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(54) IMPROVEMENTS IN OR RELATING TO METHODS OF AND APPARATUS FOR CONTROLLING THE OPERATING BEHAVIOUR OF A SPARK-IGNITED INTERNAL COMBUSTION ENGINE UPON THE COMMENCEMENT OF, DURING, AND AFTER OVERRUN OPERATIONS

(71) We, ROBERT BOSCH GMBH, a German Company of Postfach 50, 7 Stuttgart 1, Federal Republic of Germany, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to methods of and apparatus for controlling the operating behaviour of spark-ignited internal combustion engines upon the commencement of, during, and after overrun operations.

Overrun operation of a motor vehicle is characterised by an engine speed in excess of a value which would normally correspond to a given state of load and a given position of the throttle butterfly valve, particularly at an engine speed in excess of normal idling speed when the butterfly valve is closed. Overrun operation always occurs when the accelerator pedal is brought into its normal position during a normal travelling operation. This is predominantly the case during transition from a travelling operation to a braking operation, although also before and without the accelerator pedal being actuated, for example, when travelling downhill.

Braking of a motor vehicle by its internal combustion engine is desirable during overrun operation. However, for this purpose, it is necessary that the internal combustion engine should no longer supply any positive torque to the drive transmission, which means that combustion operations must no longer take place relative to the normal firing angle. In order to save fuel, provision is also made to entirely stop the supply of fuel, this being known as "cut-off" or "overrun cut off". In order to ensure idling operation at the idling speed n_{id}, the supply of fuel is re-established at a so-called restoring speed n_r.

This cut-off operation can be realised, in principle, in all fuel injection systems, and, by means of solenoid valves in the idling system, also in internal combustion engines having carburettors. It has the advantage that the braking action of the internal combustion engine can be fully utilized, and, in particular, that there can be a distinct saving of fuel particularly in very dense traffic and in the case of motor vehicles of high performance.

The present invention is based on a fuel supply system for an internal combustion engine in which the supply of fuel during overrun operation is shut off until the restoring speed n_r is attained. Fuel is subsequently again fed to the combustion chambers of the inernal combustion engine. It has been found that a so-called restoring jolt can occur upon the restoration of the fuel supply, this being detrimental to the travelling comfort. In addition to this, the emission of injurious substances is increased for a specific period of time after the supply of fuel has been restored, since the formation of the mixture is impaired as a result of the internal combustion engine having under the circumstances been cooled to a considerable extent, and thus the combustion operation is not effected in an optimum manner.

According to the present invention there is provided a method of controlling the operating behaviour of a spark-ignited internal combustion engine during and after overrun operation, in which the supply of fuel is cut off during overrun operation, and the point of ignition is retarded after the commencement of the overrun operation in response to a signal from an overrun detection stage, and in which the point of ignition is restored to its normal point in response to a signal from the overrun detection stage in response to at least one operating parameter.

According to another feature of the present invention apparatus for carrying out the method comprises transducers for providing signals responsive to at least the load and the speed of the internal combustion engine to

an ignition point control stage, a device for determining the quantity of fuel to be fed to the internal combustion engine, and an overrun detection stage to which are connected, in particular, the transducers providing signals responsive to the engine speed and to the load, which which is connected to the ignition point control stage and/or to a fuel enrichment stage, and to a device for cutting off the supply of fuel.

By using the method of the present invention the restoring jolt can be avoided since the internal combustion engine does not supply any drive torque when the ignition is retarded, and the torque increases when the ignition retardation is reduced. By virtue of the ignition operations effected at a retarded ignition angle, the combustion operations serve almost exclusively to heat the internal combustion engine, whereby an exhaust gas having a low content of injurious substances can be obtained relatively rapidly after the supply of fuel commences to be restored. By virtue of the additionally proposed enrichment of the fuel/air mixture at the end of the overrun operation, the internal combustion engine is heated even more rapidly and thus an exhaust gas having a low content of injurious substances can be obtained more rapidly.

In a further development of the invention, the supply of fuel is shut off only after a predetermined period of time after commencement of overrun operation, although the point of ignition is retarded immediately after the commencement of overrun operation. This measure also contributes to travelling comfort and renders possible a smooth transition from normal travelling operation to overrun operation.

The invention will be further described by way of example with reference to the accompanying drawings in which:— Fig. 1 is a graph of ignition angle plotted against engine speed before, during and after an overrun operation according to one method of retarding the ignition,

Figs. 2 and 3 are graphs of ignition angle plotted against time according to other methods of retarding the ignition,

Fig. 4 shows four graphs against time relating to the cutting-off of the fuel supply and retarding the instant of ignition at the commencement of overrun operation,

Fig. 5 is an outline block circuit diagram of apparatus according to one embodiment of the invention,

Fig. 6 is a simplified illustration of an overrun detection stage,

Fig. 7 is an outline circuit diagram of an ignition timer,

Fig. 8 illustrates diagrammatically a pneumatic embodiment of the invention, and

Fig. 9 is a circuit diagram of two solenoid valves in the embodiment of Fig. 8.

The following description relates to an internal combustion engine in which fuel is injected into the inlet manifold. The point of ignition is dependent upon at least the operating parameters engine speed and load. Overrun operation is detected by means of an overrun detection stage such as that subsequently described with reference to Figs. 5 and 6.

In the graph of Fig. 1 the ignition angle αz is plotted against the speed n of the internal combustion engine during overrun operation, characteristic speeds such as idling speed n_{id}, the restoring speed n_r, and the cut-off speed n_{co} being plotted on the abscissa. The cut-off speed n_{co} characterises that speed above which the fuel supply is interrupted when the throttle butterfly valve is closed. The supply of fuel is restored at the restoring speed n_r in order to ensure that the internal combustion engine operates at idling speed. The difference between the engine speeds n_{co} and n_r thereby acts as a hysteresis. It will be seen from the graph of Fig. 1 that the ignition angle α is retarded up to an engine speed below the restoring speed n_r and that this ignition retardation is reduced only between this restoring speed n_r and the idling speed n_{id}. The ignition angle 0° is shown as the end point of the reduction of ignition retardation in Fig. 1, although, in accordance with the type of internal combustion engine, the optimum ignition angle during idling operation can be other than 0°.

The ignition timing shown in Fig. 1 ensures that the torque of the internal combustion engine is low in the range of engine speed in which the supply of fuel is restored. The reason for this is that the ignition angle is advanced from the retarded range only at speeds below the restoring speed. The extent to which it is advanced depends upon the particular internal combustion engine, since only the idling operation has to be ensured.

The graph of Fig. 2 shows the reduction of the retardation of the ignition from the instant t_r at which the restoring speed n_r is reached. Accordingly, ignition retardation is reduced linearly with respect to time, for example over a period of 2 seconds, while Fig. 1 shows a linear reduction with respect to engine speed.

The graphs of Figs. 1 and 2 deal with the case in which the restoring speed n_r is reached before or without actuating the accelerator pedal or opening the butterfly valve, that is, as a result of a drop in the engine speed.

In the graph of Fig. 3 the ignition angle αz is plotted against time t in the case in which ignition retardation is reduced linearly with respect to time after a time t_o at which the butterfly valve is opened. Here also, the final ignition angle is given as 0° for the sake of simplicity, although this is in no way impera-

tive.

The graph of Fig. 3 deals with the case in which the driver of the motor vehicle arbitrarily terminates overrun operation.

Four graphs characterising conditions during overrun operation are shown in Fig. 4. The angle of the throttle butterfly valve α_t is plotted against time t in Fig. 4*a*. The butterfly valve is plotted as opened with a constant angle up to an instant t_c at which the butterfly valve is closed and overrun operation commences. Since the supply of fuel is not terminated at the commencement of overrun operation, but only after a time lag t_d, a time delay stage produces a delay signal of duration t_d, as is shown in Fig. 4*b*. Fig. 4*c* shows the supply of fuel against time and it will be seen that the supply of fuel is terminated only after the duration t_d has expired.

In order to ensure smooth transition from normal travelling operation to overrun operation, Fig. 4*d* shows that the ignition angle is retarded from the commencement of overrun operation at t_c (butterfly valve closed), and that the final value of the retardation of the angle of ignition is reached within the duration t_d of the time delay stage so that the final value of retardation is obtained before the supply of fuel commences to be cut off.

Fig. 5 is an outline block circuit diagram of one form of apparatus for carrying out the method of the present invention. The circuit diagram is divided into three regions, an ignition region 10, an injection region 11, and a transducer region having a tachogenerator 12 responsive to engine speed, a butterfly valve angle sensor 13 which produces a signal when the butterfly valve is closed, and an air quantity sensor 14 which is responsive to the throughput of air in the air intake.

The main feature of the ignition region 10 is a stage 20 for determining the instant of ignition which, in dependence upon the engine speed and pressure signals, ascertains an optimum instant of ignition in accordance with the instantaneous pressure and the instantaneous engine speed. The output of the stage for determining the instant of ignition is connected to a shift stage 21 which operates in dependence upon the output signal of an ignition point control stage 22, and to a synchronizing device 23 which sets the ignition angle relative to top dead centre, thus to feed an ignition signal to the spark plugs 24 at the desired instant. The ignition point control stage 22 receives input signals from an overrun detection stage 25 and from the tachogenerator 12 and the butterfly valve angle sensor 13. Switches in the connection leads from the transducer 12 responsive to the engine speed and from the sensor 13 responsive to the butterfly valve angle to the ignition point control stage 22 indicate the overrun-dependent ignition timing can selectively be dependent upon the butterfly valve angle or the engine speed.

The injection region 11 includes a pulse generator stage 30 which supplies injection pulses whose pulse length is dependent upon engine speed and the throughput of air. The pulse generator stage 30 is followed by a cut-off device 31 in which the output signals of the pulse generator stage 30 are cut off, suppressed or gated out preferably in a delayed manner in dependence upon the output signal of the overrun detection stage 25. The output signals from the cut-off device are fed to an injection device 32 which includes at least one electromagnetically operable injection valve. Finally, the injection region also includes an enrichment stage 33 which is coupled to the pulse generator stage 30 and which ensures that the fuel/air mixture is enriched at the end of overrun operation by prolonging the injection pulses produced in the pulse generator stage 30.

The subdivision of the ignition region 10 into the stage 20 for determining the instant of ignition, the shift stage 21 and the synchronization stage 23 may be omitted according to the construction of the ignition system. In this respect, it is conceivable to use a double pressure box having two inputs in order to permit adjustment in dependence upon two input variables. However, with a view to greater functional clarity, the foregoing subdivision proves to be advantageous in an electronic ignition system.

During normal travelling operation, ignition pulses are prepared in the ignition region 10 at predetermined instants or ignition angles, in dependence upon the normally relavant parameters, that is to say, the pressure (P) in the air intake and the engine speed. Pulses originating from the engine speed and the throughput of air in the intake are likewise formed in the injection region 11 and are fed to the solenoid injection valves 32.

When the overrun detection stage 25 detects overrun operation from data concerning the engine speed and the angle of the butterfly valve, the ignition point control stage 22 retards the angle of ignition, that is the instant of ignition is shifted in the direction of a large negative ignition angle. The ignition point stage 22 has to be connected to the tachogenerator 12 when the ignition retardation is reduced in dependence upon engine speed in conformity with the graph of Fig. 1. Likewise, the ignition point control stage 22 requires data concerning the angle of the butterfly valve in order to cause the reduction of the ignition retardation after the butterfly valve has opened. However, this connection can be omitted according to the construction of the overrun detection stage. The case under consideration here is particularly that in which overrun operation not only occurs when the butterfly valve is closed

and the engine speeds are in excess of idling speeds, but also when there is a specific correlation between the butterfly valve angle and idling.

In dependence upon the output signal of the ignition point control stage 22, the instant of ignition which is ascertained in the stage 20 for determining the instant of ignition, and which results from the instantaneous parameter values of the engine speed and the pressure, is retarded and is converted to a specific angular value by means of the synchronization stage 23.

In the injection region 11, the enrichment stage 33 connected to the pulse generator stage 30 has a circuit arrangement for detecting the end of overrun operation. Furthermore, it includes a timing element for enriching the fuel/air mixture for a predeterminable period of time after overrun operation has ended.

The output of the pulse generator stage 30 is connected to a cut-off device 31 which, in order to save fuel during overrun operation and to fully utilize the braking action of the internal combustion engine, interrupts the supply of fuel to the internal combustion engine or to the inlet manifold during overrun operation. This may be effected by suppressing or gating-out the output signals of the pulse generator stage 30.

Fig. 6 shows in block form an overrun detection stage 25 which comprises a threshold value switch 35 for the rotational speed signal from the tachogenerator 12, and a switch 36 between an output lead 37 and an earth lead 38. The switch 36 is shown in the position it assumes during idling operation (butterfly valve closed), and it will be seen that, in this case, the signal level on the output lead 37, which is connected to the output of the threshold value switch 35, is solely dependent upon the switching state of the threshold value switch 35, and thus upon the engine speed. The switch 36 is closed outside the idling range, and then the potential on the output lead 37 is zero irrespective of the engine speed.

Preferably, the threshold value switch 35 operates with hysteresis, in order to be able to fix different engine speeds for the commencement of fuel cut off during an overrun operation and for the restoration of fuel supply towards the end of an overrun operation.

Fig. 7 shows an example of an ignition point control stage 22 which essentially includes an operational amplifier 40 connected as an integrator. Two circuits lead from an input 41 of the ignition point control stage 22 to the negative or inverting input of the operational amplifier 40, wherein the first circuit comprises a resistor 42 and a diode 43 forward biassed for positive input signals, and the other circuit comprises a series combination comprising two resistors 44 and 45 and a diode 46 biassed in the opposite direction to the diode 43. The resistor 44 can be bridged by means of a switch 47 which responds to the position of the butterfly valve and which is open during idling. An output signal dependent upon overrun operation is present at the output 48 of the ignition point control stage 22, the resistor 42 determining the time characteristic at the commencement of overrun operation in accordance with Fig. 4*d*, the resistors 44 and 45 determining the time characteristic towards the end of overrun operation in accordance with Fig. 2, and the resistor 45, together with the switch 47, determining the time characteristic in accordance with the graph of Fig. 3.

One way in which the method of the present invention may be realised pneumatically is shown in Fig. 8 which shows, diagrammatically, an ignition distributor 50 having a double pressure box 51, an air filter 52 upstream of an air intake 53 having a butterfly valve 54, an inlet manifold 55, and a highly simplified section through an internal combustion engine. An additional volume chamber 61 is located between an inlet 60 of the double pressure box 51 and the air intake 53 or inlet manifold 55 and is connected to the air intake 53 by way of a throttle 62 on the one hand and, on the other hand, by way of a series combination comprising a further throttle 63 and an electro-magnetically operable solenoid valve 64. Furthermore, a series combination comprising a throttle 65 and a solenoid valve 66, which can also be operated electro-magnetically, is located between the additional volume chamber 61 and the inlet manifold 55. Alternatively, the additional volume of the chamber 61 can comprise the volume of the lines and the retarding box 51.

The degree of admission to or the pressure in the additional volume chamber 61 can be controlled in dependence upon the engine speed and the angle of the butterfly valve, whereby the double pressure box 51 receives a signal for timing the ignition. An electrical circuit for the electromagnetically operable solenoid valves 64 and 65 is shown in Fig. 9. It has to be taken into account that the solenoid valve 66 is pneumatically closed when it is non-energized and is pneumatically open when it is energized. The solenoid valve 64 operates in the opposite manner. Fig. 9 shows a series combination comprising a butterfly valve switch 70 and a parallel combination whose first circuit includes only the solenoid valve 64 and whose second circuit comprises a series combination consisting of a speed-dependent switch 71 and the solenoid valve 66. This entire arrangement is located between a positive lead 72 and a negative lead 73. The rotational speed switch is preferably subjected to hysteresis, that is, it should be closed when the engine

speed exceeds the cut-off speed n_{co} and remains closed until the rotational speed drops below the restoring value, that is, the restoring speed n_r.

The switch 70 constitutes a butterfly valve switch of known construction whose contacts are closed when the butterfly valve is also closed. Proceeding from this mode of operation of the switching elements specified, the mode of operation of the circuit arrangement of Fig. 9 resides in the fact that the solenoid valve 64 is open when the butterfly valve is closed. In contrast to this, the criterion of speed dependence enters into the switching behaviour of the solenoid valve 66, wherein, in accordance with the mode of operation of the individual switches, the solenoid valve 66 is open when the butterfly valve is closed and the engine speed is in excess of the cut-off speed n_{co}, or down to the restoring speed n_r as the engine speed decreases. Fig. 8 shows that the device for the additional volume chamber 61 is continuously coupled to the air intake by way of the throttle 62 irrespective of the signal from the sensor responsive to the butterfly valve angle, and irrespective of the rotational speed signals.

While the throttle 65, together with the solenoid valve 66, is responsible for the time-dependent behaviour of the ignition angle in accordance with the graph of Fig. 4*d*, the actions of the throttles 63 and 65 commonly determine the time function in accordance with the graph of Fig. 3.

A modification of the pneumatic realization of the invention illustrated in Fig. 8 can, in particular, reside in omitting the throttle 63 and the solenoid valve 64. In this case, it is still ensured that the ignition is timed in dependence upon the angle of the butterfly valve and in dependence upon the engine speed.

WHAT WE CLAIM IS:—

1. A method of controlling the operating behaviour of a spark-ignited internal combustion engine during and after overrun operation, in which the supply of fuel is cut off during overrun operation, and the point of ignition is retarded after the commencement of an overrun operation in response to a signal from an overrun detection stage, and in which the point of ignition is restored to its normal point in response to a signal from the overrun detection stage in response to at least one operating parameter.

2. A method as claimed in claim 1, in which the point of ignition is retarded in accordance with a selectable parameter after overrun operation has commenced, and the supply of fuel is still maintained for a predeterminable period of time after such commencement.

3. A method as claimed in claim 1, in which the end of overrun operation and/or the end of the cutting-off of the supply of fuel to the internal combustion engine is or are determined by a signal from the overrun detection stage in response to the aperture angle of a throttle butterfly valve and/or from a transducer responsive to engine speed, and the ignition retardation is subsequently reduced.

4. A method as claimed in claim 3, in which the retardation of ignition is reduced particularly in a linear manner when plotted against time.

5. A method as claimed in claim 3, in which the retardation of ignition is reduced particularly in a linear manner during a predeterminable interval of time.

6. A method as claimed in claim 3, in which the retardation of ignition is reduced in dependence upon at least one of the variables: engine speed, pressure in an air intake, and throughput of air in the intake.

7. A method as claimed in any of claims 1 to 6, in which the quantity of fuel fed to the internal combustion engine is temporarily increased towards the end of overrun operation and/or thereafter.

8. Apparatus for carrying out the method as claimed in any of claims 1 to 7, comprising transducers for providing signals responsive to at least the load and the speed of the internal combustion engine to an ignition point control stage, a device for determining the quantity of fuel to be fed to the internal combustion engine, and an overrun detection stage to which are connected, in particular, the transducers providing signals responsive to the engine speed and to the load, and which is connected to the ignition point control stage and/or to a fuel enrichment stage, and to a device for cutting off the supply of fuel.

9. Apparatus as claimed in claim 8, in which the overrun detection stage includes at least one threshold value switch responsive to a signal responsive to the engine speed and a switching element controlling the output signal of the threshold value switch and responsive to signals from, in particular, the transducer responsive to the butterfly valve aperture angle.

10. Apparatus as claimed in claim 8, in which the ignition point control stage includes a timing circuit embodying an operational amplifier which is controllable at least by one of the signals responsive to engine speed, overrun operation, and the aperture angle of the butterfly valve.

11. Apparatus as claimed in claim 8, in which the cut-off device comprises a pulse gating-out stage preferably having a time-lag element.

12. Apparatus as claimed in any of claims 8 to 11, in which the ignition point control stage is formed by an electro-pneumatic system which has at least one device

for providing an additional volume or store, preferably having connection points communicating with the air intake at least upstream and/or downstream of the throttle butterfly valve, and is connected to an ignition distributor vacuum adjusting box, for effecting additional adjustment of the point of ignition.

13. Apparatus as claimed in claim 12, in which the additional store is connected to the inlet manifold preferably through a throttle and a solenoid operated valve which is open during overrun operation.

14. Apparatus as claimed in claim 12 or 13, in which the additional store is connected by way of a throttle and/or a series combination comprising a throttle and a second solenoid operated valve, to a point at which, in particular, atmospheric pressure prevails.

15. Apparatus as claimed in claim 13 or 14, in which an engine speed-dependent switch and a switch whose switching state is dependent upon the aperture angle of the butterfly valve, are connected in series with the solenoid of the first mentioned solenoid operated valve.

16. Apparatus as claimed in claim 15, in which the solenoid of the second solenoid valve is connected in parallel with the series combination comprising the speed-dependent switch and the solenoid of the first mentioned solenoid operated valve.

17. Apparatus as claimed in claims 13 and 14, characterised in that the action of the pneumatic throttles can be realised by solenoid operated valve operated in a pulsed manner.

18. Apparatus as claimed in claim 8, in which the fuel enrichment stage is in the form of a pulse prolongation stage for output pulses of a pulse generator stage forming part of the device for determining the quantity of fuel fed to the internal combustion engine.

19. Methods of controlling the operating behaviour of spark-ignited inernal combustion engines during and after overrun operation, substantially as hereinbefore particularly described with reference to and as illustrated in the accompanying drawings.

20. Apparatus for controlling the operating behaviour of spark-ignited internal combustion engines during and after overrun operation, constructed and arranged and adapted to operate substantially as hereinbefore particularly described with reference to and as illustrated in Figs. 5, 6 and 7 of the accompanying drawings.

21. Apparatus for controlling the operating behaviour of spark-ignited internal combustion engines during and after overrun operation, constructed and arranged and adapted to operate substantially as hereinbefore particularly described with reference to and as illustrated in Figs. 8 and 9 of the accompanying drawings.

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3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheet 1

Fig.1

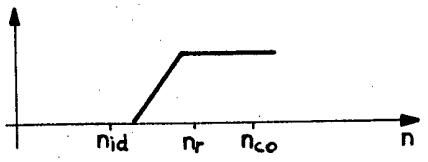


Fig.2

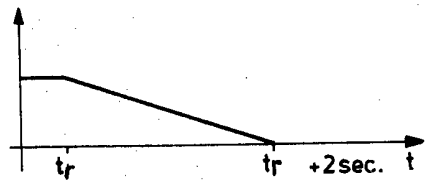


Fig.3

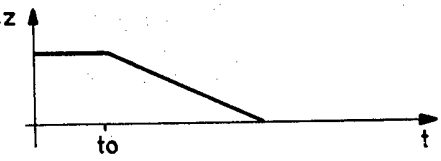


Fig.4

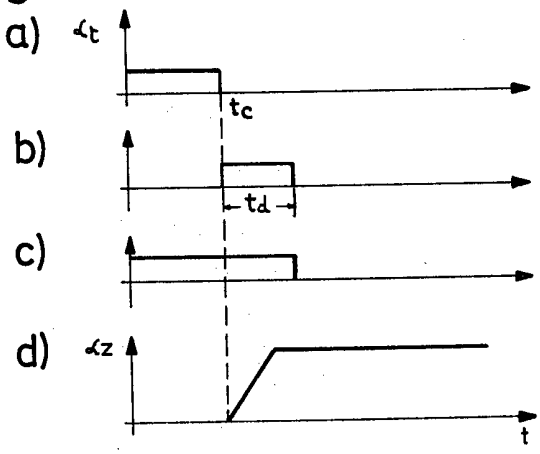


Fig.5

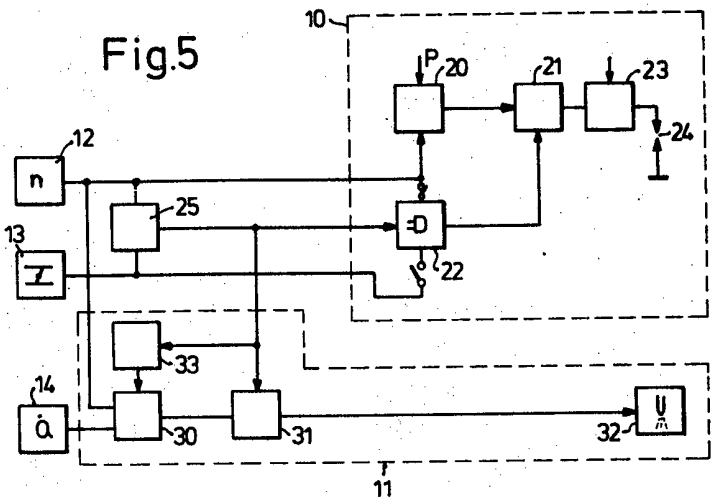


Fig.6

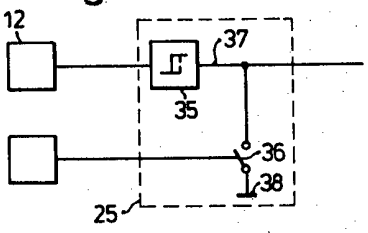
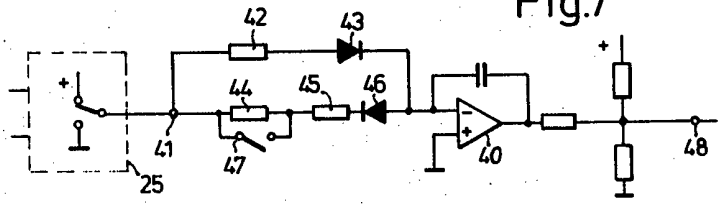


Fig.7



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Sheet 3

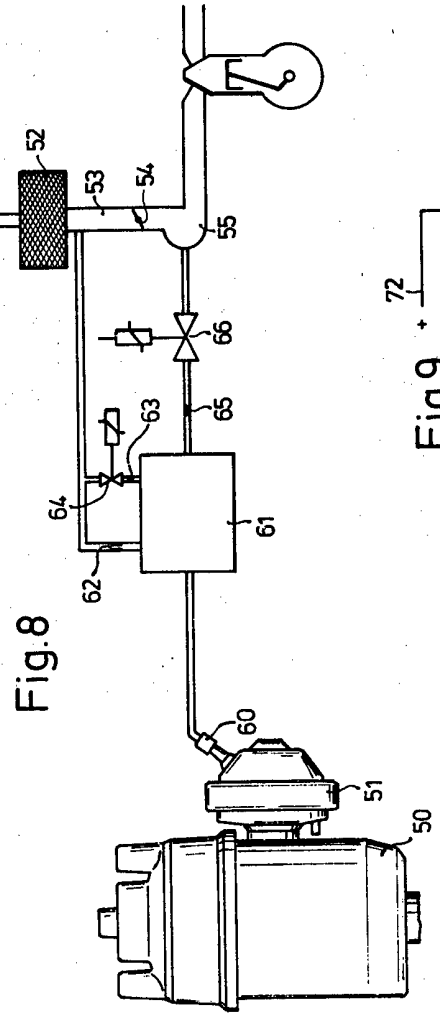

Fig.8

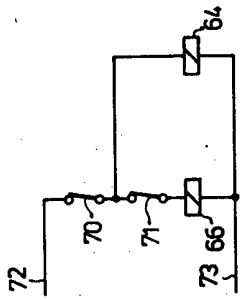

Fig.9