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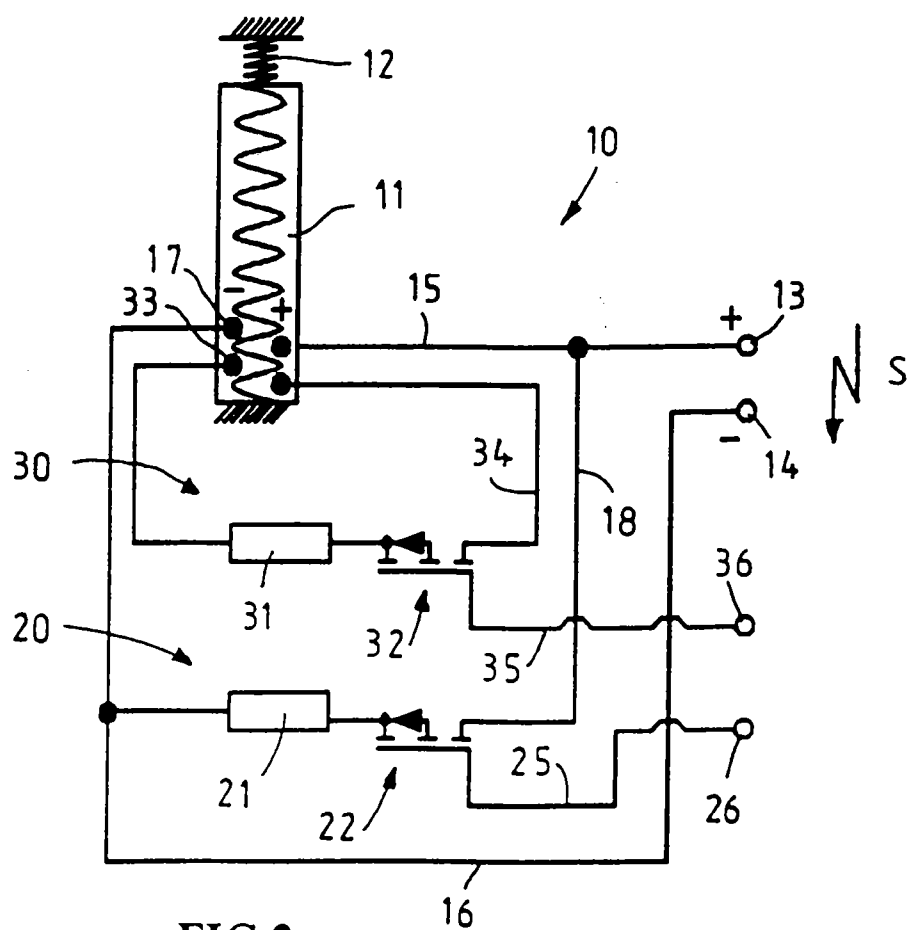
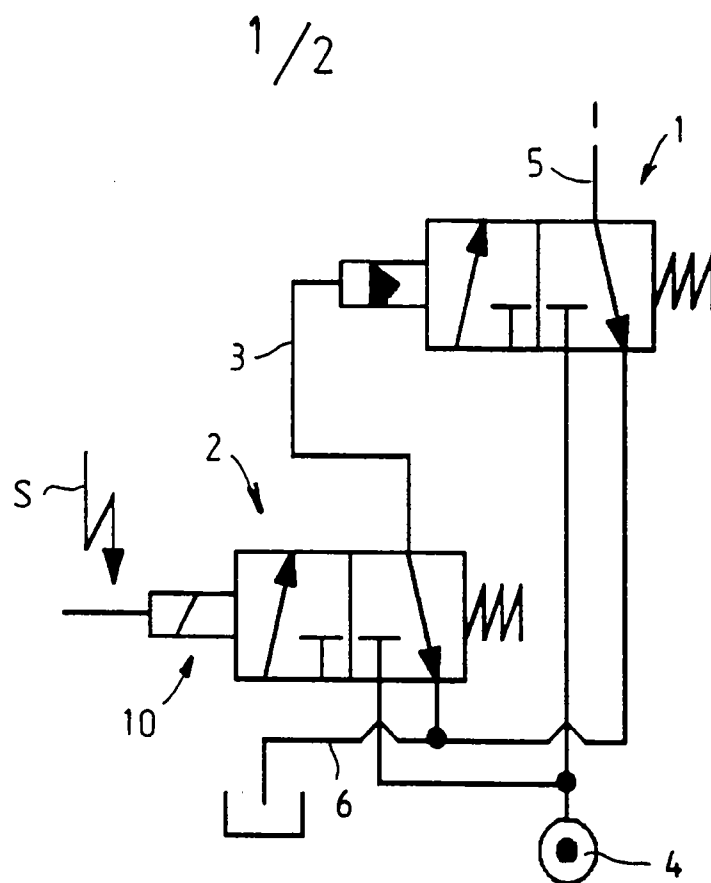
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ABSTRACT

A piezoelectric actuator unit 10 for valve switching has a piezoelectric element 11 changing its size on the application of a control voltage for switching the valve. So as to ensure a Totmann (safety) function of the valve and a fast return of the piezoelectric element into its initial position, the piezoelectric actuator unit 10 comprises a discharge circuit with at least one discharge element 21, 31 connected to the piezoelectric element 11. Discharge of the piezoelectric element is effected when the actuator is in its initial, safe position. The discharge circuit has to be switched actively so as to be able to exert a maximum stroke with the piezoelectric actuator.

(Figure 2)



PIEZOELECTRIC ACTUATOR UNIT

The invention relates to a piezoelectric actuator unit for valve switching, in particular but not exclusively for use in mining for switching pilot valves for oil or water hydraulics in underground mining, with a piezoelectric element changing its size on application of a control voltage for switching the valve.

In underground mining, electromagnetic actuators consisting of pilot valves and main control valves are usually used in underground mine roof supports for switching the valves. The current requirement of the electromagnetic actuators can be limited with suitable circuits at the electromagnetic actuators, in particular with a circuit for reduction of the holding current. A limited current intake of each individual electromagnetic actuator enables a favourable ratio between installed electrical power and the valves being driven with the installed power in underground mining. All electromagnetic actuators used in underground mining are provided with a reset spring which ensures, for example with circuit errors, or with a short-term voltage drop in the power network, or with a cable break caused by a fault and in other situations that the pilot valve and the main control valve connected downstream return to their initial position. With the valves for driving the plungers of the underground mine roof supports, the initial position mostly corresponds to the closed position of the valve, so that the hydraulic or support jack of the mine roof support keep their current extension length or moving drives stay still. In underground mining, the automatic return of the electromagnetic actuators into their initial position is often referred to as a "Totmann circuits function" or a "Totmann circuits position", which is demanded in a compelling manner with actuators or the valves switched therewith due to safety reasons, in underground mining .

In underground mining, furthermore significant attempts are made to reduce the electric power input of the actuators for switching the valves. An approach for this comprises the use of piezoelectric actuators, as these use the charging current for the capacity of the piezoelectric element only during the application of a control voltage and afterwards keep their switching state, that is their volume and length change while using a negligible residual current. Piezoelectric elements are distinguished by freedom from wear, fast switching times, and a high retaining

strength at the beginning of the switching process, as well as a very low use of energy. Admittedly, piezoelectric elements only show small volume changes during the application of the control voltage, so that the maximum stroke necessary for switching the valves is as a rule only achieved by interposition of a mechanical lever device (DE 5 102 33 316 A1). DE 102 33 316 A1 discloses a possibility of a solution for a fast return of the switching lever with the Totmann circuits function of the actuator, by assigning a hydraulically loadable piston to the operating lever.

Piezoelectric actuators distinguish themselves in particular by their capacitive 10 behaviour. If a voltage is applied to a piezoelectric element, a load flux results on the piezoelectric element which holds this charge until it is discharged. An automatic discharge only takes place in a negligible manner by means of a leakage current via the internal resistance of the piezoelectric element. A short, automatic return of the piezoelectric element into its initial position by removing the control voltage is 15 therefore not possible.

It is the object of the invention to create a piezoelectric actuator unit for 20 mining which enables a safe and fast return into the initial position or initial extension of the piezoelectric element for the Totmann circuits function.

According to the invention there is provided a piezoelectric actuator unit as recited in claim 1.

The piezoelectric actuator unit comprises a discharge circuit with at least one 25 discharge element connected to the piezoelectric element. The discharge circuit is constructed in such a manner that the discharge element discharges the piezoelectric element permanently or constantly, as long as no signal opens actively the discharge circuit. The active opening of the discharge circuit for interrupting the discharge process preferably takes place by applying the control voltage and/or an blocking 30 voltage. The discharge circuit with the discharge element is consequently constructed in such a manner that the piezoelectric element is passively discharged with the discharge element, as long as no control signal is applied to the actuator unit or no control voltage is applied to the piezoelectric element or the discharge circuit activating the maximum stroke. Only when a control signal or a control voltage is

applied to the piezoelectric element of the piezoelectric actuator unit by a superposed control unit, then the discharge element is driven by means of the discharge circuit in such a manner that the discharge element is separated from the piezoelectric element, whereby the discharge process is interrupted and the piezoelectric element can now
5 execute the desired maximum stroke. The actuator for this is a suitable blocking signal fed to the discharge circuit.

With the drivable discharge circuit comprising the discharge element provided according to the invention a discharge of the piezoelectric element is effected
10 consequently for realising the Totmann circuits function required for the mining operation if the actuator is to be in the safe mining initial position. The passive discharge of the piezoelectric element is accelerated considerably by the discharge element compared to an automatic discharge under a load, whereby a discharge of the piezoelectric element in principle effects a volume change of the piezoelectric
15 element and thereby its return into the initial position.

In one embodiment according to the invention, the blocking voltage can be generated immediately by the control voltage or from the control voltage. Alternatively, the blocking voltage can be generated via a voltage reduction from the
20 control voltage. During voltage interruption at the actuator unit, the blocking voltage also collapses immediately. In an arrangement not claimed, the blocking signal can nevertheless be activated independently from the control signal, even if it is advantageous to activate the blocking signal in particular immediately through the control signal. Furthermore, an analogue circuit can be provided for generating the
25 control voltage and the blocking voltage from a switching signal. Alternatively or additionally, an upstream, in particular digital processor for generating the control voltage and the blocking voltage or the corresponding signals can be provided. This enables furthermore to exchange data, in particular nominal values, actual values and statuses with the upstream processor by means of a communication line with
30 superposed control devices.

The invention also provides as an alternative to drive the discharge element by applying the same control voltage. It is clear that, by applying the same control voltage, that it does not necessarily have to be stipulated that the same control voltage

for loading the piezoelectric element and for driving the discharge circuit is used. It is in fact sufficient for the invention that the drive of the discharge element or the discharge circuit is actuated by applying the control voltage to the actuator unit.

5 In the preferred embodiment, a switching element is assigned to the discharge circuit, which element interrupts a discharge of the piezoelectric element only during application of the control voltage or the blocking voltage or separates a circuit with the discharge element, while it bypasses the piezoelectric element and the discharge element whenever no blocking or control voltage is applied to the actuator unit. The
10 preferred embodiment has the advantage that the piezoelectric element has to be blocked actively for achieving the maximum stroke, as otherwise the piezoelectric element is discharged permanently and cannot be switched for this reason. In the case of a voltage interruption or another disturbance in the grid or in the superposed control device, a passive safety function is then permanently integrated into the
15 piezoelectric actuator unit, which causes an automatic return of the piezoelectric element into its initial position.

In the particularly preferred embodiment, the discharge element is arranged parallel to the piezoelectric element. In the simplest embodiment of the discharge
20 circuit, the discharge element consists of at least one discharge resistor. It is clear that the discharge resistor or the discharge resistors is/are adjusted to the capacity of the piezoelectric element. By a corresponding choice of the discharge resistor it is possible to discharge the piezoelectric element (the piezoelectric means or the piezoelectric actuator) within milliseconds.

25 The switching element can in particular consist of a switching transistor or a FET (field effect transistor), as in particular a NC-FET unit (NC = Normally Closed). Instead of a single switching transistor or FET, several switching transistors or FET units can be provided.

30 For the use of piezoelectric actuator units in underground mining, it is particularly advantageous if the discharge circuit is executed in a redundant manner and comprises at least two circuits with discharge element and switching element. The redundant execution of the discharge circuit with several circuits ensures the

functioning of the Totmann circuits function even during occurrence of a break of the contact between one of the discharge circuits and the piezoelectric element. As the piezoelectric element changes its volume as a matter of principle, a reliable contact of the piezoelectric element with a circuit presents a problem; after a plurality of maximum strokes, a break of individual contacts can result. In the preferred embodiment according to the invention, every circuit is therefore connected to the piezoelectric element by means of a separate contact. For the same reasons, it is particularly advantageous if some or all electrical contacts with the piezoelectric element are at least executed in a twofold manner.

It will be obvious to the expert, that, in the piezoelectric actuator unit, all types of piezoelectric elements can be used, in particular piezoelectric element stacks, as the discharge circuit according to the invention can be provided independently from the embodiment of the piezoelectric element.

Further advantages and embodiments of the invention result from the following description of an example of an embodiment for an underground hydraulic valve with piezoelectric actuator unit shown schematically in the figures, in which:

Figure 1 is an hydraulic circuit diagram, a hydraulic pilot valve having a piezoelectric actuator unit, for underground mining, in Totmann circuits position;

Figure 2 is an electric circuit diagram of the design of a discharge circuit of a piezoelectric actuator unit according to the invention; and

Figure 3 is a similar circuit diagram a second piezoelectric actuator unit of a non-claimed arrangement.

In the circuit diagram of Figure 1, a pilot valve 2 is coupled to a hydraulic control valve 1. The pilot valve can be actuated by applying a symbolically indicated control voltage S to a piezoelectric actuator unit 10. The circuit diagram shows the two valves 1, 2 in their initial position. By powering the piezoelectric actuator unit 10, the valve slide of the pilot valve is displaced in such a manner that the exit line 3 of the pilot valve 2 is connected hydraulically to the high pressure source 4, whereby the

valve slide of the main control valve 1 also changes its position and connects a jack connected by means of the jack line 5 to the high pressure source 4. Whereas, in the initial position shown, the jack line 5 and the exit line 3 of the pilot valve 2 are connected to the return run.

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In the known design of hydraulic valves for underground mining with an electromagnetic actuator, the switching rod of the electromagnet would then always again be moved back into its initial position by means of a spring, if there is no control voltage at the actuator, that is, no current flows through the coil of the electromagnet. Whereas, with the electrical actuator unit 10 for driving the pilot valves 2 according to the invention, a discharge circuit is provided, so as to move the piezoelectric element of the piezoelectric actuator unit 10 back into its initial position when no control voltage S is applied to the actuator unit 10.

Figure 2 shows the piezoelectric actuator unit 10 with the piezoelectric element 11 in an electrical schematic diagram. The piezoelectric element 11 is prestressed in its initial position by means of the symbolically shown prestress spring 12. However, the spring force of the prestress spring 12 is not sufficient for a fast electrical automatic discharge of the piezoelectric element 11. As known per se, the piezoelectric element 11 is extended in its length by applying a control voltage S to the drive poles 13, 14 of the piezoelectric actuator unit 10 for effecting a maximum stroke. Both drive poles 13, 14 are connected to the piezoelectric element 11 by means of lines 15, 16, and the system of drive poles 13, 14 as well as lines 15, 16 forms the piezoelectric drive for the piezoelectric element. In accordance with the invention, the piezoelectric actuator unit 10 is now provided with a discharge circuit which comprises two identically constructed discharge circuits 20, 30 in the example of the embodiment according to Figure 2. Each discharge circuit 20, 30 consists of a discharge resistor 21, 31 and a FET unit 22, 32 connected to it. Both discharge resistors 21, 31 are switched in a parallel manner to the piezoelectric element 11, and, in the shown example of the embodiment, the discharge resistor 21 has the same contact 17 at the piezoelectric element 11 as the negative pole line 16 of the piezoelectric drive, while the discharge resistor 31 is connected to the piezoelectric element 11 by means of a separate contact 33. In this connection, it is not shown that each contact could at the same time be made in a multiple manner. The FET units 22,

23 assigned to the discharge resistors 21, 31 are implemented in such a manner that they normally bypass the piezoelectric element 11 with the respectively assigned discharge resistor 21 or 31 via the lines, whereby the discharge resistors 21, 31 discharge the piezoelectric element. However, if the control voltage S is applied to the drive poles 13, 14 and also to the drive poles 26, 36, the FET unit 22 is loaded with the control voltage S by means of the branch line 18, 25, and the FET unit 32 by means of the contact line 34, 35, so that both FET units open and interrupt the respective discharge circuits 20, 30 or open then as well. Only when the control voltage S is applied to the drive poles 13, 14 as well as 26, 36, then consequently no active discharge of the piezoelectric element 11 takes place by means of the discharge resistors 21, 31. As soon as the control voltage S at the drive poles 13, 14 of the piezoelectric drive and at the drive poles 26, 36 drops out, the FET units 22, 32 close and thereby short circuits the discharge resistors 21, 31 with the piezoelectric element, so that the discharge of the piezoelectric element 11 starts again immediately. Thus, the piezoelectric element 11 again takes up its initial length, whereby the pilot valve (2, Figure 1) returns into its initial position.

Figure 3 shows, as a non-claimed arrangement, the piezoelectric actuator unit 10 in a drive with an upstream control 40. The piezoelectric actuator unit 10 has the same construction as in the example of the embodiment of Figure 2, and same units are provided with the same reference numerals. The previous description can be referred to. The analogue circuit 40 generates the control voltage S on the one hand from a drive signal 44 of a superposed control device 43, and also an blocking voltage E_s on the other hand. Despite the control voltage S at the drive poles 13, 14 the piezoelectric element 11 is only extended when an blocking signal, for example as blocking voltage E_s , is applied at the same time at the drive poles 26, 36; because the discharge circuits 20, 30 are only opened through the blocking voltage E_s , which drives the FET units 22, 32 via the drive lines 25, 35. This active opening of the discharge circuits 20, 30, whereby the discharge resistors 21, 31 are separated from the piezoelectric element, is a mandatory condition for a length extension of the piezoelectric element 11. Only when the blocking voltage E_s is applied to the drive poles 26, 36, then consequently no otherwise continuous discharge of the piezoelectric element 11 takes place via the discharge resistors 21, 31. As soon as the

blocking voltage E_s drops at the drive poles 26, 36, the FET units 22, 32 close and thereby bypass the discharge resistors 21, 31 with the piezoelectric element again, so that the discharge of the piezoelectric element starts again immediately. Hereby, the piezoelectric element 11 takes its initial length again, whereby the pilot valve (2, 5 Figure 1) returns to its initial position. The circuit 40 can have an processor (CPU etc.) 41, shown schematically, so as to exchange data such as nominal and actual values via the communication line 44 with the superposed control device in a bi-directional manner.

10 For the expert, numerous modifications can be seen in the preceding description, which shall fall within the scope of protection of the appended claims. Instead of just one discharge circuit or two discharge circuits, three or more discharge circuits could be used. Some or all of the contacts could be duplicated or further multiplied. Instead of FET units, which are opened by applying a control voltage, 15 other suitable switching transistors could also be used.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A piezoelectric actuator unit for valve switching, the unit comprising:
- a piezoelectric element adapted to change its size for valve switching when a control voltage is applied and
 - a discharge circuit (20;30) connected to the piezoelectric element (11),
 - the circuit comprising at least one discharge element (21,31) for discharging the piezoelectric element, and
 - the circuit be adapted to be opened for interrupting a discharge process by applying to the actuator unit the control voltage (S) for activating the piezoelectric unit,
 - with the discharge circuit constructed such that the discharge element discharges the piezoelectric element permanently as long as the discharge circuit is not opened by the control voltage.
2. A piezoelectric actuator unit as claimed in claim 1, wherein the discharge circuit (20,30) comprises a switching element (22;32) which interrupts the discharge of the piezoelectric element (11) only with an applied control voltage (S).
3. A piezoelectric actuator unit as claimed in claim 1 or claim 2, wherein the unit includes an analogue circuit for generating the control voltage (S) from a switching signal.
4. A piezoelectric actuator unit as claimed in claim 1, claim 2 or claim 3, wherein the unit includes digital processor, connected upstream in series, for generating the control voltage.
5. A piezoelectric actuator unit as claimed in claim 4, wherein the upstream processor is adapted to exchange data, in particular nominal values, actual values, and statuses by means of a communication line with superposed control devices.

6. A piezoelectric actuator unit as claimed in any preceding claim, wherein the discharge circuit with the discharge element (21;31) is arranged parallel to the piezoelectric element.

5 7. A piezoelectric actuator unit as claimed in any preceding claim, wherein the discharge element consists of at least one discharge resistor (21;31).

8. A piezoelectric actuator unit as claimed in claim 2 or any one of claims 3 to 7 as appendant to claim 2, wherein the switching element consists of or comprises a
10 switching transistor.

9. A piezoelectric actuator unit as claimed in claim 2 or any one of claims 3 to 8 as appendant to claim 2, wherein the switching element consists of or comprises an FET unit.

15 10. A piezoelectric actuator unit as claimed in any preceding claim, wherein the discharge circuit is executed in a redundant manner and comprises at least two discharge circuits with discharge elements and switching elements.

20 11. A piezoelectric actuator unit as claimed in claim 10, wherein each discharge circuit is connected to the piezoelectric element by means of a separate contact.

12. A piezoelectric actuator unit as claimed in any preceding claim, wherein all electrical contacts with the piezoelectric element are duplicated or further multiplied.

25 13. A piezoelectric actuator unit for valve switching substantially as hereinbefore described with reference to Figures 1 and 2 of the accompanying drawings.

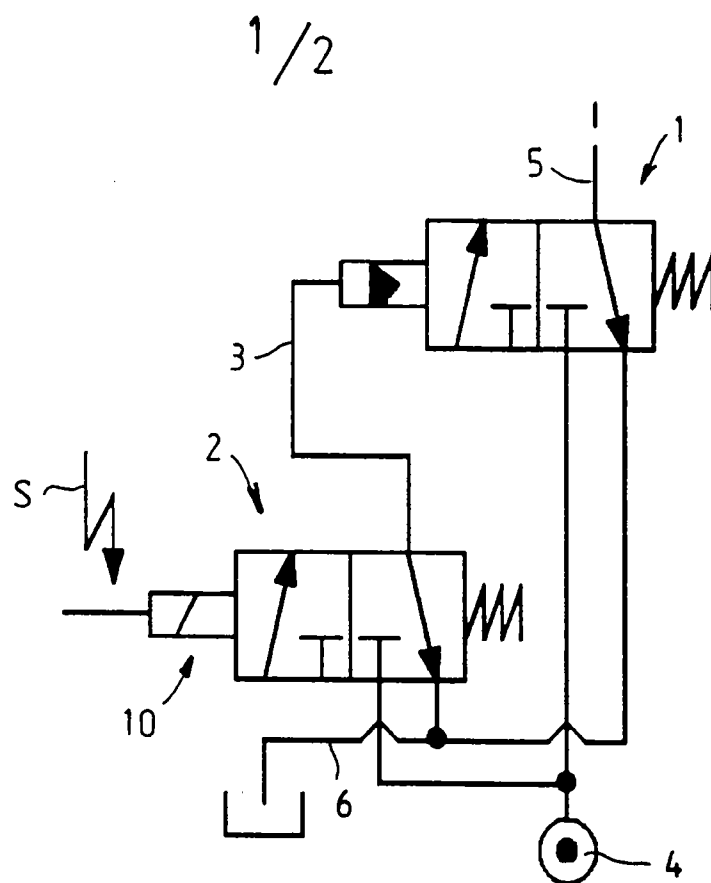


FIG 1

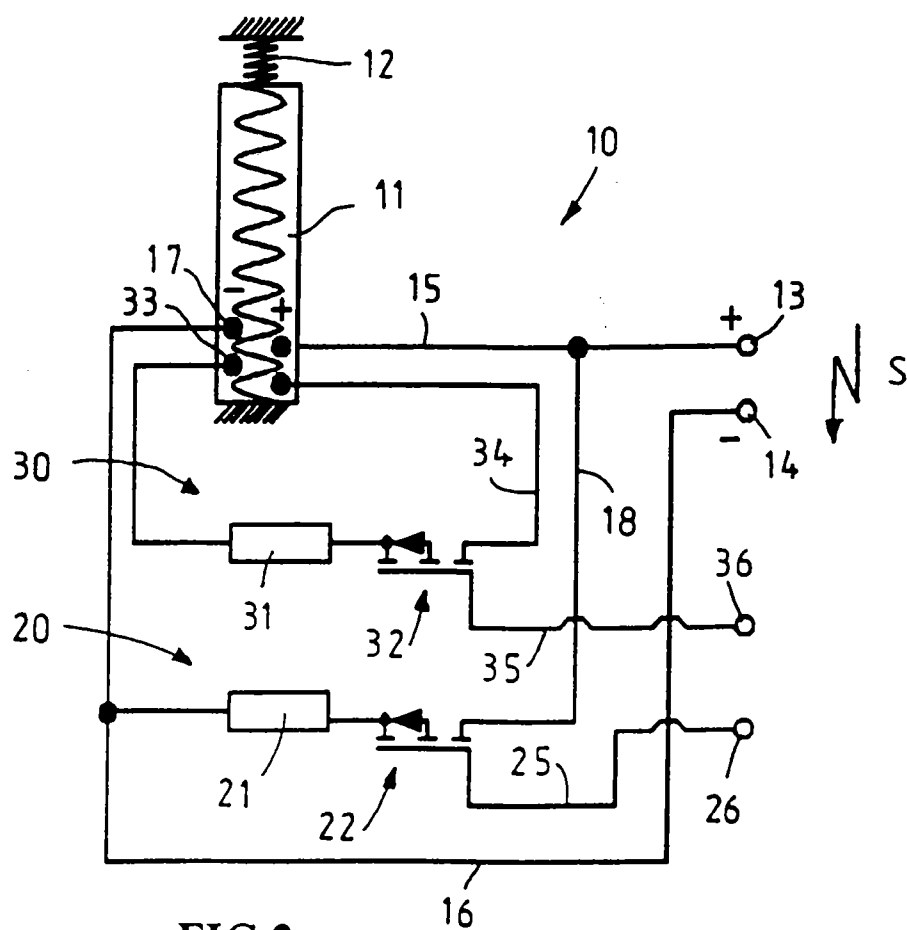


FIG 2

