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[54] **CONTROLLED FUEL INJECTION
 ARRANGEMENT FOR INTERNAL COMBUSTION
 ENGINES**
 5 Claims, 3 Drawing Figs.

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 [50] Field of Search **123/32**

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ABSTRACT: A fuel injection control arrangement for establishing the opening duration of electromagnetically actuated injection valves in internal combustion engines. A control circuit generates the control voltage for varying the duration of pulses emitted by a monostable multivibrator which is actuated by a cam-operated switch driven from the crankshaft of the engine. The control voltage has a periodically varying waveform timed with respect to the pulses realized from the monostable multivibrator. Switching transistors within the control circuit are actuated upon expiration of a predetermined time delay after the terminations of the pulses from the multivibrator. One of the switching transistors is driven into saturation for generating a first time delay, and is subsequently operated in the nonsaturated region for generating a subsequent second time delay through which the predetermined opening duration of the valve is realized.

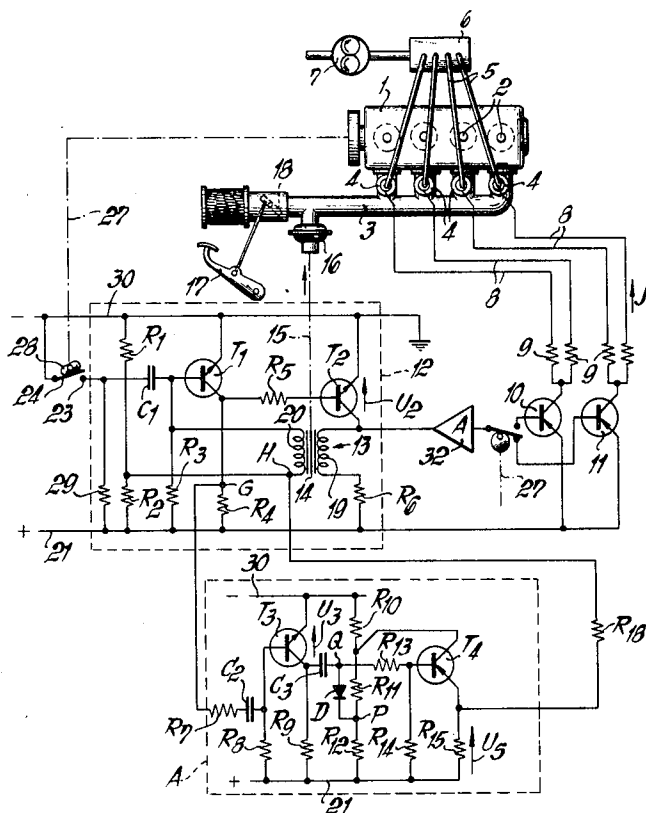
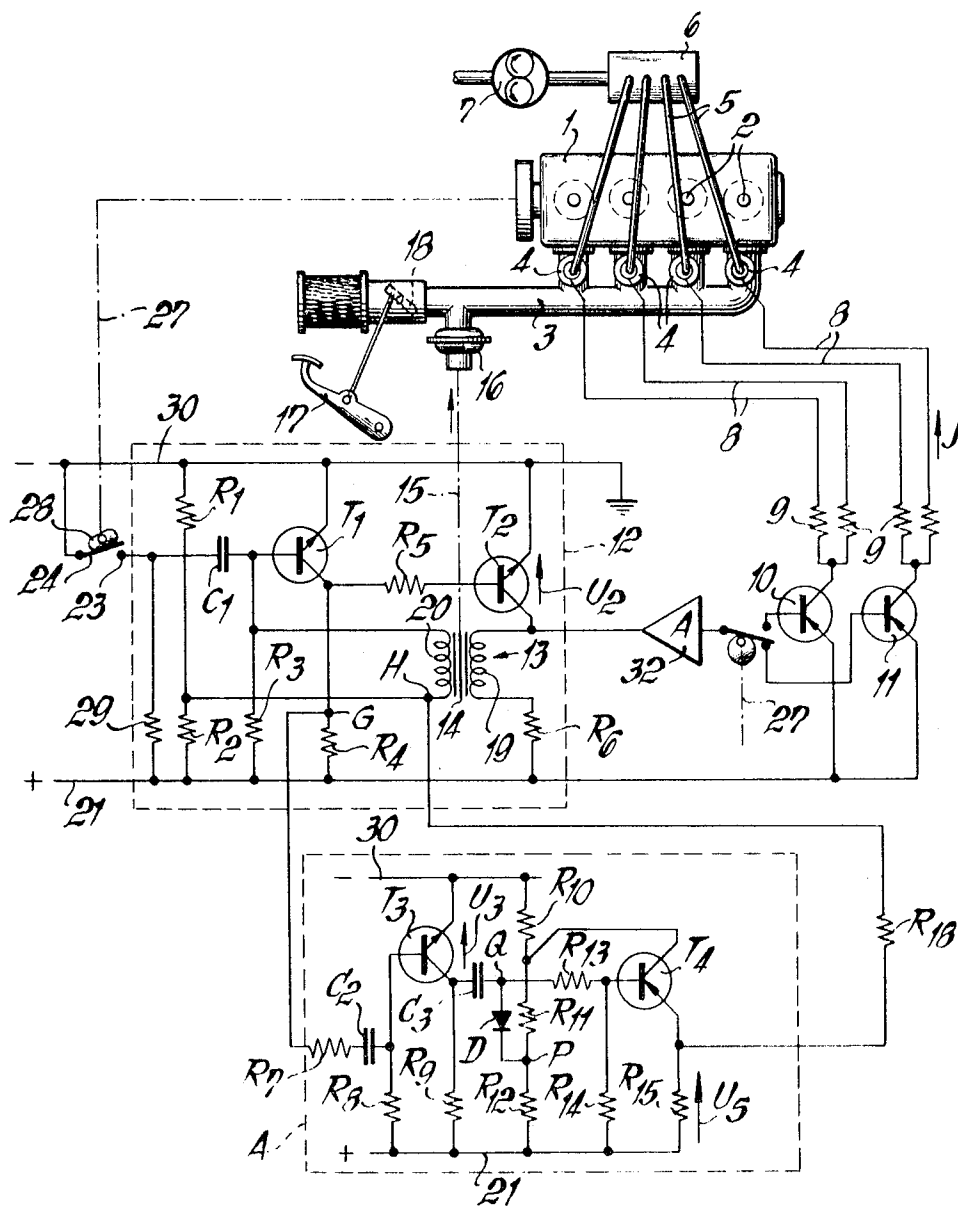


FIG. 1



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FIG. 2

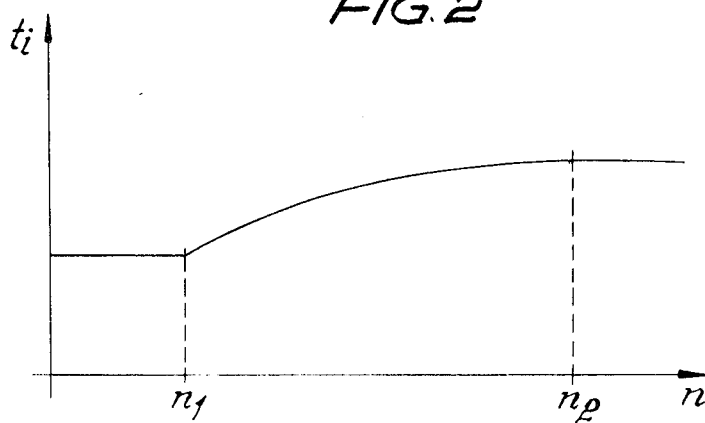
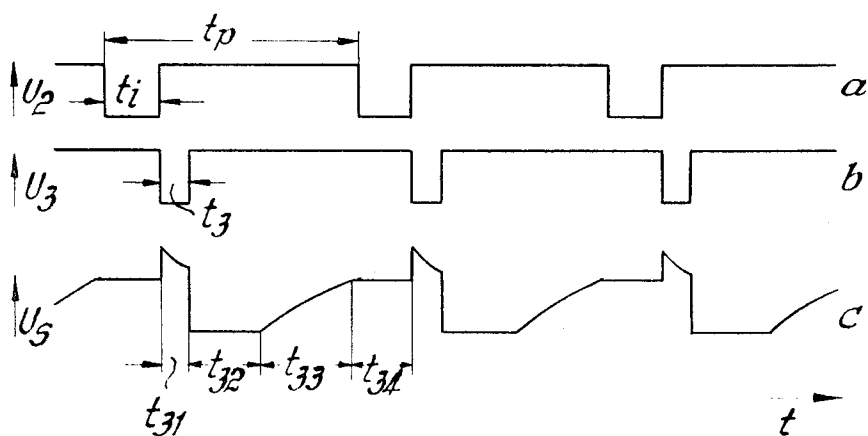


FIG. 3



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CONTROLLED FUEL INJECTION ARRANGEMENT FOR INTERNAL COMBUSTION ENGINES

BACKGROUND OF THE INVENTION

The present invention resides in a control arrangement for operating at least one electromagnetic injection valve of an injection arrangement for internal combustion engines. The arrangement has one input transistor and one output transistor, a monostable multivibrator for producing rectangular-shaped pulses for opening the injection valves. The duration of the pulses and the opening of the valves is accomplished by applying a control voltage to the base of the input transistor as a function of the rotational speed. The waveform of the pulses is varied in frequency and is produced through a control circuit which contains at least two switching transistors with delay times beyond the terminations of the switching pulses. The first switching transistor is connected with its base to a first capacitor, and from there to the collector of the input transistor. The second switching transistor, on the other hand, is connected with its base to a coupling resistor, through a second capacitor, and from there to the terminal of the operating resistor of the preceding transistor.

In fuel injection arrangements of this species, the amount of fuel required for the subsequent operating cycle of the engine is measured through the opening duration of the respective injection valve to which the fuel is applied under substantially constant pressure. For the purpose of varying the duration of the switching pulse for the injection valve, the feedback circuit of the monostable multivibrator includes an electrical storage element which consists of a ferromagnetic choke which is adjusted in magnitude through the pressure prevailing behind the throttle flap within the intake manifold. For the purpose of achieving additional corrections to the pulse duration as a function of the rotational speed, the duration of the unstable state may be shortened or extended through the feedback conditions which are usually not variable. For this purpose, a control voltage is provided as a function of time, which is produced through a control circuit and initiated at the end of a switching pulse. The control circuit has two or more switching transistors.

In one known control arrangement of the preceding species, two storage capacitors are provided with interconnections to a chain, through resistors. The voltage at the end of the chain is applied, through a resistor, to the input transistor in the monostable multivibrator. In view of such coupling, it is necessary to use substantially large storage capacitors, since the resistors connected to these capacitors may only have substantially small values. Aside from this, difficulties are incurred when matching this known control arrangement to the construction of a combustion engine in which the opening duration is fixed as a function of rotational speed. This is due to the condition that in varying the individual resistance values, complex and thereby difficult effects upon the waveform of the control voltage and the duration of the opening pulses are realized.

In order to avoid these difficulties, a control voltage is generated through a control circuit in an arrangement of the preceding species, in which a correction to the opening duration of the pulse is applied automatically as a function of speed of the engine. In this control circuit, the second transistor for producing a first time delay in its saturated state is used. This transistor also produces a second delay in its active region.

SUMMARY OF THE INVENTION

A control circuit for establishing the opening duration of electromagnetically actuated fuel injection valves in internal combustion engines. A monostable multivibrator is actuated through a cam operated switch mechanically lined to the crankshaft of the engine. The monostable multivibrator has an input and an output transistor for the purpose of generating pulses which are applied to the valve, through power amplifiers. The valve is held opened for a duration determined by

the unstable state of the monostable multivibrator. A control voltage is generated to vary the duration of the pulses of the multivibrator as a function of the rotational speed of the engine, so that the control voltage has a periodically varying waveform timed to the pulses of the multivibrator. Two switching transistors used to generate the control voltage, are actuated upon expiration of a predetermined time delay after the ends or terminations of the pulses of the multivibrator. One of the switching transistors is driven into saturation for generating a first time delay and is, furthermore, operated in the nonsaturated region for generating a subsequent second time delay.

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 drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is an electrical schematic diagram and shows the components used in the control circuitry for establishing the opening duration of the fuel injection valve of the internal combustion engine, in accordance with the present invention;

FIG. 2 is a graphical representation of the opening duration of the valves as a function of rotational speed of the engine, which is realizable with the circuitry of FIG. 1; and

FIG. 3 shows waveform diagrams of three voltage signals arising in the circuitry of FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The fuel injection arrangement of FIG. 1 is designed to drive a four-cylinder internal combustion engine 1 which has spark plugs 2 connected to a high-voltage ignition arrangement. An electromagnetically actuated injection valve 4 is provided in direct proximity to the inlet valves of the internal combustion engine (not shown). These electromagnetically actuated injection valves 4 are arranged on the branches on the intake manifold 3, so that one electromagnetically actuated injection valve is provided for each cylinder. Fuel is supplied to each valve through fuel lines 5 leading from a distributor 6. The fuel is maintained in the distributor in the fuel lines 5 at a pressure of approximately 2 atmospheres, through a pump 7 driven by a motor.

Each of the injection valves 4 possesses a magnetizing coil, not shown, which has one end connected to ground potential. The other end of these magnetizing coils is connected to one of four resistors 9, through connections 8. Two groups of two resistors 9 are connected together at one terminal and joined to the collector of one of the power transistors 10 and 11 which belong to an electronic regulating and control circuit to be described further.

Aside from the power transistors 10 and 11, this regulating and control circuit includes a transistorized monostable multivibrator 12 which is outlined through dashed lines. This monostable multivibrator 12 contains an input transistor T_1 and an output transistor T_2 , as well as a timing element in the form of a choke or inductive coil 13.

The inductive coil or choke 13 is designed in the form of a transformer, and has an adjustable armature 14. This armature is mounted on a displacement rod 15 which is coupled to the membrane, not shown, of a pressure-sensing device 16. The suction side of this pressure-sensing device 16 is directly connected to the intake manifold 3 of the internal combustion engine, and behind the adjustable throttle flap 18 which is linked to a foot pedal. When the pressure drops within the intake manifold, the armature 14 is lifted in the direction of the arrow shown in the drawing, so that the airgap of the ferromagnetic core, not shown, of the transformer with primary winding 19, is increased. As a result of the increase in the airgap, the inductance of the primary winding 19 is reduced, and

consequently, the inductance decreases with decrease in pressure within the intake manifold 3.

The transformer has a secondary winding 20 which has one terminal connected to the base of transistor T₁ and, at the same time, to the positive voltage supply line 21, by way of resistor R3. The other end of this secondary winding 20 is connected to the junction H. A resistor R2 is connected between the junction H and the positive voltage supply line 21. A resistor R1 is, furthermore, connected between the junction H and the negative voltage supply line 30. Both transistors T₁ and T₂ are of the NPN type, and are directly connected with their emitters to the negative voltage supply line 30. A resistor R4 is connected between the collector of the transistor T₁ and the positive voltage supply line 21. The collector of the transistor T₂, on the other hand, leads to this positive voltage supply line 21, through the primary winding 19 of the ferromagnetic choke 13 and a resistor R6 connected in series with this primary winding 19. The base of the transistor T₂ is connected through the collector of the transistor T₁, through a coupling resistor R5. One electrode of a differentiating capacitor C1 is connected to the base of the input transistor T₁, whereas the other electrode of this capacitor is connected to the fixed contact 23 of a switch having a movable contact 24. This movable contact of the switch is connected to the negative supply line 30. The switch is operated through a two-lobed cam 28 which is coupled to the crankshaft 27 of the internal combustion engine. The switch becomes closed with each rotation of the crankshaft and turns, thereby, the transistor T₁ off. For purposes of charging and discharging the differentiating capacitor C1, the electrode of this capacitor connected to the fixed switching contact 23, is also connected to the positive voltage supply line 21, through a resistor 29. The other electrode of this capacitor is connected to the positive voltage supply line 21, through the resistor R3. Simultaneously, this other terminal or electrode of the capacitor C1 leads to the junction H through the secondary winding 20.

Prior to describing the additional circuit components of the control circuit, a description will be provided of the manner in which the pulse currents J vary the opening duration of the injection valves 4, at each closure of the switching contacts 23 and 24.

Such variation in the pulse currents J takes place as a result in variations in pressure within the intake manifold 3 and hence in the inductance of the primary winding 19.

The input transistor T₁ conducts or is turned on directly before each individual instant of time that the switching arm 24 rests against the contact 23 so that a circuit closure is realized through the switch. With the input transistor T₁ in the conducting state, the output transistor T₂ is held in its turned-off state. As soon as the switching arm 24 is pressed against the contact 23 through the cam 28, the stored charge within the capacitor C2 drops the base potential of the input transistor T₁ below the potential of the negative voltage supply line 30. As a result, the transistor T₁ is turned off, and the monostable multivibrator 12 is transferred to its unstable state, in which the transistor T₂ conducts. The transistor T₂ then tends to have an exponentially rising collector current which flows through the primary winding 19. This current through the primary winding 19 produces a corresponding rising magnetic field in the ferromagnetic core, not shown, and in the armature 14 of the transformer. The larger the airgap, the more rapid is the rise in the current. At the same time, the inductance of the primary winding 19 decreases with increase in the airgap. With such rise in current, a feedback voltage is induced within the secondary winding 20. This induced voltage is a maximum at the instant of time that a circuit closure prevails through the switching contacts 23 and 24. The induced voltage decreases from this maximum value at a rate determined by the magnitude of the inductance, and the decrease is exponentially. The induced voltage has, furthermore, the polarity by which the input transistor T₁ tends to be turned off, so that the induced voltage acts against the positive base potential through the resistor R3. This positive base

potential, on the other hand, tends to return the input transistor T₁ to its stable conducting or turned on or operating state. This situation occurs when the induced feedback voltage within the secondary winding 20 is lower in magnitude than the base potential.

As long as the transistor T₁ is turned off, the conducting transistor T₂ maintains the power transistors 20 and 11 also in the conducting state, through an amplifier 32. Assume, however, the transistor T₁ is returned to its stable conducting operating state, the transistors T₂, 10 and 11 become again turned off. The duration that the valves 4 are held in their open position through the pulse J is determined, thereby, from the instant of closure of the switching arm 24 to the instant time at which the output transistor T₂ is turned off and the input transistor T₁ is again turned on or is conducting. When the pressure within the intake manifold 3 decreases and the inductance of the primary winding 19 becomes correspondingly reduced, the collector current of the transistor T₂ rises more rapidly. As a result, the induced feedback voltage within the secondary winding 20 drops rapidly in a corresponding manner, and the input transistor T₁ returns again to its conducting state. The valves 4 become closed substantially earlier in this case than when the inductance is greater corresponding to higher pressures within the intake manifold.

Through the variation of the inductance of the primary winding 19 as described above, the duration of the opening pulse J for the injection valves, becomes matched to the prevailing pressure within the combustion engine. Experimentation in motor vehicle operation has shown, however, that the quantity of fuel to be injected must be varied as a function of the rotational speed, in addition to the suction pressure. Since the pulse durations are independent of the rotational speed, and are dependent only upon pressure, the regulating and control circuit of FIG. 1 has, in addition, a control circuit A. Through this control circuit A, the voltage between the junction H and the negative voltage supply line 30 becomes varied periodically and in rhythm to the injection processes. As a result, a control voltage U_s with waveform shown in FIG. 3c is realized from the control circuitry.

The pulse duration t_i of each subsequent pulse J becomes determined through the instantaneous value of the control voltage U_s at each subsequent pulse termination. The period t_p prevails, thereby, between the instant of time that the control voltage is realized and the instant of time at which the control voltage coincides in instantaneous value of the pulse duration. As a result, a firm relationship is realized between the pulse duration t_i and the period t_p or the rotational speed of the engine.

The control circuit A in FIG. 1 serves to mechanize the relationship between the duration t_i of the opening pulse and the rotational speed of the engine, as shown in FIG. 2. In accordance with the graphical representation of this Figure, the opening pulse is to have a constant duration for increase in engine speed n, until a value n₁=1,000 revolutions per minute have been attained. The duration t_i then increases to a second value n₂=4,000 revolutions per minute. This increase between n₁ and n₂ occurs first more rapidly and then tends to level off. Beyond engine speeds of n₂, the duration t_i is substantially constant.

For this purpose, the control circuit A includes a first switching transistor T₃ with base coupled to the circuit junction G, through a coupling capacitor C2 and a resistor R7. Through this capacitor and resistor, a constant delay time t₃ is realized. The circuit junction G corresponds to the junction between the collector of the input transistor T₁ and the resistor R4.

The switching transistor T₃ is of the NPN type and has its emitter connected to the negative voltage supply line 30. The base of this transistor is also connected to the positive voltage supply line 21, through a resistor R8. At the same time, the collector of this transistor T₃ is also connected to the voltage supply line 21 through the resistor R9. A voltage divider composed of resistors R10, R11, and R12, is connected across the

positive and negative voltage supply lines, so that one terminal of the resistor R10 is connected to the negative line 30, and one terminal of the resistor R12 is connected to the positive line 21. A series coupling circuit consisting of a capacitor C3 and coupling resistor R13, is connected between the collector of the transistor T3 and the base of a transistor T4. The anode of a diode D is connected to the junction of the capacitor C3 and the resistor R13. The cathode of this diode, on the other hand, is connected to the junction of the resistors R11 and R12. Through the resistor R14, the transistor T4 acquires a base potential by which this PNP transistor T4 is held in the cutoff or nonconducting state. The collector of the transistor T4 is connected to the junction of resistors R10 and R11 of the voltage divider. A resistor R18 is, furthermore, connected between the emitter of the transistor T4, and the circuit junction H of the monostable multivibrator 12.

In operation of the control circuit A, a negative step voltage appears at the collector of the transistor T1, at the end of the time interval t_1 of the monostable multivibrator 12. This negative step voltage signal is transmitted to the base of the transistor T3 which is conducting during its quiescent state. The transmission of this signal to the base of the transistor T3 is accomplished through the resistor R7 and the capacitor C2. As a result of such actuation of the transistor T3, the latter is turned off until the voltage across the capacitor C2 has discharged to the extent that the voltage between the base and emitter of the transistor T3 become again positive in relation to the emitter. A positive voltage pulse thereby appears at the collector of the transistor T3, and the duration of this pulse is determined by the capacitance of the capacitor C2 and the magnitude of the discharge resistors connected to this capacitor C2.

During the presence of the preceding positive pulses, the capacitor C3 becomes charged through the resistor R9, the diode D, and the resistors R10, R11, and R12. The charging of this capacitor C3 takes place until a voltage appears across the capacitor, which is determined through the potential of the junction point P between the resistors R11 and R12.

The relative timing of the individual pulses is shown in FIG. 3. FIG. 3a shows the timing or time relationship of the voltage U_2 appearing at the transistor T2 of the multivibrator 12. FIG. 3b shows the time relationship or timing of the voltage U_3 at the transistor T3 of the control circuit A. In this regard, FIG. 3b is a graphical plot of the voltage $-U_3$. The voltage U_3 provides a train of positive pulses having a duration t_3 . FIG. 3c shows the control voltage U_s appearing at the emitter of the transistor T4. This control voltage U_s is transmitted to the junction H of the monostable multivibrator 12, through the resistor R18. The pulse duration denoted by t_{31} in FIG. 3c, coincides with the duration t_3 of the pulse shown in FIG. 3b. At the end of this positive pulse, the transistor T3 returns to its conducting state. As a result, a negative pulse appears at its collector, and this negative pulse is transmitted to the base of the transistor T4, through the capacitor C3, the coupling resistor R13 and the resistor R14. The diode D becomes thereby cut off.

This transistor which was held turned off through the resistor R14 while in the quiescent state, is switched to the conducting state through the negative pulse of duration t_3 at the collector. A negative step voltage thereby appears at its emitter. The collector of the transistor T4 which is connected to the junction Q between the resistors R10 and R11 of the voltage divider, becomes held thereby to a fixed potential prevailing at this junction, as determined through the potential of the voltage supply line 30. The voltage divider is made of substantially low resistance, so that feedback effects of the collector currents of the transistor T4 may be neglected with regard to the voltages prevailing at the voltage divider.

During the time intervals t_{32} shown in FIG. 3c, a transfer of charge takes place on the capacitor C3, mainly through the base-emitter diode of the transistor T4, and through the coupling resistor R13. As a result of such transfer in charge, the transistor becomes overdriven. Since the base-emitter

diode of the transistor T4 is fully conducting, the base of this transistor also has somewhat of a negative potential during this overdriven state. The transistor T3 is in the conducting state, and the voltage limit to which the capacitor C3 may acquire maximum charge, is firmly established through the collector potential of the transistor T4. This results from the condition that this collector potential is determined by the circuit junction Q between the voltage divider resistors R10 and R11. Since the transistor T4 is overdriven, the potential of its emitter corresponds also substantially to the constant potential of the voltage divider junction Q between resistors R10 and R11. The time constant associated with this transfer of charge is determined through the product of C3 and R13. The resistor R14 influences the charge transfer time constant by only a substantially small amount, as long as the transistor T4 is overdriven so that its base-emitter path functions as a fully conducting diode.

As soon as the capacitor C3 is discharged to the extent that the charge transfer current no longer overdrives the transistor T4, then this transistor functions as an emitter follower. The control voltage U_s now appearing at its emitter, is no longer constant, and instead follows the relationship of the voltage across the capacitor C3, determined through the voltage divider resistors R13 and R14. As an emitter follower, the transistor T4 now has a high input resistance, and when the charge of the capacitor C3 is transferred, a time constant prevails of the order of C3 (R13+R14). Since the transistor T4 is no longer overdriven, the limit to which the capacitor C3 can become charged to a maximum, is fixed through the potential of the voltage divider junction P between the resistors R11 and R12. This results from the condition that when this threshold is achieved, the diode D becomes again conducting. The time interval between this region in which the transistor T4 is overdriven and in which the diode D conducts, is denoted by t_{33} in FIG. 3c.

The time intervals t_{34} in this FIG. 3c, represents the remaining time until the transistor T3 becomes again turned off, while the control voltage U_s remains again constant. When the rotational speed of the engine increases to the extent that the diode D no longer conducts, the desired variation in the time interval of the multivibrator 12 is realized through the instantaneous value of the control voltage U_s . With increase in the rotational speed of the engine, the period t_p decreases.

By varying the resistors R13 and R14, it is possible to vary the time intervals t_{32} and t_{33} shown in FIG. 3c. These variations affect each other so that the time duration t_{32} cannot be set on one resistor, and the time duration t_{33} can be set on the second resistor without experiencing interactions or coupling effects. Instead, these resistors must be set relative to each other. If independent settings of the time intervals t_{32} and t_{33} are desired, then this can be accomplished through an additional variable voltage threshold which is determined through a voltage divider applied across an operating voltage source. Under such conditions, the emitter of the transistor T4 is connected to a tap of this voltage divider. Through this voltage divider, the potential of the control voltage is limited within the time interval t_{34} , and the time constant for the first transfer in charge may be varied without interaction, at the coupling resistor R13. During this time interval t_{34} , the transistor is overdriven. The time for the second transfer of charge of the capacitor C3 is limited through the magnitude of the additional threshold potential.

The function of the injection duration t_i with respect to the rotational speed n in accordance with FIG. 2, is derived as follows:

The control voltage U_s determines the pulse duration t_i directly through its prevailing instantaneous value. For rotational speeds n less than n_1 , the pulse duration t_i is constant. The period t_p is inversely proportional to the rotational speed n , so that when the rotational speed increases, the period t_p decreases. The suction pressure within the intake manifold is thereby assumed constant. For rotational speeds which are smaller than n_1 , the control voltage U_s has the waveform

shown in FIG. 3. During the time interval t_{34} , the control voltage U_c has a constant value, so that no variable influence upon the control voltage U_c at the junction H takes place for rotational speeds n which are less than n_1 . If, however, the period t_p , which depends upon the reciprocal of the rotational speed n , becomes smaller than $t_{31}+t_{32}+t_{33}$, the instantaneous value of the control voltage U_c has an effect at the circuit junction H. To this region belongs a rotational speed which is greater than n_1 and is less than n_2 in FIG. 2. For rotational speeds greater than n_2 , only the constant portion of the control U_c which extends beyond the time interval t_{32} , has an effect upon the circuit junction H. Thus, the pulse duration t_1 no longer increases for rotational speed which exceeds n_2 , since the period is then smaller than t_p+t_{32} .

The control circuitry in accordance with the present invention, thereby allows corrections as a function of rotational speed, through very simple means, since the overdrive region of the transistor T4 is also used for influencing the switching time. Furthermore, two voltage threshold values in the form of limits for charging and discharging a capacitor are produced through only a single transistor.

It will be understood that each of the elements described above, or two or more together, may also find a useful application in other types of constructions differing from the types described above.

While the invention has been illustrated and described as embodied in fuel injection control arrangements for 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.

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

1. A controlled injection arrangement for an internal combustion engine comprising, in combination, at least one electromagnetically actuated valve; monostable multivibrator means with input transistor and output transistor for generating pulses applied to said valve to open said valve for a time interval determined by the duration of said pulses; control voltage generating means connected to said monostable multivibrator means for generating a voltage signal to vary the duration of said pulses as a function of the rotational speed of said engine, said voltage signal having a periodically varying waveform timed relative to said pulses; at least two switching transistors within said control voltage generating means and being actuated upon expiration of a predetermined time delay after the ends of said pulses; a first capacitor connected between the base of a first one of said switching transistors and the collector of said input transistor; a series combination of a second capacitor and a resistor connected between a second one of said switching transistors and said first one of the switching transistors, said second one of the switching

transistors being driven into saturation for generating a first time delay and being driven into nonsaturated region for generating a subsequent second time delay, said first time delay being produced by the discharging of said second capacitor with a first time constant to a first predetermined voltage limit and said second time delay being produced by the charging of said second capacitor with a second time constant to a second predetermined voltage limit; a source of voltage; and a resistance voltage divider connected across said source of voltage for providing the first and second voltage limits of said capacitor, said resistance voltage divider having two taps, one of said taps being connected to the collector of said second one of the switching transistors, the other one of said taps being connected to the collector of said first one of the switching transistors through said second capacitor.

2. The controlled injection arrangement as defined in claim 1 including diode means connected between said other tap and said second capacitor.

3. The controlled injection arrangement as defined in claim 2 including coupling resistor means connected between said diode means and the base of said second one of the switching transistors.

4. The controlled injection arrangement as defined in claim 3 wherein the resistance values of the different sections of said voltage divider are such that the collector current of said second one of the switching transistors has negligible effect upon the voltage relationships of said voltage divider.

5. A controlled injection arrangement for an internal combustion engine comprising, in combination, at least one electromagnetically actuated valve; monostable multivibrator means with input transistor and output transistor for generating pulses applied to said valve to open said valve for a time interval determined by the duration of said pulses; control-voltage-generating means connected to said monostable multivibrator means for generating a voltage signal to vary the duration of said pulses as a function of the rotational speed of said engine, said voltage signal having a periodically varying waveform timed relative to said pulses; at least two switching transistors within said control-voltage-generating means and being actuated upon expiration of a predetermined time delay after the ends of said pulses; a first capacitor connected between the base of a first one of said switching transistors and the collector of said input transistor; a series combination of a second capacitor and a resistor connected between a second one of said switching transistors and said first one of the switching transistors, said second one of the switching transistors being driven into saturation for generating a first time delay and being driven into nonsaturated region for generating a subsequent second time delay; and voltage divider means connected to the emitter of said second one of the switching transistors for limiting said voltage signal.

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