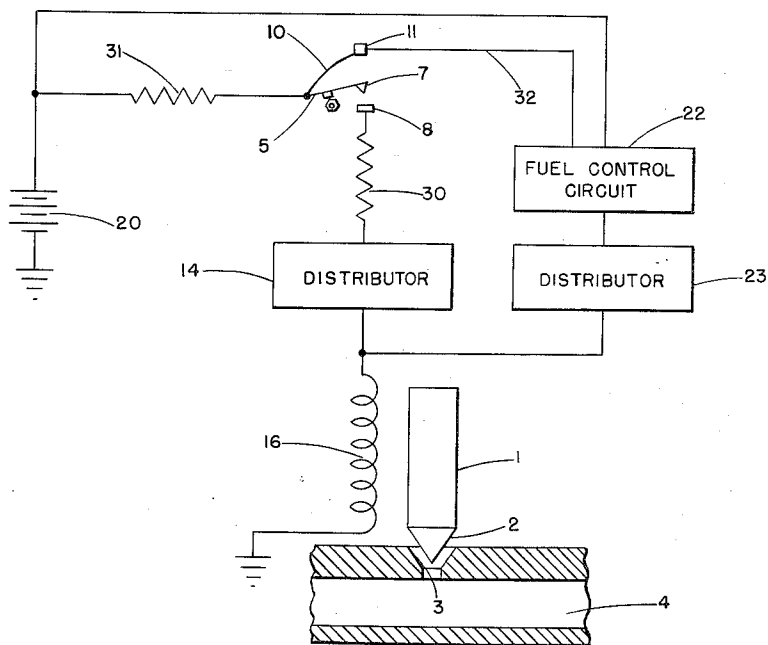


FIG. 4

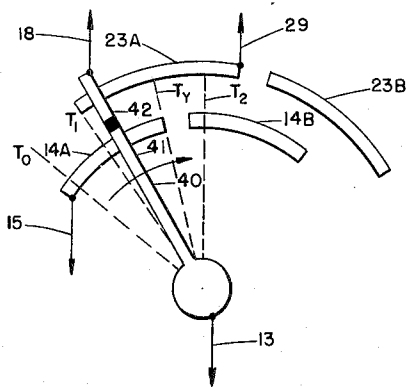


FIG. 3

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SOLENOID ACTUATING CIRCUIT

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6 Claims. (Cl. 317-123)

This invention relates to circuits for the energization of solenoids in response to current impulses of short duration.

As an example of the type of device in which the invention may be employed, there will be illustrated and described a solenoid operated valve forming a part of a fuel injection system for internal combustion engines. Such valves are used in systems in which the fuel is maintained under pressure and a separate solenoid operated valve is furnished for each cylinder. The valves are sequentially actuated in synchronism with the rotation of the engine by means of current impulses, the amount of fuel supplied being controlled by varying the duration of the current impulse or the fuel pressure.

In such systems at high engine speeds the time available for the opening of each valve is very short. A typical solenoid operated valve requires 0.9×10^{-3} seconds to reach an open condition from the initial application of the pulse. For pulse lengths a little shorter than this time the valve will not open fully until after the termination of the pulse. For still shorter pulses the valve will not open fully. A considerable portion of this time following the initial application of the pulse is consumed in the build up of the flux density in the valve armature to the valve actuating threshold. The flux density at the actuating threshold is at a considerably higher level than that necessary to hold the valve in its open position once it has been opened.

It is an object of this invention to greatly shorten the time required for the valve actuating threshold to be reached after the impulse is applied and to thus correspondingly shorten the opening time of the valve.

It is a further object of the invention to greatly reduce the power content required in the valve actuating impulse for the actuation of the valve.

These and other objects and advantages of the invention are realized by a circuit in which the valve is provided with two windings, so wound that their individual fluxes will have a cumulative effect. One coil is supplied with current from the battery by means of a mechanically operated switch and a valve selecting rotary commutating distributor, both of which are engine driven. Upon energization of this coil, flux builds up in the valve to a flux density level just below the valve actuating threshold. The second coil is fed by a monostable multivibrator, such as an Eccles-Jordan circuit, which is triggered by the opening of the above mentioned switch. The impulse applied to the second coil by this action need only have sufficient power to raise the flux density level, already present in the valve due to the first coil, to the actuating threshold level. It then declines in valve to a flux density level above the minimum holding level due to the deenergization of the first coil, and then falls rapidly to zero when the impulse applied to the second coil is terminated. A shunt resistor may be added to the first mentioned coil to help sustain the initial field.

In another form of the invention a single coil is used. When the switch is closed the coil is connected to the

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battery by way of a series pair of resistors. Opening of the switch interrupts this current and triggers the control circuit which applies to the coil a pulse of sufficient magnitude to raise the energy of the field above the actuating threshold level, by way of a connection in parallel with the resistor string.

In the drawings:

Fig. 1 is a schematic diagram of a circuit embodying the invention;

Fig. 2 is a graph showing the composite flux density curve of the two coils of the circuit of Fig. 1;

Fig. 3 is a schematic representation of portions of the distributors of Fig. 1; and

Fig. 4 is a schematic diagram of a second embodiment of the invention using a single coil.

Referring now more particularly to the drawing, there is shown in Fig. 1 a valve for a fuel injection system such as discussed above, comprising a solenoid actuated armature 1, carrying a valve element 2 on its lower end which seats in a seat 3 formed in a portion of an air intake manifold 4 of an internal combustion engine.

There is shown a breaker or switch comprising an arm 5 pivoted at 6 and terminating in a contact element 7. A fixed mating contact element 8 is connected to ground. Secured to the pivoted end of the arm 5 is one end of a spring 10, the other end being in continuous contact with a fixed contact element 11 which terminates a conductor 12.

The conductor 12 is connected to a conductor 13 which extends to a commutating type distributor 14 driven in synchronism with engine rotation. The distributor is connected by a conductor 15 to a coil 16, the remaining terminal of which is connected to one terminal of a battery 20 which in turn has its remaining terminal grounded. The energization of the coil causes eddy currents to be set up and causes the coil to behave as though it were part of a critically damped oscillatory circuit. If necessary, this effect can be increased by a resistance 17 connected across the distributor 14 and the coil 16.

The conductor 12 is also connected for triggering purposes by a conductor 21 to a fuel control circuit 22, which may consist of a conventional monostable Eccles-Jordan or multivibrator circuit, arranged to trigger on the application thereto of a voltage impulse of selected value having the same polarity as the battery voltage, and an amplifier. The fuel control circuit 22 is also part of a series circuit including a second commutating type distributor 23, and a coil 24 connected by a conductor 19 to the battery 20. The coils 24 and 16 are so wound that the flux produced by a flow of current therethrough is cumulative.

Fig. 2 illustrates the flux density pattern generated by the action of the circuit of Fig. 1 in the armature 1. At time T_0 the contacts 7, 8 close and current from the battery 20 flowing through the coil 16 generates the first portion of the curve C, which by the time T_1 has reached a substantially fixed value, as indicated, which is below the actuating threshold value. At time T_1 the contacts 7, 8 open. This interrupts current flow through coil 16 and the flux density due to current flow through this coil declines immediately in an exponential fashion as indicated by the dashed line E. The presence of the resistor 17 slows the rate of decline of the flux density. At a time T_x the distributor 14 opens, thus removing resistor 17 from the circuit. The flux density now drops rapidly as indicated in the curve E.

The opening of the contacts 7 and 8 at time T_1 triggers the fuel control circuit, however, and said circuit delivers an impulse to the coil 24 which causes the total flux density to rise. At time T_x the total flux density crosses the actuating threshold and the valve opens. After the initial rise the total flux density declines due

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to the decay of flux in coil 16, but coil 24 maintains said flux above the minimum holding level. At a time T_2 the impulse from the fuel control circuit is terminated and the total flux drops to zero as indicated.

Fig. 3 illustrates a combination of the distributors 14 and 23 into one device for the purpose of showing the relationship between their actions. Two segments 23A and 23B of the distributor 23 are shown as are segments 14A and 14B of the distributor 14. The segments 23A and 14A may be taken as pertaining to the valve illustrated, the segments 23B and 14B being connected to another valve of the set. A rotating contact arm 40 is formed into two insulated contact elements 41 and 42, the element 41 being connected to the conductor 13 and wiping the contacts of distributor 14, while the element 42 is connected to the conductor 18 and wipes the contacts of distributor 23. Segment 14A is connected by conductor 15 to the coil 16 and element 41 is connected by conductor 13 to the breaker arm 5. Element 42 is connected by a conductor 18 to the output of the fuel control circuit, while segment 23A is connected by a conductor 29 to the coil 24.

The embodiment illustrated in Fig. 4 utilizes a single coil 16 which is connected through two parallel circuit branches to one terminal of the battery 20. One of these branches includes a series arrangement of the distributor 14, a resistor 30, contacts 8 and 7, the arm 5, and a resistor 31. The other branch comprises the distributor 23 and fuel control circuit 22 in series. The spring 10 is connected to the fuel control circuit 22 by a conductor 32.

In the operation of this embodiment, as long as the contacts 7 and 8 are closed, the voltage drop across the two resistors maintains the flux level below threshold value. With the opening of the contacts, the voltage at point 11 triggers the fuel control circuits so that it applies an impulse to the coil which raises its flux level above threshold. The flux-level decays to a point above the minimum holding level, as in Fig. 2, until the impulse is terminated.

In either of the above embodiments the two distributors may be somewhat out of phase, since the two branches of the circuit require the application of battery voltage at times which are sequential over time intervals which are not identical.

What is claimed is:

1. Means for magnetically actuating an armature from a first position to a second position and maintaining it in said second position for a predetermined time, comprising: induction means so positioned that the magnetic field generated by the energization thereof will actuate said armature, a source of direct current, a pair of circuits, each connecting said source to said induction means, one of said circuits applying to said induction means a current sufficient to only partially energize it, means for periodically interrupting said one of said circuits, means in the other of said circuits, responsive to the application thereto of voltage of a selected value to generate and apply to said induction means a current impulse sufficient in magnitude to complete the energization thereof, and means connecting said generating means to a point in said one circuit the voltage of which attains said selected value upon the said interruption of said one circuit, the magnitude of said impulse being sufficient to maintain said armature in said second position but less than the magnitude required to actuate said armature.

2. Means for magnetically actuating an armature from a first position to a second position and maintaining it in said second position for the duration of a selected time interval, comprising: induction means so positioned that the magnetic field generated by the energization thereof will actuate said armature, a source of direct current, a pair of circuits, each connecting said source to said induction means, one of said circuits applying to said in-

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duction means a current sufficient to only partially energize it, means for periodically interrupting said one of said circuits, a monostable multivibrator in the other of said circuits having an unstable period equal to said selected time interval, said multivibrator being responsive to the application thereto of voltage of a selected value to generate and apply to said induction means a current impulse sufficient in magnitude to complete the energization thereof and means connecting said multivibrator to a point in said one circuit, the voltage of which attains said selected value upon the said interruption of said one circuit, the magnitude of said impulse being sufficient to maintain said armature in said second position but less than the magnitude required to actuate said armature.

3. Means for magnetically actuating an armature from a first position to a second position and maintaining it in said second position for the duration of a selected time interval, comprising: a coil wound around said armature, a source of direct current, a pair of circuits, each connecting said source to said coil, one of said circuits applying to said coil a current sufficient to energize it to a level below that necessary for the actuation of said armature, means for periodically interrupting said one of said circuits, a monostable multivibrator in the other of said circuits having an unstable period equal to said selected time interval, said multivibrator being responsive to the application thereto of voltage of a selected value to generate and supply to said coil a current impulse sufficient in magnitude to complete the energization thereof to a level such that said armature is actuated, and means connecting said multivibrator to a point in said one circuit, the voltage of which attains said selected value upon the said interruption of said one circuit.

4. Means for magnetically actuating an armature from a first position to a second position and maintaining it in said second position for the duration of a selected time interval, comprising: a coil wound around said armature, a source of direct current, a pair of circuits, each connecting said source to said coil, one of said circuits comprising a pair of serially connected resistors, a monostable multivibrator in the other of said circuits having an unstable period equal to said selected interval, means connecting the junction of said resistors to said multivibrator in a manner to trigger said multivibrator into its unstable state upon the application of a selected value of voltage by way of said connecting means, and means for periodically interrupting said one circuit between said connecting means and said coil, the values of said source and said resistors being such that said coil is energized at a level below that necessary to actuate said armature while said one circuit is complete, and said connecting means applies to said multivibrator a voltage of said selected value when said one circuit is interrupted, the output of said multivibrator completing the energization of said coil, whereby said armature is actuated and remains actuated until said multivibrator returns to its stable state.

5. Means for magnetically actuating an armature from a first position to a second position and maintaining it in said second position for the duration of a selected time interval, comprising: a first coil wound around said armature, a source of direct current, means serially connecting said source and said coil into a circuit including a pair of parallel branches, one of said branches comprising a monostable multivibrator and a second coil wound around said armature, said multivibrator having an unstable period equal to said selected time interval, and the other of said branches having a low impedance relative to said one branch and including a switch, the values of the parameters of the circuit including said first coil being such that when said switch is closed said first coil produces in said armature insufficient flux to actuate said armature, and the parameters of the circuit containing said second coil being such that when said switch is open said multi-

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vibrator is triggered to its unstable state and said second coil produces in said armature an amount of flux which when taken with that produced by said first coil is sufficient to actuate said armature, but which when taken alone is only sufficient to maintain said armature in said second position.

6. Means for magnetically actuating an armature from a first position to a second position and maintaining it in said second position for the duration of a selected time interval, comprising: a first coil wound around said armature, a source of direct current, means connecting said source into a series circuit comprising said coil, a monostable multivibrator and a second coil wound around said armature, said multivibrator having an unstable period equal to said selected time interval, means connected to the junction of said coil and multivibrator of said series circuit for providing a low impedance shunt around said multivibrator and said second coil, and means for inter-

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rupting said shunting means, the values of the parameters of said series circuit being such that when said shunt is complete said first coil produces in said armature insufficient flux to actuate said armature, said parameters of said series circuit being such that when said shunting means is interrupted said multivibrator is triggered to its unstable state and said second coil produces in said armature an amount of flux which when taken with that produced by said first coil is sufficient to actuate said armature, but which when taken alone is only sufficient to maintain said armature in said second position.

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