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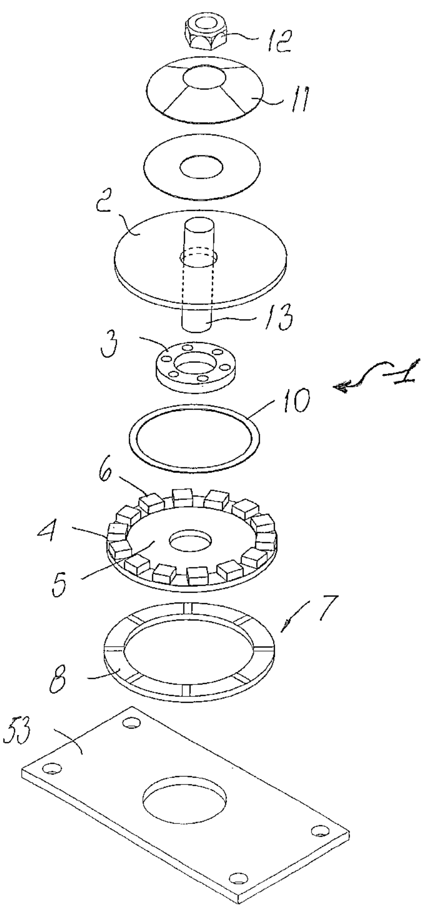
(54) Title: DRIVING DEVICE FOR ULTRASONIC MOTOR



(57) Abstract: A driving device for ultrasonic motors, whose particularity consists of the fact that it comprises at least one piezoelectric transformer for driving an ultrasonic motor.

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DRIVING DEVICE FOR ULTRASONIC MOTOR

DESCRIPTION

The present invention relates to a driving device for an ultrasonic motor. More particularly, the invention relates to a driving device suitable to drive a rotary ultrasonic motor and a linear ultrasonic motor.

As is known, an ultrasonic motor is constituted by a vibrating body that is formed by a piezoelectric body and an elastic body, and a rotational body is arranged in pressure contact with the rotating body. By applying a high-frequency alternating voltage to the piezoelectric body, elastic displacement waves are generated due to the vibration of the vibrating body, and therefore the rotating body is turned by the effects of friction forces.

The piezoelectric ultrasonic motor uses no electromagnetic effect, which is instead the principle of conventional motors. In ultrasonic motors, two ultrasonic vibrations, usually phase-shifted by 90° or 45°, are composed in order to have a progressive wave that can be converted into a continuous movement of a moving part. The ultrasonic vibrations are induced by conveniently polarized piezoelectric rings which are arranged in different manners or by stack piezoelectric elements.

Figure 1 illustrates an example of a rotary ultrasonic motor that is particularly suitable for example for application in an automatic circuit breaker.

As shown in the figure, the piezoelectric motor, generally designated by the reference numeral 1, comprises a stator unit and a rotor unit. The rotor unit comprises a metallic disk or ring 2, which is structurally rigidly coupled to the shaft of said motor. Furthermore, a bearing 3 is functionally associated with the motor shaft in order to allow its rotation.

In turn, the stator unit comprises a flange 53, to which the bearing 3 is connected and an annular elastic disk 4, which is connected to the flange 53 and has a base plate 5 and a ring 6 that is shaped with a plurality of teeth that protrude transversely, particularly at right angles, from the base plate 5.

The stator unit furthermore comprises at least one layer of piezoelectric material 7 that is fixed, for example glued, onto the elastic disk 4. In particular, the layer of piezoelectric material 7 comprises a plurality of sectors 8, which are polarized alternately in opposite directions and are excited electrically by the control signals supplied by an external control unit.

The motor 1 furthermore comprises friction means 10, constituted for example by a layer of rubber or plastics or metal, which are interposed between the metallic disk 2 and the shaped ring with teeth 6, and also comprises retention means that are constituted, for example, by a metallic elastic body 11 that is arranged on a face of the metallic disk 2 that lies opposite the annular elastic disk 4. A nut 12 is screwed onto a threaded end of a bar 13 and allows to keep the various elements of the rotor packed on the stator.

The operation of the piezoelectric motor shown in Figure 1 is as follows.

When voltage is applied, each sector 8 of the ring 7 is warped and the elastic ring also is warped. The elastic ring has teeth in order to amplify the small vibrations produced by the piezoelectric sectors. As a result, a progressive ultrasonic wave is generated along the ring. When the progressive ultrasonic flexural wave moves along the ring, the point of contact between the stator and the rotor has an elliptical motion, thus entraining the rotor, by friction, in a continuous rotary motion.

Figure 2 illustrates an example of a stator of a linear ultrasonic motor, designated in this case by the reference numeral 15, in which the piezoelectric elements 16 are mutually stacked and arranged as shown in the figure.

Other types of linear motors exploit one or more ultrasonic vibrations caused by at least one layer of piezoelectric material glued on plates which are provided with suitable protuberances.

The piezoelectric elements are connected to an elliptical structure 27, which is thus vibrated by the piezoelectric elements 16 in the direction indicated by the arrows 14.

Figure 3 illustrates a standard driving circuit for ultrasonic motors, which typically comprises a voltage-controlled oscillator 20 for generating signals that have different frequencies according to the voltage applied to the control terminal in input to the voltage-controlled oscillator.

The oscillator generates an AC voltage signal that is split into two signals: one is phase-shifted by a phase shifting circuit 21 and then the signals are sent to a power amplifier stage 22 constituted by two power amplifiers. The voltage of the signal is increased to a level high enough to drive the ultrasonic motor by virtue of transformers 23 constituted by wire windings of the conventional type. The signals are then sent to two terminals for driving the vibrating body of the ultrasonic motor, which is designated by the reference numeral 1 in Figure 3. Said ultrasonic motor is designated by the same reference numeral used in Figure 1, but it might also be an ultrasonic motor of the type shown in Figure 2 and would therefore be designated by the reference numeral 15 in this case.

As a result of the emission of said signals, flexural vibration displacement waves are excited in the vibrating body of the ultrasonic motor, thus inducing the rotating body to rotate, as explained earlier with reference to Figure 1. The circuit shown as a block diagram in Figure 3 is supplied by a DC supply voltage.

The circuit is completed by a circuit 24 for sensing the speed of the ultrasonic motor and by a speed control circuit 25 that is suitable to drive the voltage-controlled oscillator 20 and the phase shifting circuit 21.

However, driving devices of ultrasonic motors, such as the driving device shown in Figure 3, have drawbacks.

First of all, the circuit shown in Figure 3 requires the use of transformers that have special wire windings for high frequencies. Furthermore, the accuracy of the oscillation frequency is approximately 20%, and due to the large number of components the electronic board is not very compact.

Moreover, the cost of the electronic circuit of Figure 1 is very high and the efficiency of the control system is low.

The aim of the present invention is to provide an ultrasonic motor driving device that is simpler and more reliable than known driving devices.

Within the scope of this aim, an object of the present invention is to provide a driving device for ultrasonic motors in which the electronic part is simplified considerably with respect to known types of driving device.

Another object of the present invention is to provide a driving device for ultrasonic motors that has a higher efficiency and a higher attainable oscillation frequency accuracy than known types of driving device.

Another object of the present invention is to provide a driving device for ultrasonic motors that self-protects in case of short-circuit at the terminals of the motor.

Another object of the present invention is to provide a driving device for ultrasonic motors that has smaller dimensions than a known type of device for an equal output voltage.

Another object of the present invention is to provide a driving device for ultrasonic motors that is highly reliable, relatively simple to provide, and at competitive costs.

This aim, these objects and others that will become apparent hereinafter are achieved by a driving device for ultrasonic motors, characterized in that it comprises at least one piezoelectric transformer for driving an ultrasonic motor.

Further characteristics and advantages of the invention will become apparent from the description of preferred but not exclusive embodiments of the driving device according to the present invention, illustrated only by way of non-limitative example in the accompanying drawings, wherein:

Figure 1 is an exploded perspective view of a rotary ultrasonic motor;

Figure 2 is a schematic view of the stator of a linear ultrasonic motor;

Figure 3 is a block diagram of a known type of driving device for ultrasonic motor;

Figure 4 is a schematic view of a driving device of an ultrasonic motor according to the present invention;

Figure 5 is a view of a piezoelectric transformer used in the ultrasonic motor driving device shown in Figure 4;

Figure 6 is a perspective view of the piezoelectric transformer shown in Figure 5; and

Figure 7 is a more detailed block diagram of the ultrasonic motor driving device according to the present invention.

With reference to the figures cited above, and particularly with reference to Figure 4, the ultrasonic motor driving device according to the present invention, shown schematically in Figure 4, has the particularity that it comprises at least one piezoelectric transformer and more preferably a pair of piezoelectric transformers for supplying the terminals of the ultrasonic motor.

In Figure 4, the ultrasonic motor, again designated by the reference numeral 1, is driven by a driving device according to the invention, designated by the reference numeral 30, which comprises two piezoelectric transformers 31, which are in turn driven by an alternating wave generator 32.

The generator is supplied by a DC power supply.

A piezoelectric transformer is formed by two electrodes, a primary one and a secondary one, as shown in Figure 6, wherein the primary electrode is designated by the reference numeral 33 and the secondary electrode is designated by the reference numeral 34.

In general, a piezoelectric transformer can also have multiple secondary electrodes and annular shapes.

The electrodes work together like a vibrator, producing piezoelectric vibrations. When a natural AC electric voltage frequency, determined by the dimensions, particularly the length, or by the constraint conditions of the transformer is introduced by the primary electrode, it generates an intense mechanical vibration by virtue of a piezoelectric effect, which produces a high voltage output from the secondary electrode that supplies the load, in this case the ultrasonic motor 1.

Vice versa, the piezoelectric transformers can also be used to reduce the voltage if the ultrasonic motor requires a lower input voltage than the voltage in input to the piezoelectric transformer.

Figure 5 is a schematic view of the piezoelectric transformer already shown in perspective view in Figure 6.

Figure 7 instead illustrates a piezoelectric inverter suitable to drive the ultrasonic motor 1.

Essentially, the driving device of the ultrasonic motor, according to the present invention, comprises in this case again a pair of piezoelectric transformers 31, which are driven by a phase shifting circuit 35 and by a voltage-controlled quadrature oscillator 38, which in turn receives in input a clock frequency f_0 that is the result of the processing of a feedback signal 36 that originates from the ultrasonic motor 1 and is input to a circuit 37 for sensing and controlling the speed of the ultrasonic motor 1, which also receives in input a reference speed V_{rif}.

The speed sensing and control circuit 37 in turn provides a signal that is proportional to the intended speed and sent in input to a voltage-controlled oscillator 38, which in turn emits the above described clock frequency f_0.

The quadrature oscillator provides low-voltage sine and cosine signals at the intended frequency, which drive the piezoelectric transformers 31, which in turn allow to reach the voltage required for the ultrasonic motor 1.

Essentially, the driving device according to the invention provides for the replacement of transformers having high-voltage wire windings with piezoelectric transformers, which allow higher efficiency, a driving circuit that is less complicated from the electronic standpoint, a higher oscillation frequency accuracy thanks to the absence of electromagnetic noise, and more compact dimensions for an equal voltage obtainable in output.

Further, piezoelectric transformers can be advantageously exploited for realizing DC/DC or DC/AC or AC/DC converters, in particular when input or output high-voltages and galvanic insulation are required.

The alternating wave generator 32 shown in Figure 4 is essentially constituted by the voltage-controlled quadrature oscillator, which provides in output sinusoidal and cosinusoidal waves, i.e., waves that are mutually phase-shifted by 90°, in order to supply the piezoelectric transformers and thus obtain in output a voltage for driving the ultrasonic motor 1.

In practice it has been found that the driving device according to the invention fully achieves the intended aim and objects, since it allows a significant improvement in the driving accuracy and efficiency of an ultrasonic motor by using piezoelectric transformers and in general a piezoelectric inverter to drive the ultrasonic motor.

The driving device of the present invention is particularly suitable for use with automatic circuit breakers, mainly of the remote-controlled type, and for high-voltage, either alternate or continuous, piezoelectric actuators, in particular thanks to the presence of the piezoelectric transformer(s). Therefore, further objects of the present invention concern an automatic circuit breaker characterized in that it comprises an ultrasonic motor driven by a driving device as previously described, and a driving device for high-voltage piezoelectric actuators characterized in that it comprises at least one piezoelectric transformer.

The device thus conceived is susceptible of numerous modifications and variations, all of which are within the scope of the inventive concept; all the details may furthermore be replaced with other technically equivalent elements. In practice, the materials used, so long as they are compatible with the specific use, as well as the contingent shapes and dimensions, may be any according to the requirements and the state of the art.

CLAIMS

1. A driving device for ultrasonic motors, characterized in that it comprises at least one piezoelectric transformer for driving an ultrasonic motor.
2. The driving device according to claim 1, characterized in that it comprises a piezoelectric inverter that comprises said at least one piezoelectric transformer.
3. The driving device according to claim 2, characterized in that said piezoelectric inverter comprises two piezoelectric transformers suitable to be driven by means for generating signals that are phase-shifted by 90°, in order to generate a pair of voltages for driving the ultrasonic motor.
4. The driving device according to one or more of the preceding claims, characterized in that it comprises means for sensing and controlling the speed of said ultrasonic motor which are suitable to receive in input a speed signal of said ultrasonic motor and a reference speed signal, said means for sensing and controlling the speed of the ultrasonic motor being suitable to drive a voltage-controlled oscillator, which emits in output a clock frequency that is suitable to drive a quadrature oscillator, which in turn emits said signals phase-shifted by 90° in order to drive said piezoelectric transformers.
5. The driving device according to claim 3, characterized in that each one of said piezoelectric transformers comprises a primary input electrode and a secondary output electrode.
6. The driving device according to one or more of the preceding claims, characterized in that said ultrasonic motor is a rotary ultrasonic motor.
7. The driving device according to one or more of the preceding claims, characterized in that said ultrasonic motor is a linear ultrasonic motor.
8. An automatic circuit breaker, characterized in that it comprises an ultrasonic motor driven by a driving device according to one or more of the preceding

claims.

9. A driving device for a high-voltage piezoelectric actuator characterized in that it comprises at least one piezoelectric transformer.

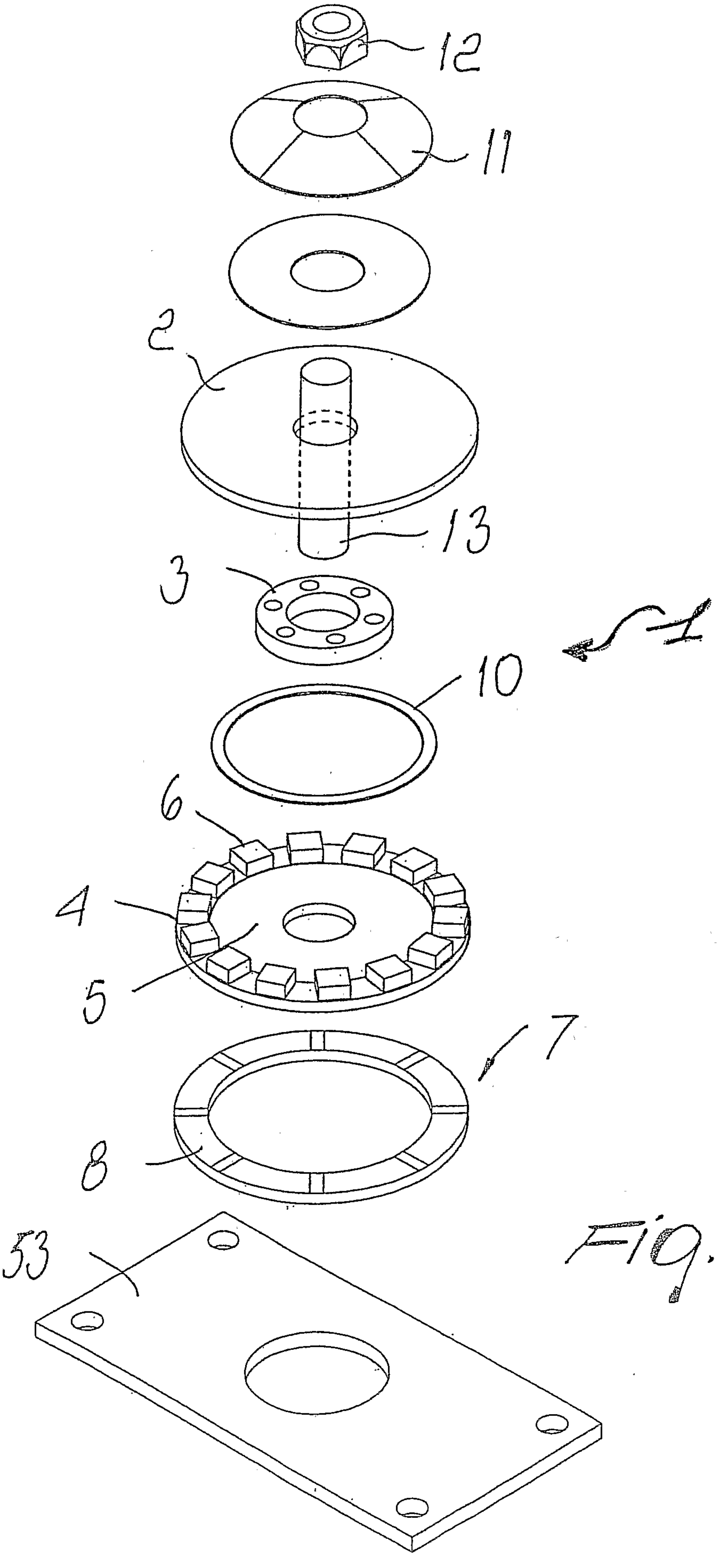

Fig. 1

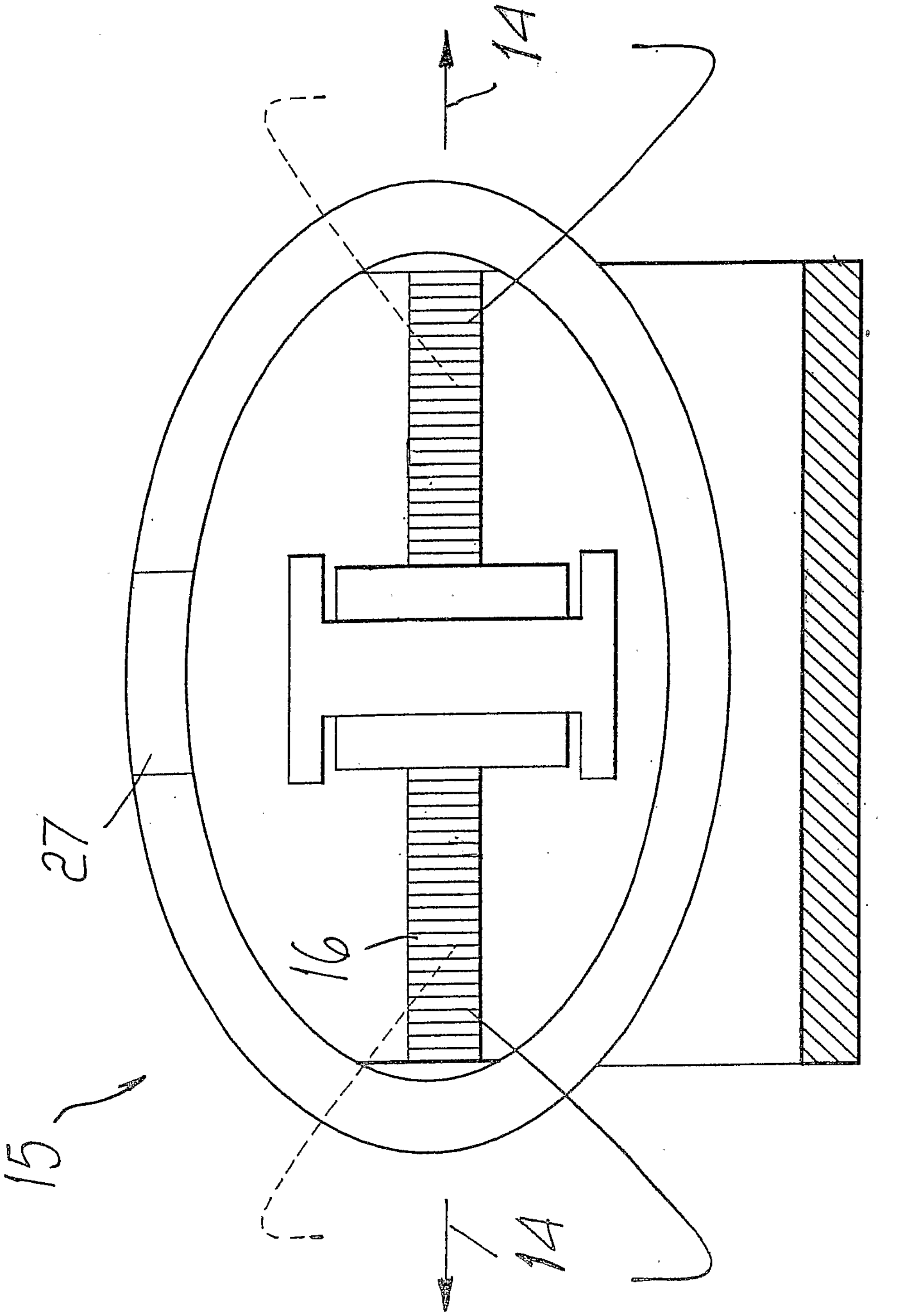

Fig. 2

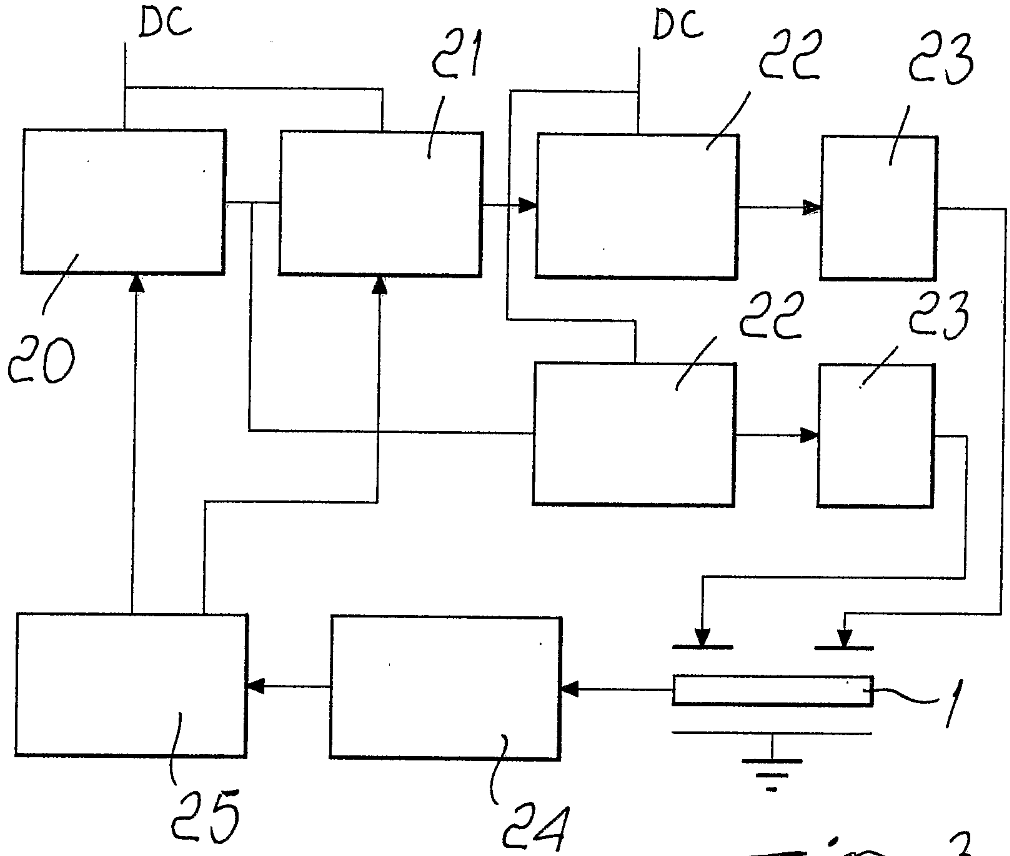

Fig. 3

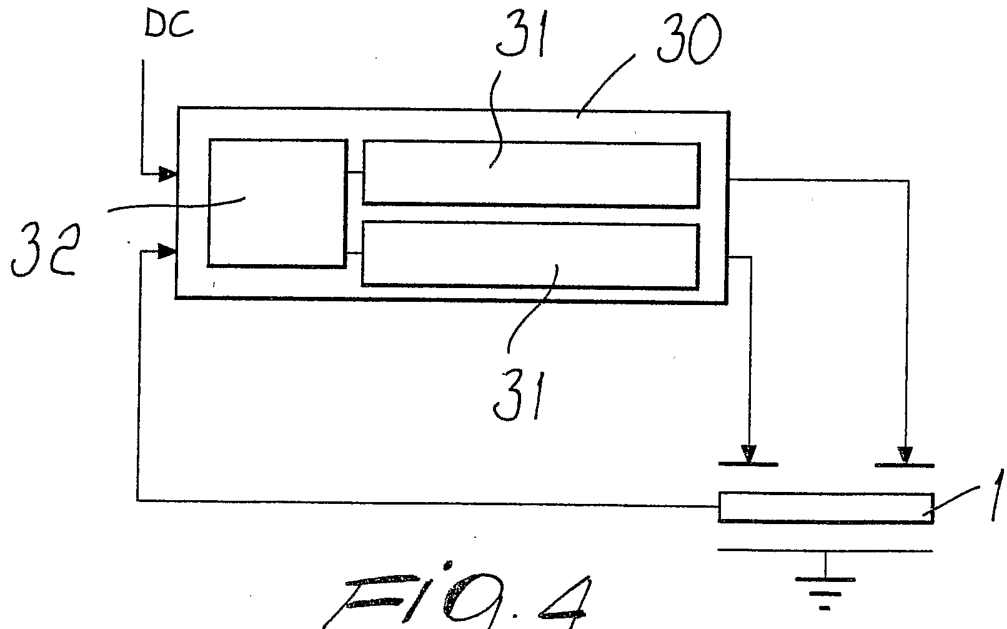

Fig. 4

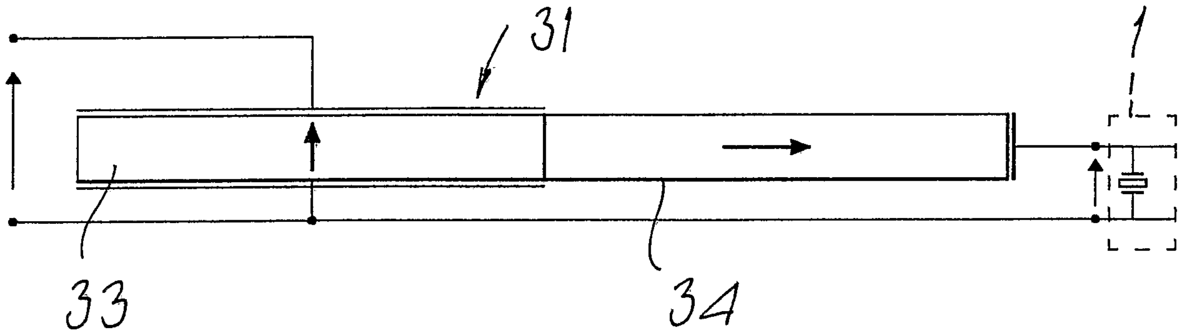

Fig. 5

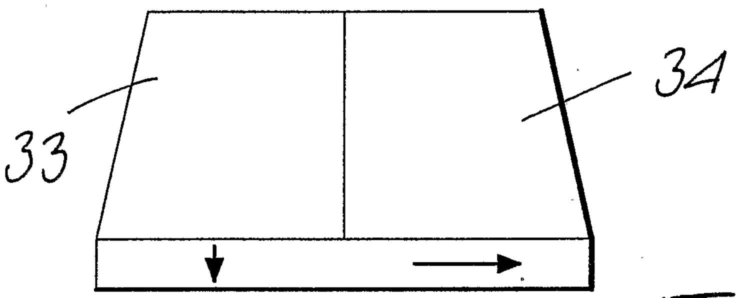

Fig. 6

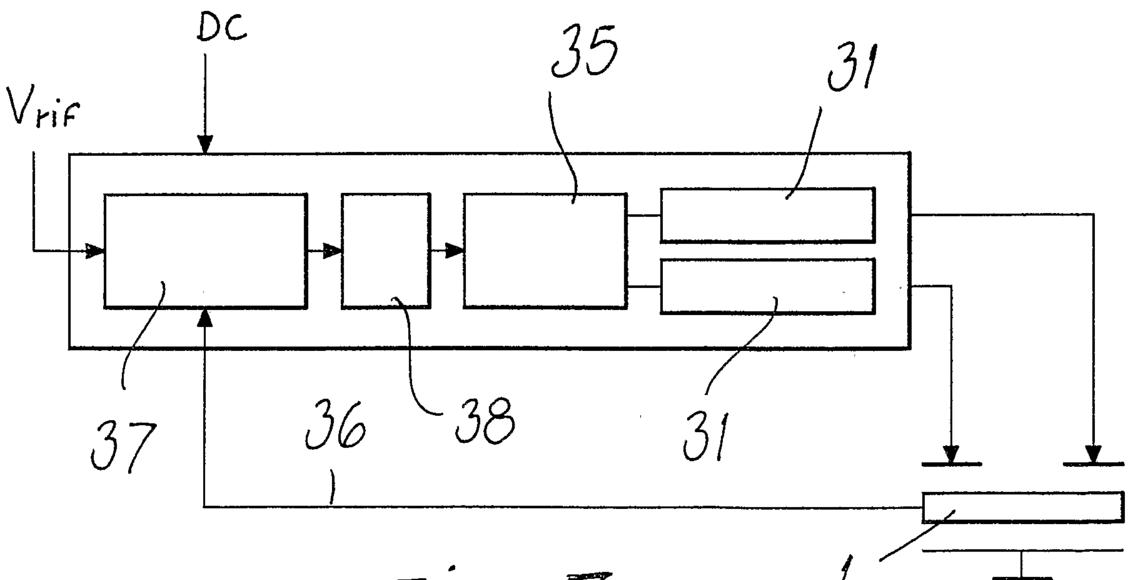

Fig. 7