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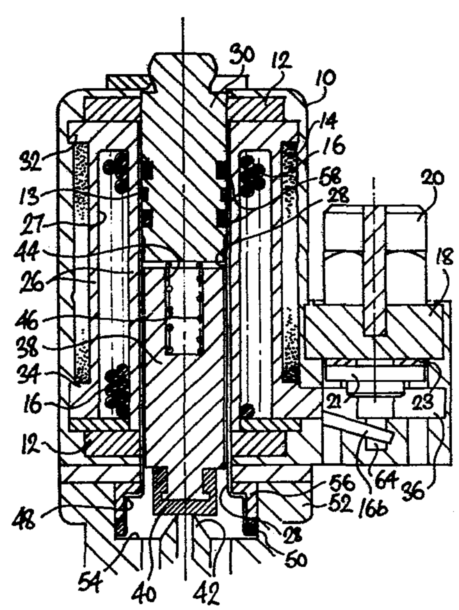
(71) Applicant: **WEBBER ELECTRO COMPONENTS PLC., Knapps Lane, Clay Hill Bristol BS5 7UJ (GB)**

(72) Inventor: **Webber, Anthony Ronald, Flat 34 Berkeley House, Charlotte Street Bristol 1 (GB)**
Inventor: **Strand, Timothy David, 8, St. Margaret's Gardens, Chippenham Wiltshire (GB)**
Inventor: **Black, Archibald, 7, The High Leys, Crick Northamptonshire (GB)**
Inventor: **Patrick, Bernard John, 19, Inchford Close Crowhill, Nuneaton Warwickshire (GB)**

(74) Representative: **Clark, Stuart Vincent Edward, STUART CLARK & CO. "Blandings" Bickleigh, Tiverton Devon, EX16 8RH (GB)**

(54) **Solenoid valve with external sensor control.**

(57) A solenoid valve for controlling the flow of a fluid, such as gas to a burner, has two or more windings on its magnetic circuit. One (boost) winding is adapted to be energised for a short initial period by an external supply to pull in the armature, which is mechanically coupled to the valve element; another is a hold-on winding designed to be energised directly by a sensor, suchs as a thermocouple observing the burner. Release of the armature, to cut off the gas in the case referred to, occurs at the end of the initial period if failure to ignite the gas results in no energisation of the hold-on winding. Deliberate release of the armature is accomplished by reverse-pulsing one of the above two windings or a third, independent, winding on the same core. This obviates switch or relay contacts in the circuit from the sensor. The provision of a plurality of windings on the magnetic circuit of a solenoid facilitates a wider range of, and more sensitive, response.



EP 0 109 155 A1

SOLENOID VALVE WITH EXTERNAL SENSOR CONTROL

This invention relates to electromagnetically operated fluid flow control valves (hereinafter called generically "solenoid valves") which are required to respond to signals of relatively low power which are indicative of the behaviour of an observed phenomenon. The response is the release of the valve from an operated condition whenever the behaviour of the observed phenomenon departs from a prescribed level or range of levels. For example, in a gas-operated appliance, the solenoid valve is required to control the gas flow in such a way that if the flame is extinguished, the valve responds to the resultant signal from a thermocouple or other sensor observing the flame so as to cut off the supply of gas to the burner. Similarly, on start-up, the solenoid valve is required to be opened electromagnetically by power from an independent boost source but to close again after a predetermined initial period if ignition does not occur. If ignition occurs within the predetermined initial period, the solenoid valve is held open by the magnetic field generated in a winding of the operating electromagnet by the flame-on signal from the thermocouple after the power supply from the independent boost source is cut off.

A solenoid valve according to the present invention is equally capable of controlling the flow of a fluid in a situation where the sensor observes a different phenomenon such as light or pressure.

The electromagnet which operates a solenoid valve according to the present invention is conventionally of the kind in which an armature slides in a tunnel on the axis of a bobbin carrying the winding or windings and is mechanically coupled to a valve seat which opens or closes a port in the circuit of a fluid whose flow is to be controlled. It is to be understood, however, that the term "solenoid" embraces other forms of construction in which the armature does not slide in the bore of a bobbin.

The present invention arises primarily from the need to provide a sensitive and reliable automatic change-over control for the source of energisation of a refrigerator in a caravan which is towed by a car or other road vehicle. It has become standard practice to provide such refrigerators with a dual cooling system, one energised from the electrical system of the towing vehicle for use chiefly during transit and the other from a supply of bottled gas carried by the caravan for use when the caravan is parked. If the electrical system on the towing vehicle fails during transit, or if the caravan is uncoupled from the towing vehicle, the driver must normally remember to enter the caravan immediately and change over the refrigerator system before the temperature within the cabinet rises to a dangerous level. A solenoid valve according to the present invention is designed to respond to signals from an automatic control circuit or programming unit in the towing vehicle which detects interruption of the electrical supply to the refrigerator so as to effect the change-over from electrical to gas energisation automatically. Thereafter, the solenoid valve monitors the behaviour of the burner, and is required to cut off the gas supply if the burner is extinguished.

Clearly, a solenoid valve according to the present invention can be designed to suit other operating situations where it is desired to provide automatic control of a fluid flow circuit in response to signals from a sensor for observing a phenomenon whose behaviour is required to govern the fluid flow - for example, the flow of water through a solar heating panel which is required to be cut off during periods of obscuration of the heating rays.

One problem which arises in solenoid valves which are required to fail safe on removal of a low-energy signal such as the output from a thermocouple is the relatively large effort which will be required to "pull in" the armature initially to its working position, corr-esponding to "gas on" in the refrigerator example quoted above. Normally, having regard to the armature loading which is necessary to keep the fluid flow port closed against the fluid pressure, the opening effort will be greater by a significant margin than the power which is directly available from a thermocouple. Similar considerations apply, mutatis mutandis, where the solenoid valve is required to operate under the control of a different sensor, or where the solenoid valve is required to operate in the reverse manner - i.e. to open a fluid flow port when the behaviour of an observed phenomenon passes through a prescribed level. Since the output of the sensor is almost inevitably D.C. - i.e. the phenomenon which it observes behaves in a basically steady-state condition - amplification of the direct sensor output in order to produce a more powerful control signal is relatively complicated and expensive compared with the direct application of the low-power sensor output to a solenoid winding, and brings its own problems of achieving a fail-safe characteristic.

Other factors also tend to render impossible the initial operation of a fluid flow valve by the sensor which governs it in response to a change in the observed phenomenon. These include inertia and friction of the moving armature and valve element; external forces such as acceleration acting on the valve due to vibration of the structure in which it is mounted, and so on.

It has been proposed to control a gas valve by an electromagnetic actuator comprising two separate solenoids - primary and secondary - each having its armature mechanically coupled to a common valve actuating lever. The primary solenoid is adapted to be energised for a short initial period at a value of current such as to produce sufficient effort on the lever to lift the valve element off its seating in a gas supply line. The secondary solenoid winding is connected to a thermocouple which senses the flame conditions at a gas burner, and, if the flame conditions are satisfactory, exerts sufficient effort on the valve lever to hold the valve open after deenergisation of the primary solenoid at the end of the initial period. If, however, satisfactory flame conditions have not been established before the end of the intial period, the valve spring reseats the valve element.

If, during normal functioning of this actuator, it is required to shut the valve deliberately, the secondary solenoid is deenergised by opening a switch or relay contacts in the circuit of the thermocouple. This allows the field in the core of the secondary solenoid to decay, releasing the valve element lever. However, since the output of a theremocouple is low, it is undesirable to interpose switch or relay contacts in the circuit to the seconday solenoid because they increase its resistance. Furthermore, unless special precautions are taken such as gold-flashing the contacts, the circuit resistance will tend to increase with time and the performance of the actuator can become unreliable. The present invention aims at overcoming this drawback by placing both solenoid windings on the same magnetic circuit. In this way, the same effect can be realised as opening the circuit of the secondary solenoid by applying a reverse polarity pulse to one of the windings, or to a third on the same magnetic circuit. At the same time the resistance of the secondary winding circuit is reduced by the removal of contacts.

A solenoid valve according to the present invention has a single magnetic circuit carrying a plurality of windings. The first is a primary or boost winding which provides the ampere turns necessary to initiate the action of the valve - usually the lifting or "pull-in" of the armature and its attached valve element off or onto the fluid flow port against either fluid pressure or the force of its return spring, according to whether the valve is operated to open or close the fluid flow port. This boost winding is designed to energise the solenoid for a period sufficient to allow the observed phenomenon (flame in the case of a gas-operated appliance) to become established in a satisfactorily stable state. Thereafter, its energising source is cut off, and the solenoid valve is held in its operated state by the field generated by the secondary or hold-on winding, so long as it is energised by the output from the sensor, aided by the remanence or coercive force of the magnetic circuit.

Each of the components of the "hold-on" force can be expressed in terms of ampere-turns; and these are jointly opposed by the force of the armature loading spring which can also be expressed in terms of ampere turns. The primary or boost winding, designed to carry the boost current, is energised from an independent source of power supply; the secondary winding is connected direct to the sensor by a circuit designed to have minimum resistance. The first winding provides enough ampere turns to magnetise the core of the solenoid strongly enough not only to ensure that the travel of the armature is sufficient to open the valve but also to generate enough remanence in the core to ensure that, when added to the flux contribution made by the secondary winding, the resultant effective ampere turns exceed those which are equivalent to the weight of the moving parts or to the spring load tending to reclose the valve.

Assuming that such a solenoid valve having more than one exciting winding acting on its magnetic circuit has been successfully operated to its working position and is being maintained by the output current from its sensor, excessive drop in or interruption of the sensor output current due to excessive decrease in or total disappearance of the observed phenomenon (e.g. flame) will cause the solenoid field to decay substantially exponentially until it falls below the designated threshold for safe operation, allowing the armature loading spring to return the armature to its valve closing position. This is the normal fail-safe sequence of events. It has, however, a potential defect in gas burner control systems. At start-up of the appliance, the initial period of opening of the gas valve must be long enough both to allow adequate gas flow to reach the burner, ignition to occur, and the thermocouple temperature to rise to the level at which its output can generate the minimum ampere turns in the secondary winding to hold the valve open. But this period - typically 30 seconds for a caravan refrigerator - may, in the event of failure to ignite the gas, lead to a hazardous build-up of unburnt gas. Concentration of the windings on a single magnetic circuit, coupled with the facility to minimise the resistance of the thermocouple output circuit, in a solenoid valve according to the present invention, affords various opportunities for improvement of the sensitivity and reliability of the control system in a fail-safe context. Accordingly, the present invention provides for the following operational modifications:

(1) Stepped reduction in the primary or boost current after the initial operation of the valve has been achieved: the duration of the full voltage pulse can be reduced after, say 20 m.s. - the time required for the valve element to complete its travel - to the hold-on value. If the flame or other observed phenomenon does not become established within the prescribed initial period, the reduced level of current is cut off,

giving a quicker valve closure because of the reduction in magnetic field decay time.

(2) Reduction of the primary or boost current over the intial period first down to the hold-on threshold value after the valve operates, and then to zero at the same rate as the known rate of increase of sensor output under correct working conditions, so that at all times during the initial period the total ampere turns on the magnetic circuit remain at or above the designed hold-on value.

(3) Preheating of a thermocouple sensor by a supplementary heater element in close proximity to the thermocouple; the element is energised prior to or simultaneously with the application of the boost voltage pulse, and this latter is removed as soon as the thermocouple responds to the heat from the element. Energisation of the supplementary heater is cut off at the end of a predetermined normal ignition period, and if flame has not been established the valve is released. The element can act as an igniter.

(4) Mains failure protection: where the boost winding is mains-energised, both the boost and the hold-on windings are made to share the ampere turns needed to hold the valve operated - either by increasing the strength of the armature loading spring or by reducing the ampere turns generated by the hold-on winding - during normal working conditions, and by retaining a level of excitation of the boost winding after expiry of the initial period which

is too low to generate the requisite hold-on ampere turns but which, added to those produced by the hold-on winding, is sufficient to make up the required total. Failure of current in either winding will cause release of the valve.

All the above techniques serve to reduce the response time of a solenoid valve according to the present invention under fail-safe conditions.

Besides providing improved fail-safe operation, the present invention also enables the use of techniques for rapid intentional closure of a multi-winding solenoid valve. The principal method of deliberate valve closure is the neutralisation of the field in the solenoid core. There are three main techniques:

1. Additional Winding

Besides the primary and secondary windings already described, the magnetic circuit may be provided with a third winding which can be either wound of opposite hand to the others or reverse connected to a supply of the same polarity. If rapid shut-down of the solenoid valve is required at any point during the operating cycle, the third winding can be temporarily energised to produce enough negative ampere turns to neutralise, or at least reduce below the threshold value for hold-on, the flux in the magnetic circuit. This can be achieved without breaking the thermocouple output circuit.

2. <u>Negative Primary Winding Pulse</u>

The primary or boost winding may be negatively pulsed at the instant of required closure from a source of reverse polarity, such as a capacitor, so as to cancel the ampere turns on the magnetic circuit, or at least the hold-on contribution from the secondary or sensor winding.

3. <u>Negative Sensor Winding Pulse</u>

The sensor circuit can be provided with tappings for the injection of a reverse-polarity pulse to neutralisr the hold-on ampere turns generated by the winding.

In addition to the foregoing flux neutralisation techniques, the following could be used as a valve closure mechanism:

4. <u>Heated Cold Junctions</u>

The connection between the "tails" of a thermocoule and its external circuit are often referred to as the "cold junctions", to distinguish them from the sensitive junction which is exposed to the temperature changes to be detected or measured. The output of a thermocouple is a function of the difference in temperature between the sensitive junction and the cold junctions whose temperature is normally kept at a steady value, as by means of a heat sink, so as to maintain the sensor's calibration. If the sensitive junction is measuring flame temperature, its output decreases as the temperature of the cold junction rises, and a solenoid valve according to the present invention can be deliberately deenergised by heating them. Thus a heater intimately associated with the cold junctions could constitute a means for the automatic shut-down of a burner if another part of the equipment involved overheats.

The above phenomenon can also be used to boost the output of a thermocouple by the deliberate cooling of the cold junctions. In a caravan refrigerator, for example, the cold junctions can be kept in physical contact with the cooler while it is being operated electrically so that their temperature is artificially lowered when gas operation is substituted. Since ambient temperatures in some parts of the world can rise very high, this technique can be used with advantage to ensure more rapid response of the hold-on winding at change-over from electric to gas operation.

A practical embodiment of the present invention will now be described, by way of illustration only thereof, with reference to the accompanying drawings in which:

Figure 1 is a front elevation of a complete multiple-wound solenoid valve for the automatic control of the change-over from electrical to gas operation of a refrigerator, the thermocouple sensor being omitted;

Figure 2 is a plan view of Figure 1;

Figure 3 is a scrap section on the line A-A of Figure 1;

Figure 4 is a scrap section on the line B-B of Figure 2;

Figure 5 is a part-sectional elevation on the arrow C in Figure 2;

Figure 6 is a part-sectional elevation on the arrow D of Figure 5;

Figure 7 is an underplan view of the solenoid assembly;

Figures 8 and 9 show schematic voltage/time curves for the operation of the solenoid valve of Figures 1 - 7, the positive and negative voltage scales in Figure 9 differing by a factor of 10, and

Figures 10 and 11 are typical thermocouple voltage and current response curves.

Referring first to Figures 1 - 7, the multiple-winding solenoid valve illustrated is designed to control the gas supply to a mobile refrigerator of the kind frequently fitted to a caravan. It is under the command of an automatic control circuit or programming unit (not shown, and which forms no part of this invention) which is responsive to the state of functioning of the electrical system of a towing vehicle so that if there is an unacceptable voltage drop, or the vehicle ignition is switched off, the solenoid valve is automatically activated to change over the refrigerator operation from electric to gas.

The solenoid assembly is encapsulted in an outer cover or casing 10 which embraces the upright C-shaped magnetic yoke 12 and separate windings 14, 16 (Figures 3 and 5), constituting respectively primary or boost and secondary or sensor-energised hold-on windings, together with a terminal block 18 on which are carried a socket 20 for the thermocouple sensor (not shown) which observes the gas flame in the evaporator unit of the refrigerator, and terminal prongs 22, 24 for the connection of the windings 14, 16 to their external circuits.

The windings 14, 16 are wound coaxially on a bobbin 26 whose axial bore is lined by a thin-walled stainless steel tube 28 (Figure 3) which constitutes an armature tunnel. The tube terminates at its top end short of the upper limb of the C-shaped yoke 12 and is crimped at 13 to a cylindrical magnetic stop 30 which fits snugly into a hole in the upper limb of the C-shaped yoke 12. The bobbin 26 is double-walled, providing a deep coaxial annular cavity 27 in which the sensor-energised winding 16 is located, and on the outside of the outer wall of the coaxial cavity 27 is wound the boost winding 14. The bobbin 26 has the usual end cheeks 32, 34 to retain the winding 16, but the lower cheek 34 has two lateral horns 36 which support the terminal block 18. Thus both the boost and the sensor-energised windings 14, 16, respectively act on the same magnetic circuit. This allows deliberate closure of the valve, even while flame conditions are stable, by applying a reverse-polarity pulse to either of the windings 14, 16 (or to a third independent winding (not shown) on the same magnetic yoke 12, if provided) which obviates the interposition of switch or relay contacts in the circuits of the sensor-energised winding 16 to achieve deliberate closure.

Within the tunnel 28 slides a single cylindrical valve-operating armature 38. At its lower end the armature carries a captive rubber thimble 40 to form a resilient washer which is engageable with a coaxial conical seating around the gas flow port 42. The upper end of the cylindrical armature 38 is axially counterbored at 44 to accommodate a helical loading spring 46 whose ends are ground accurately square to axis to bear against the bottom or inner face of the magnetic stop 30 and the axially opposed blind end of the counter-bore 44 in the armature. Both these latter axially opposed surfaces are machined accurately square to the axis of the armature, thus ensuring that the loading spring 46 deflects axially without lateral distortion which would cause binding of the spring against the wall of the counter-bore 44 and of the armature 38 against the tunnel 28.

The lower end of the thin-walled tube 28 passes snugly through a coaxial hole in the lower limb of the magnetic yoke 12 to project below the bottom wall of the casing 10 and is stepped at 48 to an increased diameter to form a chamber around the gas flow port 42. This enlarged diameter end 48 is sealed by a gas-tight seal 50 into a cylindrical socket machined coaxial with the gas flow port 42 in a valve body 52. The bottom of the enlarged diameter end 48 of the liner 28 is flanged below the gas seal 50 to rest on the floor 54 of the socket, and when the valve body 52 is assembled on the casing 10 of the solenoid an internally flanged bush 56 embracing the shoulder of the enlarged diameter end 48 clamps the liner to ensure gas-tightness in the valve body 52. The magnetic stop 30 is also sealed by compressible seals 58 into the top end of the liner 28 so as to prevent leakage of gas past the armature 38. The valve body 52 has a gas supply pipe connector 60 (Figure 1) and a gas pressure test socket which is normally closed by a threaded plug 62.

As already noted, the terminal block carries a sensor socket 20 and winding terminal prongs 22, 24. The terminal prong 22 is integral with a flat plate 23 lying at right angles thereto on the underside of the terminal block 18 (see especially Figure 7) and clamped by a lock nut 21 to the lower end of the sensor socket 20. To the prong 22 are sweated or otherwise electrically bonded the tails 14a, 16a at the one ends of the windings 14, 16. The other tail 14b of the boost winding 14 is bonded to the prong 24 while the other tail 16b of the sensor winding 16 is bonded to a contact pin 64 which projects downwards coaxially with the socket 20 and insulated therefrom by a tubular insulator 66. The contact pin 64 has a head 68 exposed within the bottom of the socket 20 to make contact with a central electrode on a conventional adaptor (not shown) for the sensor circuit to be threaded into the socket 20 when the valve is operational. The sensor may be either a thermocouple or a photocell, and the sensor itself may be mounted directly in the socket 20 or located more remotely and connected to the adaptor by a low-resistance lead.

Figures 8 and 9 are schematic representations of typical voltage/time response curves for a practical installation. The curves are only roughly to scale and are illustrative of the performance of a valve according to the present invention, excluding any of the operational modifications (1) - (4) above.

The curve 70 (Figure 9) represents the boost pulse applied to the boost winding 14 at the instant of start-up of the cycle. It rises rapidly to a value V which is substantially equal to the voltage at the terminals of, say, the battery of a towing vehicle. The winding 14 is designed to apply to the yoke 12 of the bobbin 26 a magnetising field which is suitably stronger than the minimum required to lift the armature 38 against the magnetic stop 30 so as to generate enough remanence in the yoke 12 to constitute a significant portion of the requisite hold-on ampere turns. The pulse 70 is removed after a period T which is suitably longer than the period t_1 required to establish steady flame conditions, and has a maximum value determined by safety considerations. If the flame is not properly established within this maximum period, the pulse is removed, the magnetic field in the yoke 12 decays, and the armature 38 drops under the force of its loading spring 46, and of gravity if the assembly is mounted in the upright position shown in the drawings, to close the gas flow port 42. A new cycle must then be initiated by a new pulse V. The brief delay period T_1 is that which is normally required for the gas to reach the burner, and the igniter to initiate its ignition process.

Assuming that satisfactory steady flame conditions are established by the time t_1, the sensor feeds the "flame on" signal to the solenoid. This is the output voltage v_1 of the sensor which corresponds to a predetermined safe minimum value of ampere turns generated in the sensor winding 16 for holding the armature in the operated ("in") position where it rests against the magnetic stop 30. The value v_2 represents the normal full working voltage output of the sensor, but there will be a minimum decay voltage v_3 whose value is such that the corresponding ampere turns in the sensor winding 16, added to the equivalent of the remanence in the yoke 12 and whatever friction there is in the moving parts, just balances the effort of the return spring 46. The difference between $\underline{v}_2$ and $\underline{v}_3$ represents the flame stability tolerance which is acceptable in the event of draughts or other minor disturbing influences, including instantaneous flame extinction provided that reignition does not call for energisation of the igniter.

At some time $\underline{t}_2$, the burner is extinguished. If extinction is due to the deliberate cut-off of the gas supply, as by a programmer, the output voltage from the sensor is allowed to fall to zero and the gas flow port 42 closes at time $\underline{t}_3$, later than $\underline{t}_2$, which corresponds to the sensor voltage $\underline{v}_3$. The delay $\underline{t}_2 - \underline{t}_3$ is a period, determined by the cooling curve (C, Figure 10) of the thermocouple, during which the gas flow port 42 will remain open.

Figure 10 illustrates the general form of response characteristic which is representative of commercial theremocouples in terms of output voltage against time at an ambient temperature of 400°C. The characteristic is basically a fourth-power curve. Figure 11 illustrates the corresponding current/time response curve. For other voltaic sensors such as photocells the corresponding curves approximate, in general, to those of Figures 10 and 11. Given the type of sensor to be used in any particular situation, the design of the solenoid for controlling the flow of working fluid - gas, air, water, or whatever is the relevant substance - can be tailored to the situation.

In all cases, it is advantageous to use voltaic sensors which generate a voltage in response to fluctùations in the observed phenomenon. This avoids the necessity of providing an external power source to drive the sensor which increases the cost and introduces problems of false operation of the valve due to malfunction of the power source, and complicates the overall fail-safe operation of the solenoid valve.

If there is an emergency, the gas flow port 42 can be closed rapidly by the generation of a neutralising flux in the yoke 12 by one of the methods described above. Assuming that the emergency arises at time t_x (Figure 9) during normal steady-state operation of the system, a negative pulse $-v_4$ can be fed to the primary winding 14. The magnitude of $-v_4$ equals at least the flame stability tolerance (as defined above). This reverse polarity voltage can be derived, for example, from a capacitor. It is desirable that the magnitude of $-v_4$ should not cause reverse magnetisation of the yoke 12.

From the foregoing it will be seen that a solenoid valve according to the present invention provides a simple and self-contained fail-safe observer of an external phenomenon - in the example described, a gas flame. Other phenomena can be observed by the substitution of appropriate sensors.

Although the windings 14, 16 have been described and illustrated as separated in the radial direction, it is to be understood that they can be spaced apart axially - i.e., wound on a bobbin in endwise relation.

In cases where more than two windings are provided, all may be spaced radially or all axially, or a mixture of both. Alternatively again, the windings may be distributed on different limbs of the iron circuit. Thus, in Figure 6, one of the windings 14, 16 could be placed on the upright back section of the yoke 12; or the windings 14, 16 may be located as described above and a third winding can be placed on the upright back section of the yoke.

It will be understood that various modifications may be introduced to suit special circumstances. Thus, vibration damping means may be applied to the armature to insulate the valve from the unwanted disturbance by acceleration forces in a mobile refrigerator. Also, where the environment is liable to large fluctuations of ambient temperature, suitable temperature-insensitive materials or negative temperature characteristic materials can be incorporated in the design. For example, a caravan-borne refrigerator may be required to operate in extremes of temperature ranging from $-20^{o}F$ to $+180^{o}F$ without affecting the functioning of the solenoid valve controlling the gas flow.

The critical values of operation, hold-in, and fail-safe release of the armature 38 are dependent on a number of variables, the least accurately controllable of which is the force exerted by the loading spring 46 tending to close the gas flow valve 42. It is therefore important to reduce to a minimum the manufacturing tolerances at all other points in the design of the assembly. For example, the value of the ampere turns generated by the sensor winding 16 should be kept within very close limits by both specifying close tolerances on the specific resistance of the wire used for the winding; by keeping to a minimum the resistance of the sensor output circuit, and by winding the coil 16 on a precision spring-winding machine. Precision moulding of the bobbin 26 also ensures minimum variation in reluctance of the air gap between the armature and the windings.

The invention provides a versatile solenoid valve system of control of the flow of a fluid in response to a designated change in behaviour of an observed phenomenon. It facilitates the provision of sensitive fail-safe features and of flexible control techniques which improve the adaptability of the system to varying working requirements.

CLAIMS

1. A solenoid valve for controlling the flow of a fluid in accordance with a signal from a sensor responsive to an observed phenomenon and consisting of a fluid flow valve whose movable element is mechanically coupled to the armature of the solenoid characterised in that the magnetic circuit of the solenoid carries two or more windings the first of which is a primary or boost winding adapted on energisation by an initial boost voltage pulse to generate in the magnetic circuit at least enough ampere turns to cause the armature to displace the valve element to its operative position; the second of which is a hold-on winding which is adapted to be energised directly by the output of the sensor and, when the observed phenomenon reaches a threshold level of behaviour, to generate sufficient ampere turns in the magnetic circuit to hold the valve in its operated position; and means for energising the boost winding for an initial period to allow the observed phenomenon to reach its threshold level under prescribed conditions.

2. A solenoid valve according to claim 1 characterised in that the hold-on winding is designed, when energised normally by the sensor, to generate at least that number of ampere turns which, when added to the remanence of the magnetic circuit after removal of the energisation of the boost winding, are sufficient to hold the valve element in its operated position while the observed phenomenon does not regress from its threshold level.

3. A solenoid valve according to claim 1 or 2 characterised in that the armature is slidable in the bore of a bobbin carrying at least one of the windings, and a magnetic stop is fixed in the magnetic circuit to form an abutment for the armature when the boost winding is energised.

4. A solenoid valve according to claim 3 characterised in that the boost and the hold-on windings are both carried on the bobbin and the hold-on winding is located in a compartment of the bobbin formed between the bore and the boost winding.

5. A solenoid valve according to claim 2, 3 or 4 characterised in that a terminal block is fixed to the bobbin and is provided with an adaptor for electrically connecting the sensor direct to the hold-on winding.

6. The method of controlling the flow of a fluid in accordance with the behaviour of an observed phenomenon such that departure of the phenomenon from a threshold level in a given direction is required to stop or start the fluid flow, as the case may be, by the transmission of a signal from a sensor observing the phenomenon to a solenoid valve in the fluid circuit, characterised in that an initial boost voltage pulse is applied to a first or boost winding on the magnetic circuit of the solenoid of such magnitude as to cause the armature to displace the valve element to its operated position, and of such duration as to allow the observed phenomenon

to reach its threshold level under prescribed conditions; and the output current of the sensor observing the phenomenon is fed directly to a second or hold-on winding on the same magnetic circuit of the solenoid such that, at the threshold level of the phenomenon, the ampere turns generated in the magnetic circuit by the hold-on winding are sufficient to ensure that the valve element is held in its operated position.

7. The method according to claim 6 characterised in that the hold-on winding is matched to the output of the sensor at the threshold level of the observed phenomenon so as to generate a value of ampere turns which, when added to the value of the remanence of the magnetic circuit after removal of the initial boost voltage pulse, are sufficient to hold the valve in the operated state.

8. The method according to claim 6 or 7 characterised in that the value of the boost voltage pulse is reduced after completion of the mechanical operation of the valve to a lower value which is sufficient to hold the valve in the operated position for the remainder of such period as is allowed for the sensor to signal that the observed phenomenon has reached its threshold level.

9. The method according to claim 6, 7 or 8 for the control of a fuel burner wherein the solenoid valve

is connected in the fuel supply line to the burner characterised in that the sensor is a thermocouple, and that the value of the boost voltage is reduced, after completion of the initial opening of the fuel valve, at the same rate as the known rate of increase in output of the thermocouple when observing the correct ignition of the fuel.

10. The method according to claim 9 characterised in that a preheater element is located in close proximity to the thermocouple and is adapted when energised to raise the temperature of the thermocouple to its normal working value; that the preheater is energised prior to or simultaneously with the application of the boost voltage pulse; that the boost voltage is reduced to zero after the opening of the valve and on receipt by the hold-on winding of the normal flame-on signal from the thermocouple, and that the preheater is de-energised at the end of a predetermined maximum ignition period.

11. The method according to any of claims 6 - 10 characterised in that the energisation of the boost winding is continued after the expiry of an initial start-up period at a level below that at which the ampere turns generated are sufficient to hold the valve operated during normal functioning of the system so that failure of the power supply to either winding during said normal functioning will result in release of the solenoid valve.

12. The method according to any of claims 6 - 11 characterised in that a voltage pulse is applied to one of the windings of such polarity and magnitude as to reduce the strength of the magnetic field in the magnetic circuit below the minimum hold-on value when it is required to release the solenoid valve.

13. The method according to any of claims 6 - 12 characterised in that the sensor is a thermocouple and that a heater is closely associated with the cold junctions thereof; and that the heater is energised in order to release the valve irrespective of the behaviour of the observed phenomenon.

14. The method according to any of claims 6 - 12 characterised in that a signal for releasing the solenoid valve is fed to a third winding on the magnetic circuit and has a magnitude and polarity to neutralise the magnetic field in the solenoid.

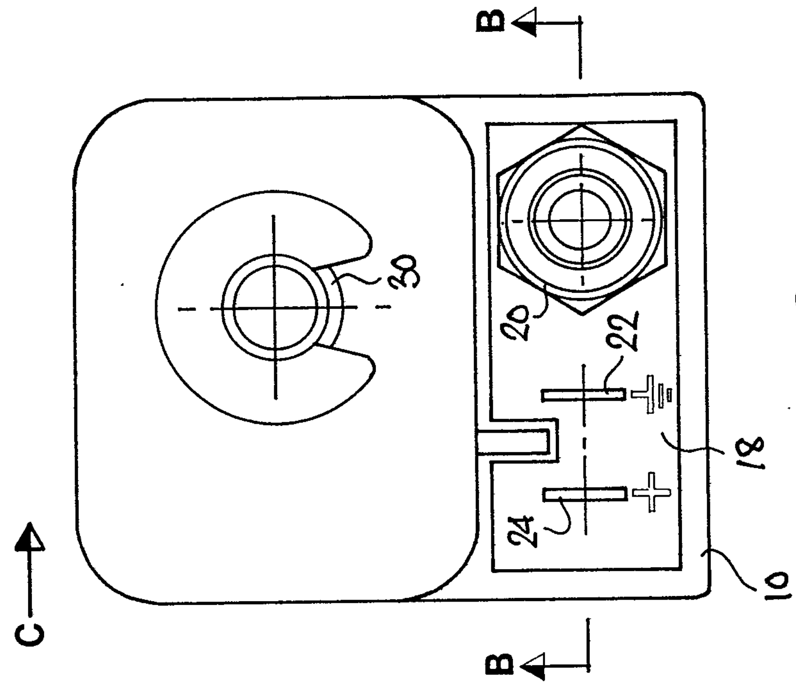


Fig. 2

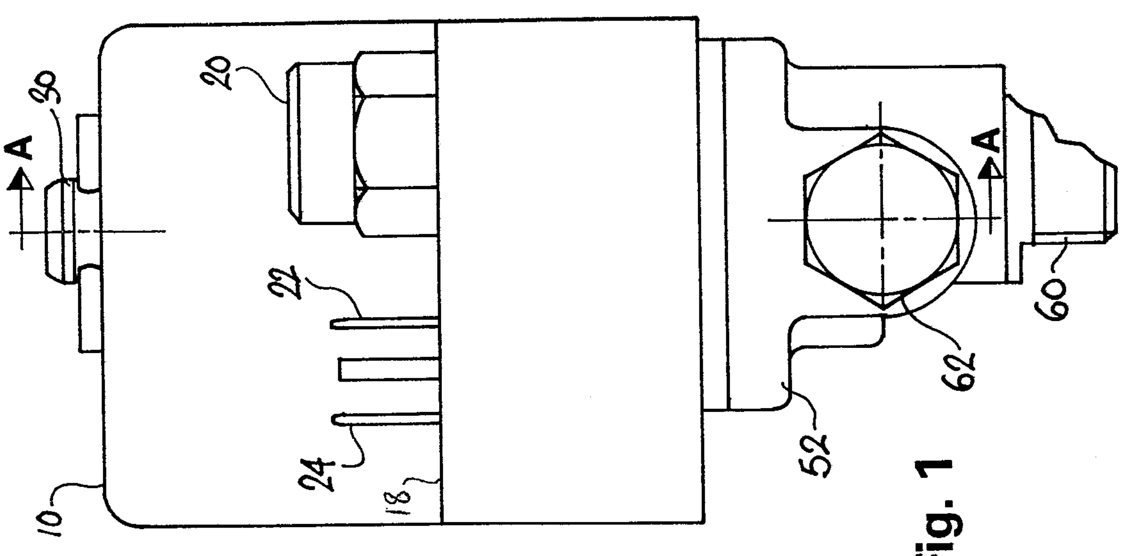


Fig. 1

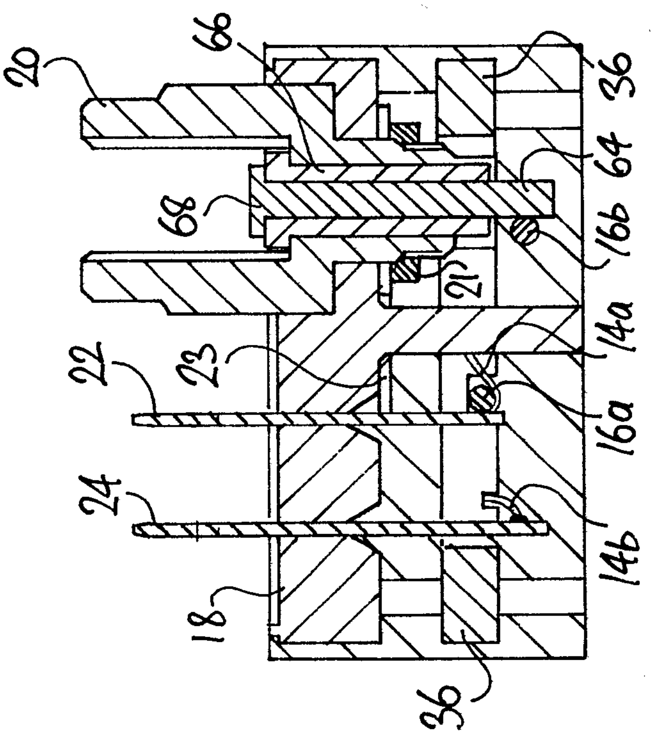
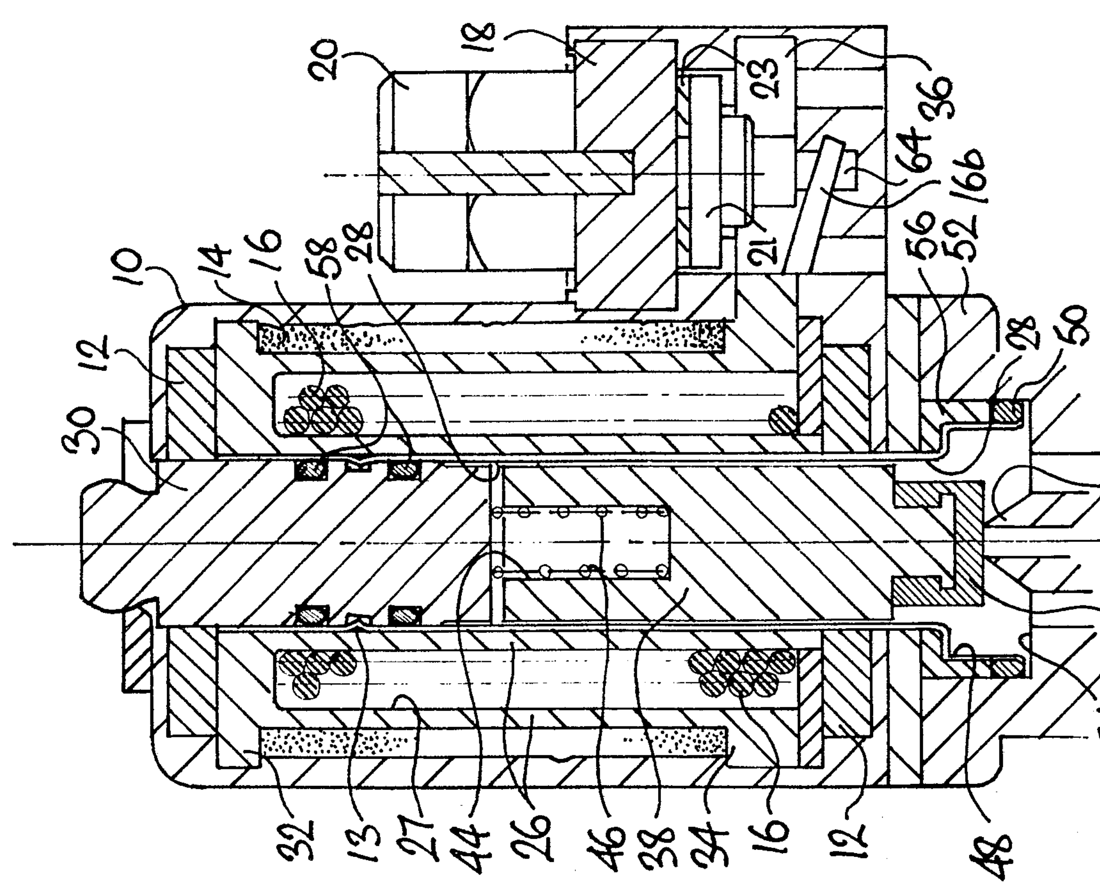

20
66
36
64
16b
68
21'
14a
22
23
16a
24
14b
18
36

Fig. 4


10
14
16
58
28
20
18
23
36
64
16b
21'
56
52
28
50
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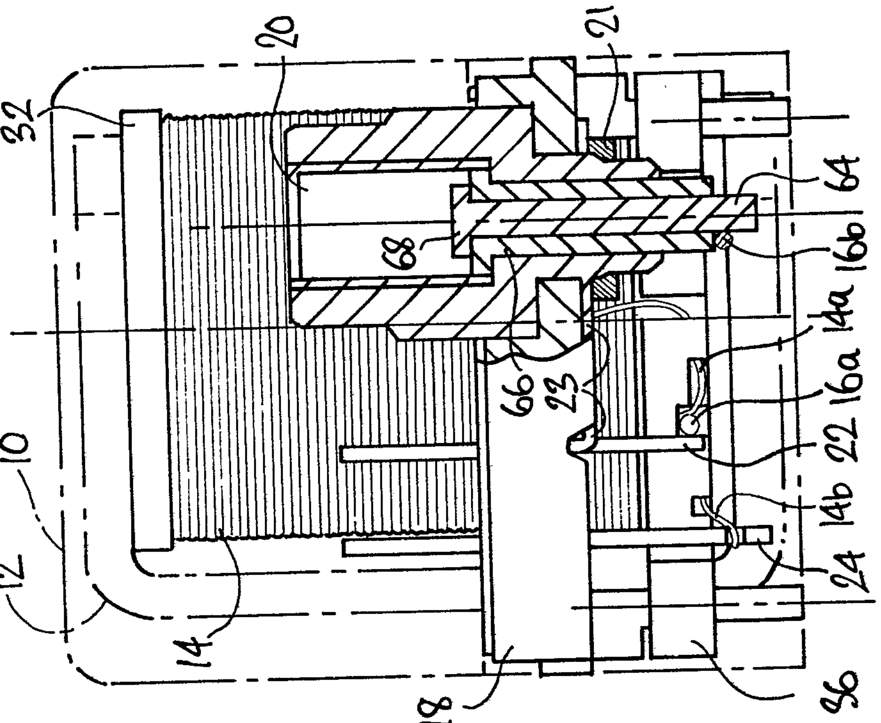
54
48
12
16
34
38
46
26
44
27
13
32
30
12

Fig. 3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14a
16a
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14b
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66
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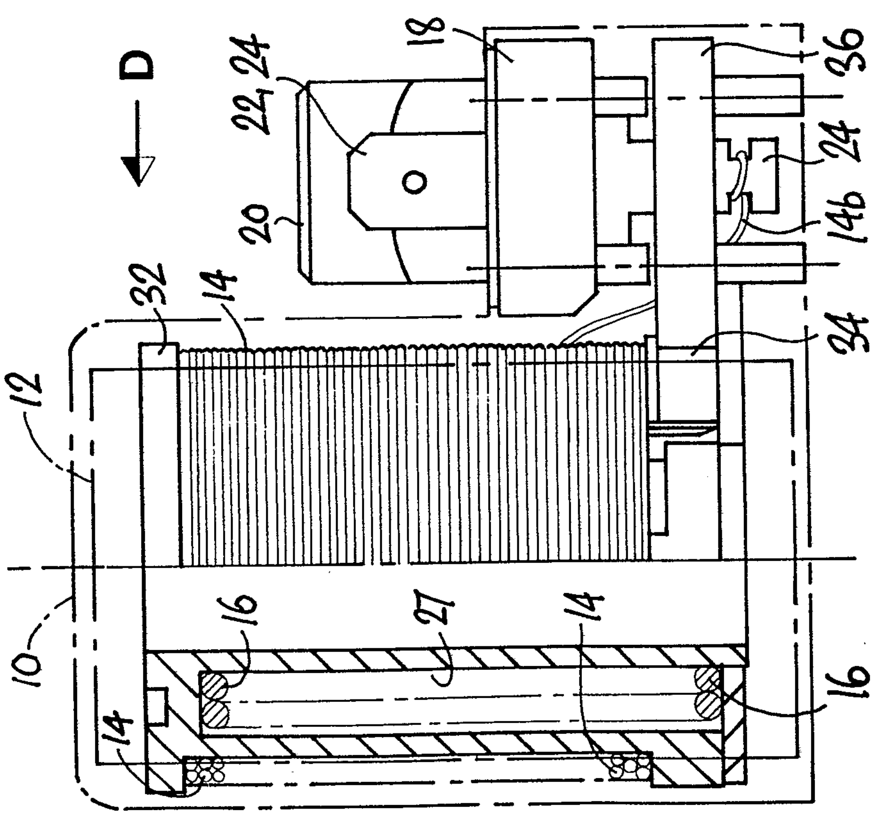
36

Fig. 6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14b
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32
14
12
10
16
27
14
16
14

Fig. 5

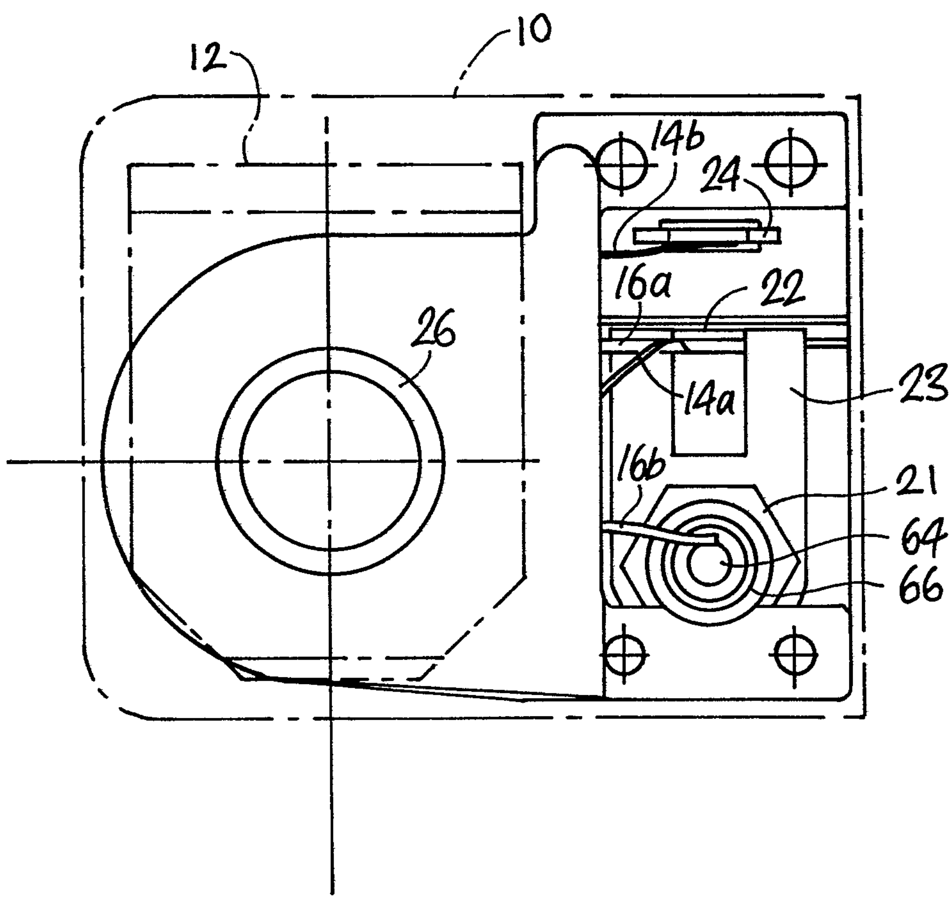


Fig. 7

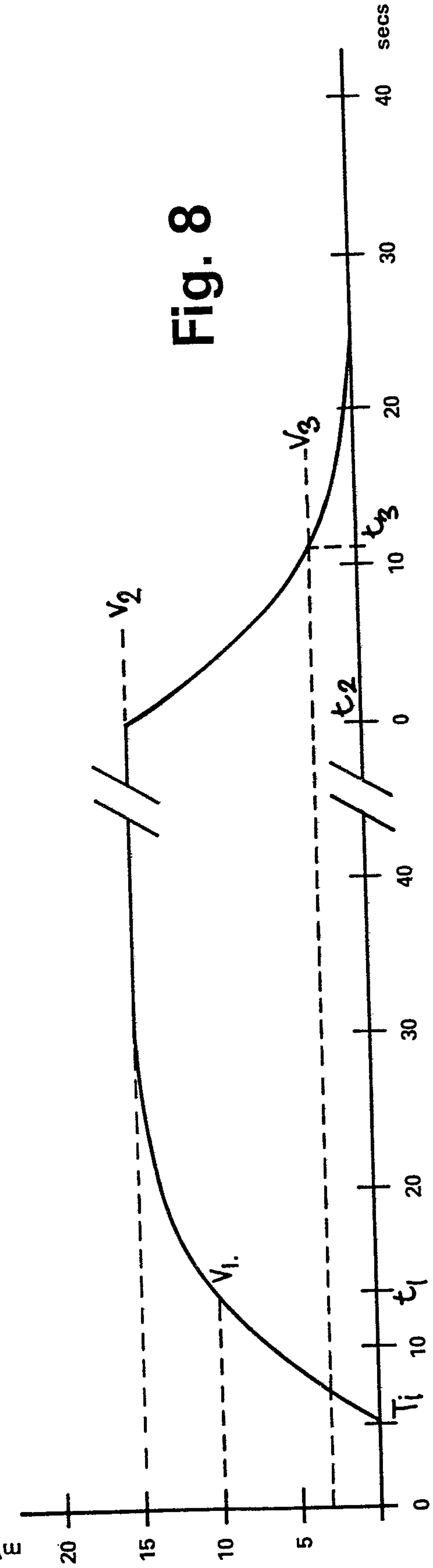
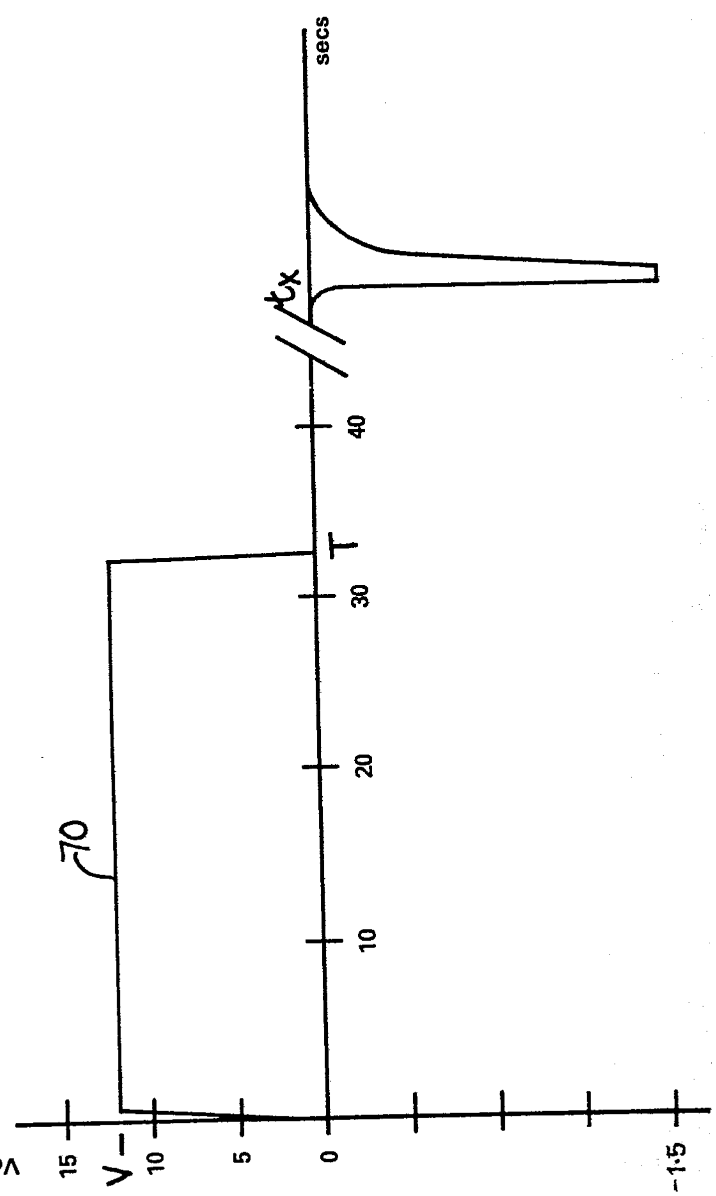

mV
20
15
10
5
0
10
20
30
40
0
10
20
30
40
secs
Ti
t1
V1.
V2
t2
V3
t3

Fig. 8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V
10
5
0
-1.5
10
20
30
40
secs
T
tx
70

Fig. 9

Fig. 10

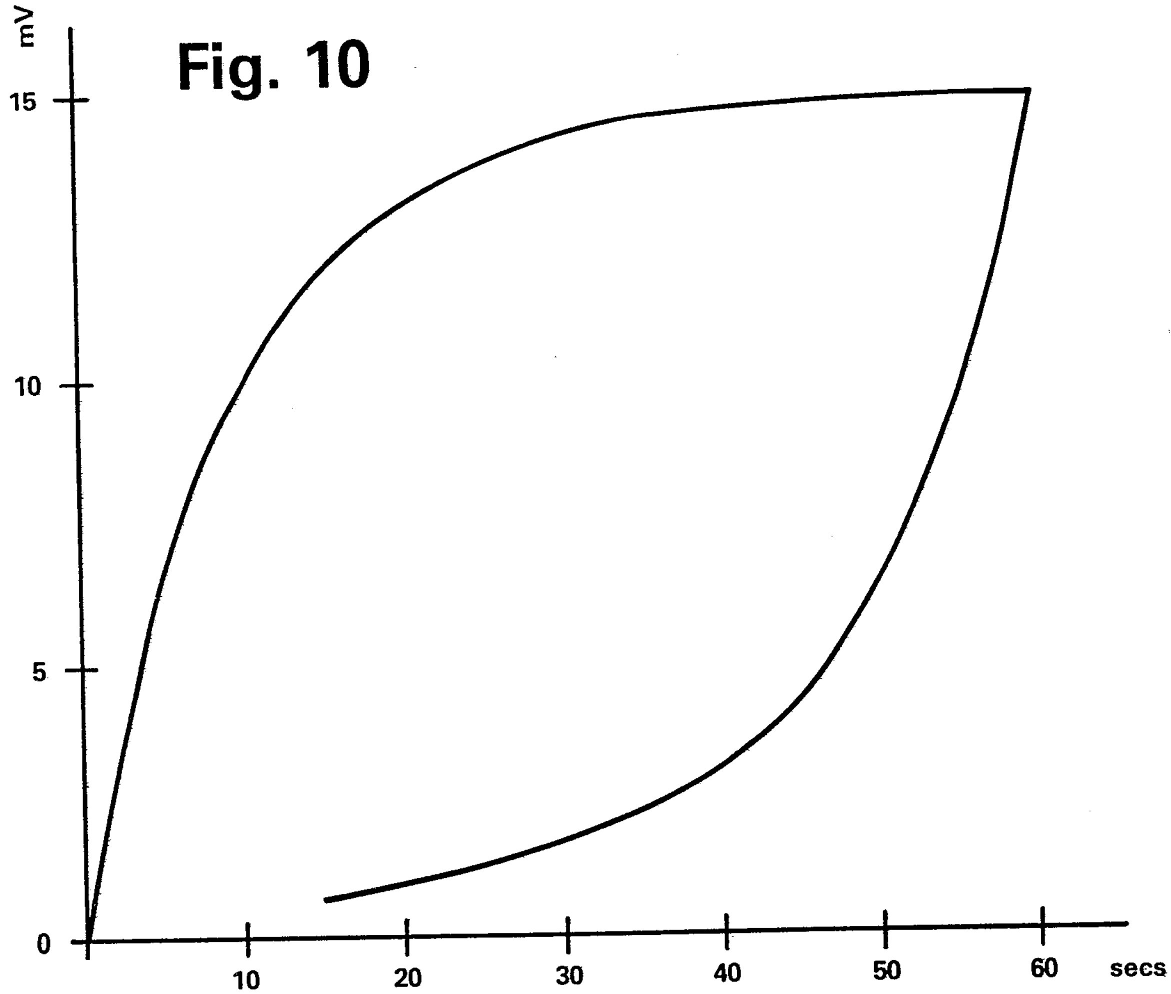
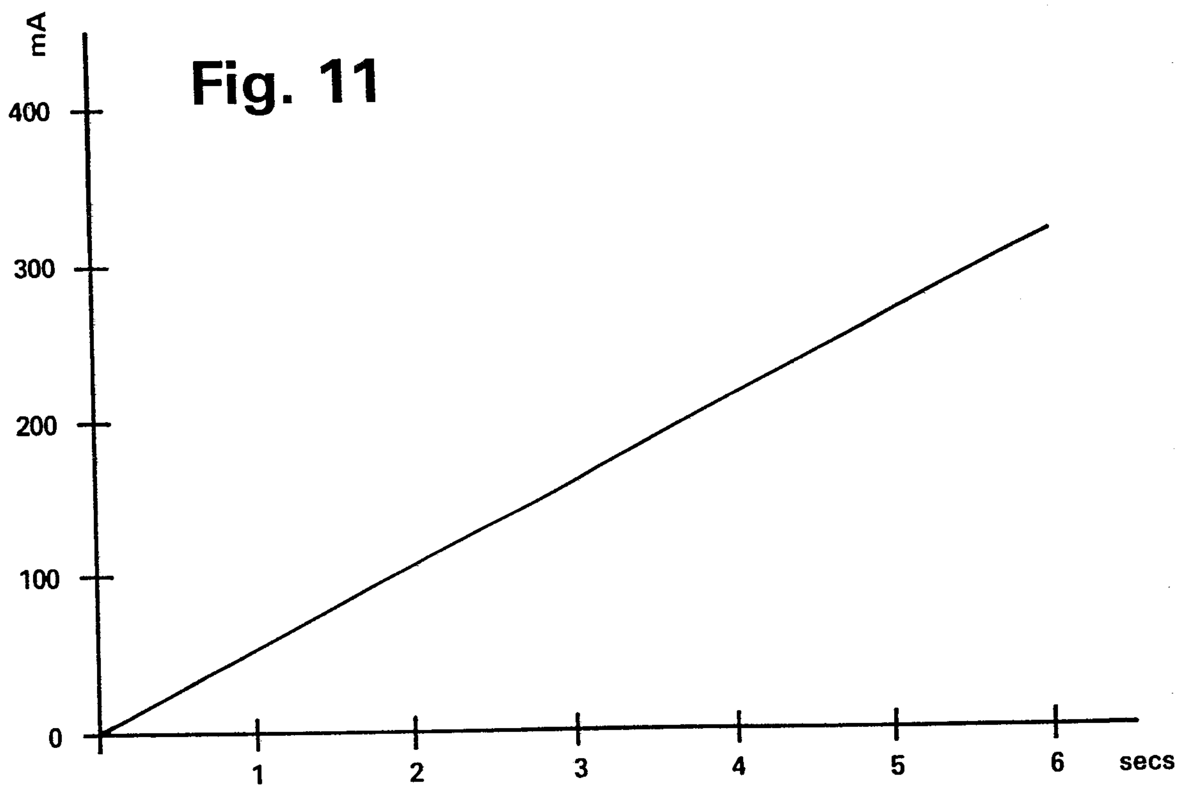


Fig. 11



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Application number

EP 83 30 5555

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 3)
X	FR-A-2 373 753 (SOC. BOURGUIGNONNE DE MECANIQUE) * figures 1-3; page 5, line 36 - page 6, line 20 *	1-4,6, 7,9	F 23 N 5/10
X	FR-A-2 434 342 (Et. EUGENE SCHOLTES) * figures 1,2 *	1,2,6, 7,9	
X	US-A-2 710 181 (W.S. PARRETT) * figure 2; column 3, lines 11-54 *	1-4,6, 7,10	
A	FR-A-1 580 257 (SAUNIER DUVAL) * figures 1,2; page 3, line 15 - page 4, line 6 *	1,2,6- 9,11	**TECHNICAL FIELDS SEARCHED (Int. Cl. 3)**
A	US-A-3 720 858 (G.M.MERCIER) * figures 1,2; column 3, line 46 - column 4, line 56 *	8,11	F 23 N
X	GB-A-2 027 536 (B. HARDING) * claim 1; figures *	12	
A	US-A-2 962 093 (R.B. MATTHEWS)		
	--- -/-		

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	23-02-1984	THIBO F.

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A	US-A-2 637 393 (C.M. MAYER et al.) ---		
A	FR-A-2 416 425 (P.B.A.V.) ---		
A	FR-A-2 005 824 (IMPERIAL-WERKE G.m.b.H.) ---		
A	FR-A-1 573 058 (SAUNIER DUVAL) ---		
A	FR-A-2 217 636 (FIRMA DIEHL) -----		
			TECHNICAL FIELDS SEARCHED (Int. Cl. 3)

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