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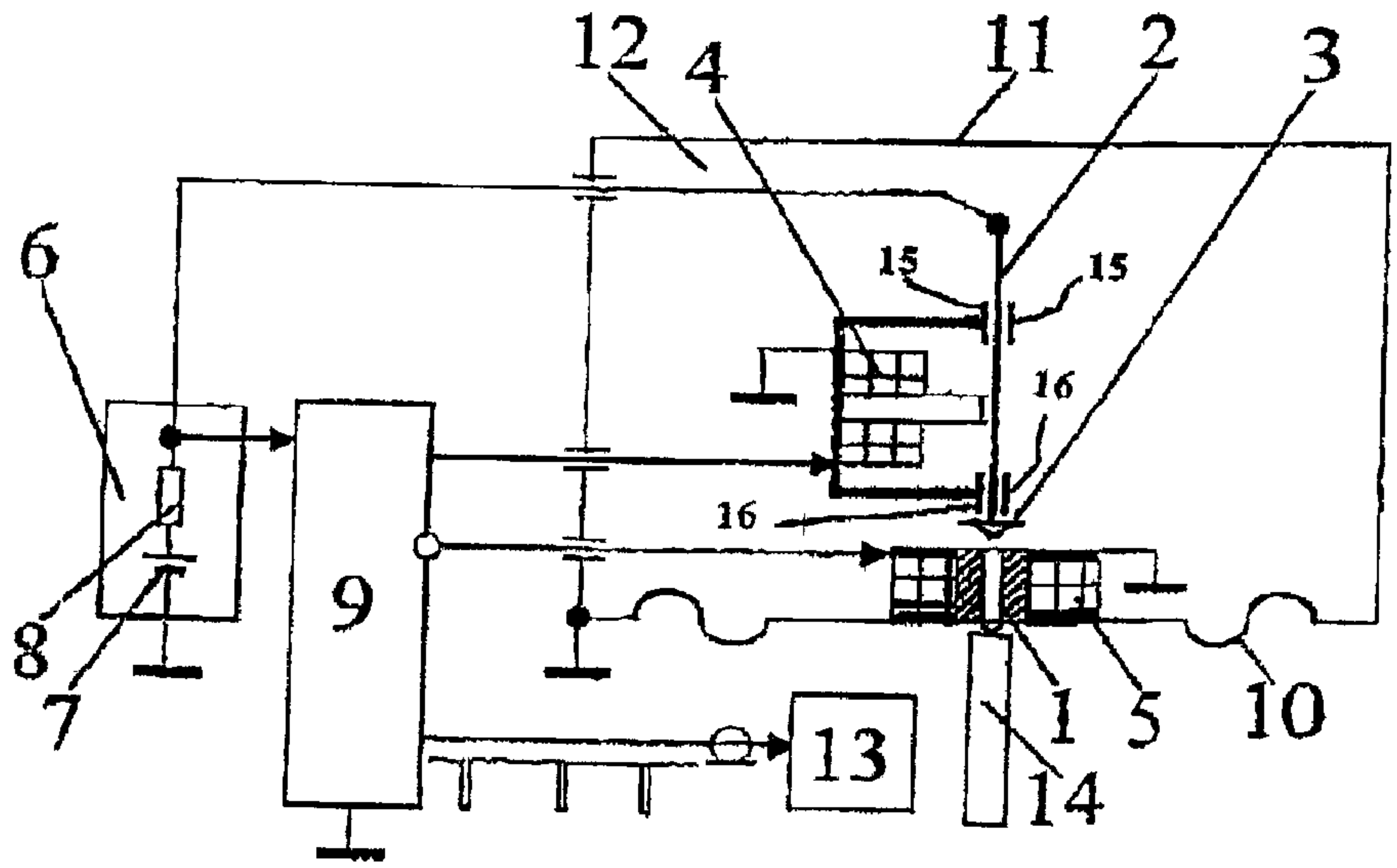
(54) Title: MICROMOVEMENT MEASURING DEVICE AND METHOD OF MOVEMENT PROCESS CONVERSION TO AN ELECTRIC SIGNAL



(57) Abrégé/Abstract:
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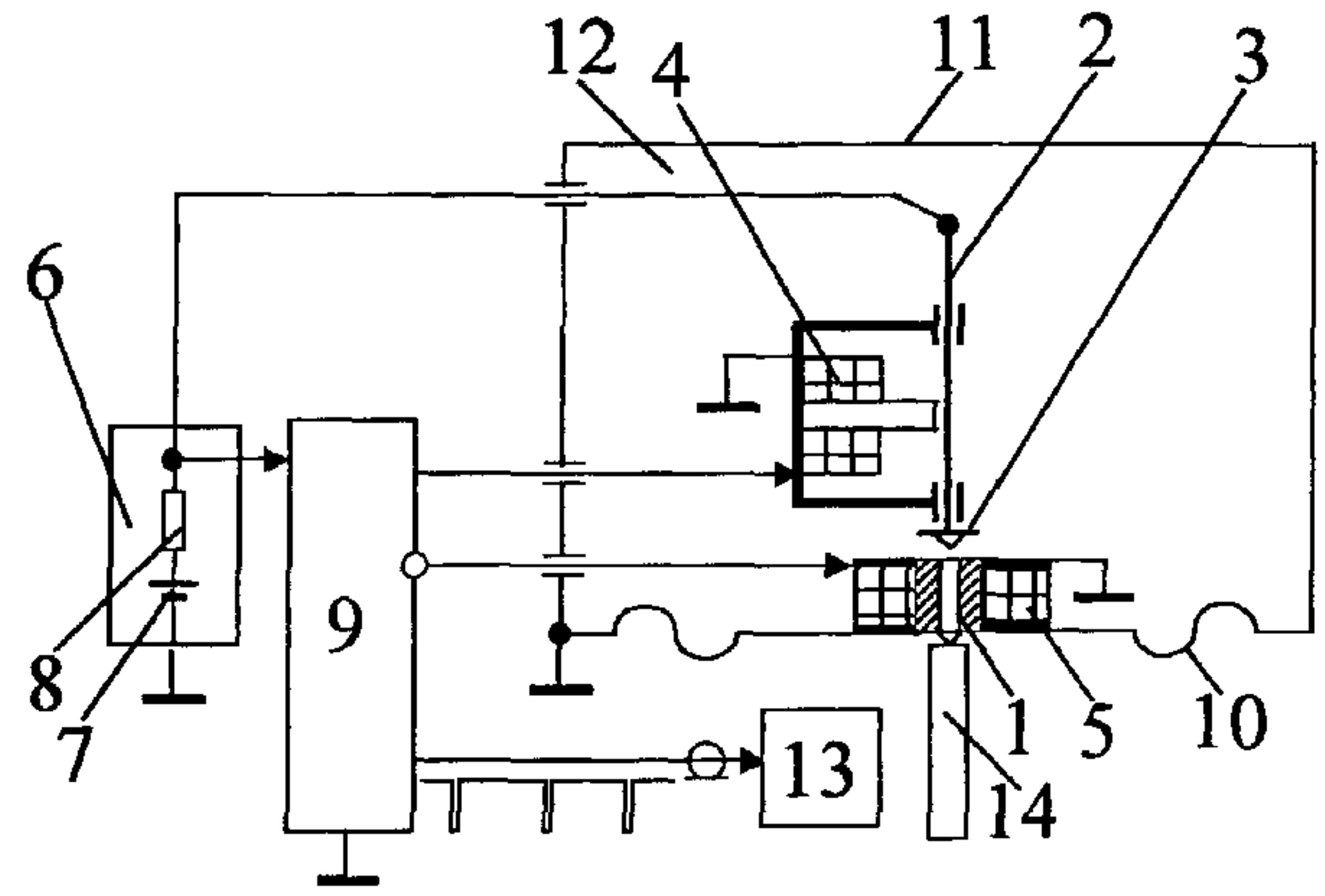
(54) **Title:** MICROMOVEMENT MEASURING DEVICE AND METHOD OF MOVEMENT PROCESS CONVERSION TO AN ELECTRIC SIGNAL



(57) **Abstract:** The invention relates to the field of micromovement measuring and can be used for recording creeping and dynamic infraprocesses both of natural and artificial origin, for example, seismic processes or infrasound and gravitation waves. The object of the invention is to raise sensitivity of measuring in a wide dynamic range. The micromovement measuring device consists of measuring element (2) and sensitive element (1), membrane (10), signal conditioner (6), the output of which is connected to the winding og the fixing electromagnet (4). According to the invention, the device is additionally provided with the pulling electromagnet (5), which interacts with the measuring element (2), the winding og the pulling electromagnet being connected to the second inverse output of the signal conditioner (6). The pulling electromagnet shall be preferably located on the membrane (10) that increases the range of the measurable movements. In addition, the prevention of formation of the oxide or similar films at the working surfaces of the measuring (2) and sensitive (1) elements can be provided by their hermetic sealing in space formed by the device housing (11) and the membrane (10). The method of converting movement to electric signal is embodied in said device; this method consists in the fact that the electronic field emission current is taken as a characteristic according to which quantization is made. The proposed approach permits the movements to be recorded in the range of Angstrom units.

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MICROMOVEMENT MEASURING DEVICE AND METHOD OF MOVEMENT PROCESS CONVERSION TO AN ELECTRIC SIGNAL

The invention relates to the field of instrumentation, in particular, to measurement of micromovement and can be used for measuring, detecting and recording creeping and dynamic infraprocesses in nature, engineering and bionics, for example, for recording baric, thermal and hygrometric tendencies in meteorology, for recording creeping of the engineering structures, for testing leakproofness of small and large installations, in security systems, as well as for recording seismic, infrasound and gravitation waves. In bionics, the proposed device can be used as a part of tactile sensitivity, in bionic prostheses, bionic robots and zoo-robots.

To embody the above problems the measuring systems shall have maximum possible sensitivity (up to Angstrom units – Å) wide dynamic range and low sluggishness.

At present the highest sensitivity and wide dynamic range are provided by X-ray interferometers which embody spectrometric method of measuring. However, in the cases that lie outside metrology and investigations of crystal structure of the materials, their use does not find application owing to high sluggishness of the sensitive element, cumbersome apparatus design, complexity and high price.

Capacitance and inductive transducers have found wide application for measuring small movements. The limitation of their use is attributed to the fact that raising of the sensitivity of these transducers necessarily leads to narrowing of the dynamic range because of non-linearity of analog measuring characteristic. The section of particular portion of characteristic determines the dynamic range of the transducer (see for example, A.M. Туричин et al., "Электрические измерения неэлектрических величин", Л., "Энергия», 1975, pp.96-98).

Devices are known for measuring small movements that are based on artificial quantization of linear or angular movements by means of the distributed quantizing measuring elements (grids). As and example an increment encoder can be referred (K. Бриндли "Измерительные преобразователи: Справочное пособие", Translated from English. M., Энергоатомиздат, 1991, pp.62-63). Resolution of such type of encoder depends on the number of sensitive segments on the disk or band of the transducer, which determines mechanical limit of their sensitivity (no more than 0.01 micron).

The closest decision accepted as prototype is a micromovement sensor according to the USSR author's certificate No. 947 626, in which a method of measuring with using natural quantization effects was embodied. This device contains the transducer consisting of sensitive and measuring elements that converts the monotonic movements to pulse delta modulated electric signal. The sensitive element is fixed on the elastic membrane and interacts with a source of the micromovement (tested object), whereas spring-loaded mobile measuring element is a core of the electromagnet that fixes the measuring element in the position of contact with the sensitive element, when applying exciting current from the signal conditioner.

In the initial state the electric contact between sensitive and measuring elements creates closed electric circuit through which electric current flows; as a result, at the output of the signal conditioner appears exciting current that energizes the electromagnet and fixes the measuring element. When the tested object shifts, the sensitive element moves in the direction of breaking the contact between measuring and sensitive elements due to the action of measuring force created by the membrane. At the instant of breaking electric circuit the signal conditioner removes the exciting current from the winding of fixing electromagnet, and the measuring element under the action of the spring moves in the direction to the sensitive element until the contact between the sensitive and measuring elements is recovered and the measuring element is fixed in a new position.

The breaking and recovering of the contact forms the leading and trailing edges of the pulse signal that is equivalent to single movement of the measuring element, thus performing conversion of monotonic movement to pulse delta modulated electric signal by the use of natural quantization effect-hysteresis. The quantized movement is characterized by the value determined by two states of the electric contact (closed-broken).

The disadvantage of the known device is determined by the fact that at the instant of the contact between measuring and sensitive elements is set up, the force of the spring pressure moving the measuring elements is transmitted through the sensitive element onto the tested object, in which elastic microdeformation arises as a result of this contact force. The value of this microdeformation restricts the ultimate attainable sensitivity to the level of 0.2 micron. In addition, when electric contact is broken, an electroerosive bridge arises. This bridge current is detected by the signal conditioner as the presence of the contact, and the measuring pulse arises only after bridge breaking. Thus, the length of every micromovement of the measuring element cannot be less than the length of the electroerosive bridge and the value of arisen microdeformation taken together. Additionally, occurrence of the electroerosive bridge leads to the geometry violation of the contact elements that causes instability of their metrological characteristics.

The object of the proposed invention is to raise sensitivity of the device in a wide dynamic range by eliminating elastic microdeformations in dimensional circuit "transducer-object" and also to eliminate the electroerosive processes at working surfaces of the sensitive and measuring elements.

The object is achieved in the following way: the device for measuring micromovements contains the measuring and sensitive elements, membrane, signal conditioner, the output of which is connected to the winding of the fixing electromagnet, is additionally provided with the measuring element; the winding of the pulling electromagnet is connected to the second output of the signal conditioner that is inverse to the output connected to the winding of the fixing electromagnet.

Maximum dynamic range of micromovements to be measured can be provided by locating of the pulling electromagnet on the membrane connected to the sensitive element.

To exclude formation of oxide, water and other similar films at the working surfaces of the sensitive and measuring elements the claimed device is located in hermetic housing filled with inert medium.

The method of converting micromovements to electrical signal which is used in the present device excludes the formation of the electroerosive bridges in running clearance. This method lies in the fact that fixation of the measuring element is provided when the current of the field electronic emission arises between the measuring and sensitive elements, and the measuring element is released and shifted when the current of the field electronic emission is interrupted.

The principal diagram of the device is given in Figure.

The micromovement measuring device consists of a sensitive element 1, a measuring element 2 with a washer 3, and a fixing electromagnet 4. The measuring element 2 is capable of longitudinal movement between guides 15, 16 due to movement of the washer 3 away from or toward the sensitive element 1 in response to attractive magnetic forces applied to the washer 3 from either of the fixing electromagnet 4 or from the pulling electromagnet 5, respectively. The measuring element 2 is electrically connected to a signal conditioner 6 which includes an operating voltage source 7 and a current limiter 8, such that a voltage from the voltage source 7 is applied to the measuring element 2. Accordingly, the voltage differential across a gap between the measuring element 2 and the sensitive element 1 creates a field electronic emission current therebetween. A first output of the signal conditioner 6 is connected to the input of an amplifier 9, the direct output of which is connected to the winding of the fixing electromagnet 4, and an inverse output of which is connected to the winding of a pulling electromagnet 5. The pulling electromagnet 5 is located on a membrane 10, which together with a housing 11 forms a hermetic chamber 12 filled with protective inert medium. The output pulse signal comes from the amplifier 9 to an indicator 13. The conditional tested object 14 is connected to the sensitive element 1.

The device operates in the following way.

When the sensitive element 1 moves under the action of an elastic force of the membrane 10 followed by the tested object 14, an interruption of the field electronic emission current between the sensitive element 1 and the measuring element 2 occurs in the measuring circuit formed by the operating voltage source 7, the current limiter 8, the measuring element 2, the sensitive element 1, the membrane 10, and the ground. At the instant of the interruption of the field electronic emission current, the amplifier 9 controlled by the signal conditioner 6 discontinues an exciting current from the fixing electromagnet 4, and simultaneously applies an exciting current onto the winding of the pulling electromagnet 5. Under the action of attractive force from the pulling electromagnet 5 which is applied to the washer 3, the measuring element 2 freed from fixing force of the fixing electromagnet 4 to move in the direction to the sensitive element 1. This movement occurs till the electronic field emission current arises between the sensitive element 1 and the measuring element 2 in the above measuring circuit; that is, at the distance that is determined by the expression:

$$\lambda = U/E,$$

where λ is the value of the clearance between the measuring element 2 and sensitive element 1 at which the electronic field emission current arises; U is the chosen value of the operating voltage; and E is the intensity of electronic field emission equal to 10^9 Volt/meter.

At the chosen value of the operating voltage 0.05Volt the distance at which the current electronic field emission will occur is equal to 5.10^{-11} m or 0.5 Å.

At the instant when the emission current arises, the electromagnets 4 and 5 controlled by the amplifier 9 change their state: the exciting current is discontinued from being applied to the pulling electromagnet 5, and the measuring element 2 is fixed in a new position because of its attraction to the fixing electromagnet 4. The proceeding movement of the sensitive element 1 under elastic force of the membrane 10 followed by the moving tested object 14 leads to the interruption of the electronic field emission current at the distance between the measuring element 2 and the sensitive element 1 equal to $\lambda + \Delta$, where Δ is a value of hysteresis of electronic field emission, and the process is repeated in above-described sequence.

Every cycle recurring at the movement of the sensitive element 1 forms both leading and training edges of pulses that are equivalent to a single movement of the measuring element 2. The occurring pulses come from the amplifier 9 to the indicator 13 and are recorded.

The "value" of one pulse is determined by the combined hysteresis, which is dependent on the sluggishness of the measuring element 2 and reaction time of the pulling electromagnet 5 and the fixing electromagnet 4 and on the value of hysteresis of electronic field emission as well.

The location of the pulling electromagnet 5 on the membrane 10 provides functioning of the device at all movement length of the measuring 2 that is determined by allowed deflection of the membrane 10. It is explained by the fact that while moving the sensitive element 1 magnetic running clearance is kept constant in this case.

The location of the measuring element 2 and the sensitive element 1 in the hermetic chamber 12 confirmed by the housing 11 and the membrane 10 and filled by inert medium excludes the formation at the working surfaces of the oxide and other films that prevent occurrence of electronic field emission current.

The proposed decision has the following features:

- conversion of the monotonic micromovements to delta modulated pulse electric signal occurs without arising microdeformations in dimensional circuit "transducer-object". As it is evident from the foregoing, it is provided in the following way: the transfer of the measuring circuit from one stable state into another occurs in the absence of the direct electric contact between the measuring element 2 and the sensitive element 1 and, therefore, without occurring elastic deformation;
- the sensitivity of the measuring circuit is set by the chosen value of operating voltage.

The whole complex of the claimed features and the method provides conversion of micromovements to delta modulated pulse electrical signal with the device sensitivity in a range of units of angstroms.

Example of embodiment

The measurement of the movement of the metallic bar was made in accordance with the procedure determined by the GOST 8.491-83 (GOST-All-Union State Standard of the former USSR). This permitted to exclude some disturbances connected with non-uniform movement in case of using of a screw pair (according to the procedure of GOST). The measuring spring head (opticator) of the 01П Type was used as a reference apparatus. When extending the bar by 1 micron (that is recorded by the opticator), the signal conditioner of the claimed transducer generated a sequence of $2 \cdot 10^4$ pulses recorded by the Ч3-34A frequency meter (when using gold surfaces of the measuring and sensitive elements and when the value of operating voltage in measuring circuit is equal to 0.05Volt). It means the one pulse corresponds to $1/2 \cdot 10^{-10}$ metre, i.e. 0.5 Å – the value defining the sensitivity of the claimed device.

The proposed device may be embodied in two-channel version, should the need arise, to measure sign-variable movements.

CLAIMS:

1. The micromovement measuring device for measuring movement of a test object, the micromovement measuring device comprising:

a signal conditioner having a first output;

an amplifier connected to the first output of the signal conditioner for generating a direct output and an inverse output therefrom;

a sensitive element;

a measuring element for receiving a voltage from the signal conditioner to create a field electronic emission current across a gap between the measuring element and the sensitive element;

a membrane substantially adjacent to the test object, with the membrane being connected to the sensitive element, wherein movement of the membrane caused by movement of the test object is transferred to movement of the sensitive element;

a fixing electromagnet, the winding of which is connected to the direct output of the amplifier; and

a pulling electromagnet interacting with the sensitive element, wherein the winding of the pulling electromagnet is connected to the inverse output of the amplifier;

wherein the signal conditioner controls the pulling electromagnet and the fixing electromagnet when the movement of the test object affects the field electronic emission current, and generates measurement signals for measuring the movement of the test object.

2. The micromovement measuring device of claim 1, wherein the pulling electromagnet is attached to the membrane connected to the sensitive element.

3. The micromovement measuring device of claim 1 or 2, wherein the measuring element and the sensitive element are located in an hermetic housing having a plurality of housing walls filled with an inert medium, and one of the housing walls is formed by the membrane connected to the sensitive element.

4. A micromovement measuring device comprising:

a signal conditioner having first and second outputs;

a measuring element;

a sensitive element;

a fixing electromagnet, the winding of which is connected to the first output of the signal conditioner; and

a pulling electromagnet for pulling the measuring element toward the sensitive element, wherein the winding of the pulling electromagnet is connected to the second output of the signal conditioner, and wherein the signal conditioner is switchable between a first state in which the fixing electromagnet is released and the pulling electromagnet energized, and a second state in which the measuring element is held by the fixing electromagnet while the sensitive element is being moved away from the measuring element.

5. A micromovement measuring device according to claim 4, wherein the pulling electromagnet is located on a membrane connected to the sensitive element.

6. A micromovement measuring device according to claim 5, wherein the sensitive element and the measuring element have a gap therebetween, the gap being located in an hermetic housing having a plurality of housing walls filled with an inert medium, one of the housing walls being formed by the membrane.

7. A micromovement measuring device comprising:

(a) a sensitive element, the movement of which is to be measured;
(b) a measuring element, moveable with respect to the sensitive element and separated therefrom by a gap, across which a voltage is applied;
(c) a fixing device for controllably fixing the position of the measuring element;
(d) a pulling device for controllably pulling the measuring element toward the sensitive element;
(e) a signal conditioner for controlling the fixing and pulling devices and being switchable between a first state in which the fixing device is released and the pulling device energized, and a second state in which the measuring element is secured by the fixing device;

wherein, in the first state, the measuring device approaches the sensitive element until a field emission current arises across the gap, the signal conditioner then switching to the second state; and

wherein, in the second state, the sensitive element is moved away from the measuring element until the field emission current is interrupted, the signal conditioner then switching back to the first state.

8. A micromovement measuring device according to claim 7 wherein the sensitive element is secured to a flexible membrane.

9. A micromovement measuring device according to any of claims 4 to 8 wherein the sensitive element and the pulling device are both secured to a flexible membrane.

10. A micromovement measuring device according to claim 8 in which the gap defined between the measuring element and the sensitive element is located within an hermetic housing having a plurality of housing walls, one of the housing walls being defined by the membrane.

11. A micromovement measuring device according to claim 8 in which the membrane forms part of an electric circuit which also includes the sensitive element and the measuring element.

12. A micromovement measuring device according claim any of claims 8 to 11 in which the gap defined between the measuring element and the sensitive element is located within an hermetic housing having a plurality of housing walls, one of the housing walls being defined by the membrane.

13. A micromovement measuring device according to any of claims 8 to 12 in which the membrane forms part of an electric circuit which also includes the sensitive element and the measuring element.

14. A micromovement measuring device according to claim 7 in which the signal conditioner includes a voltage source, for applying the voltage across the gap, and an amplifier for controlling the fixing and pulling devices.

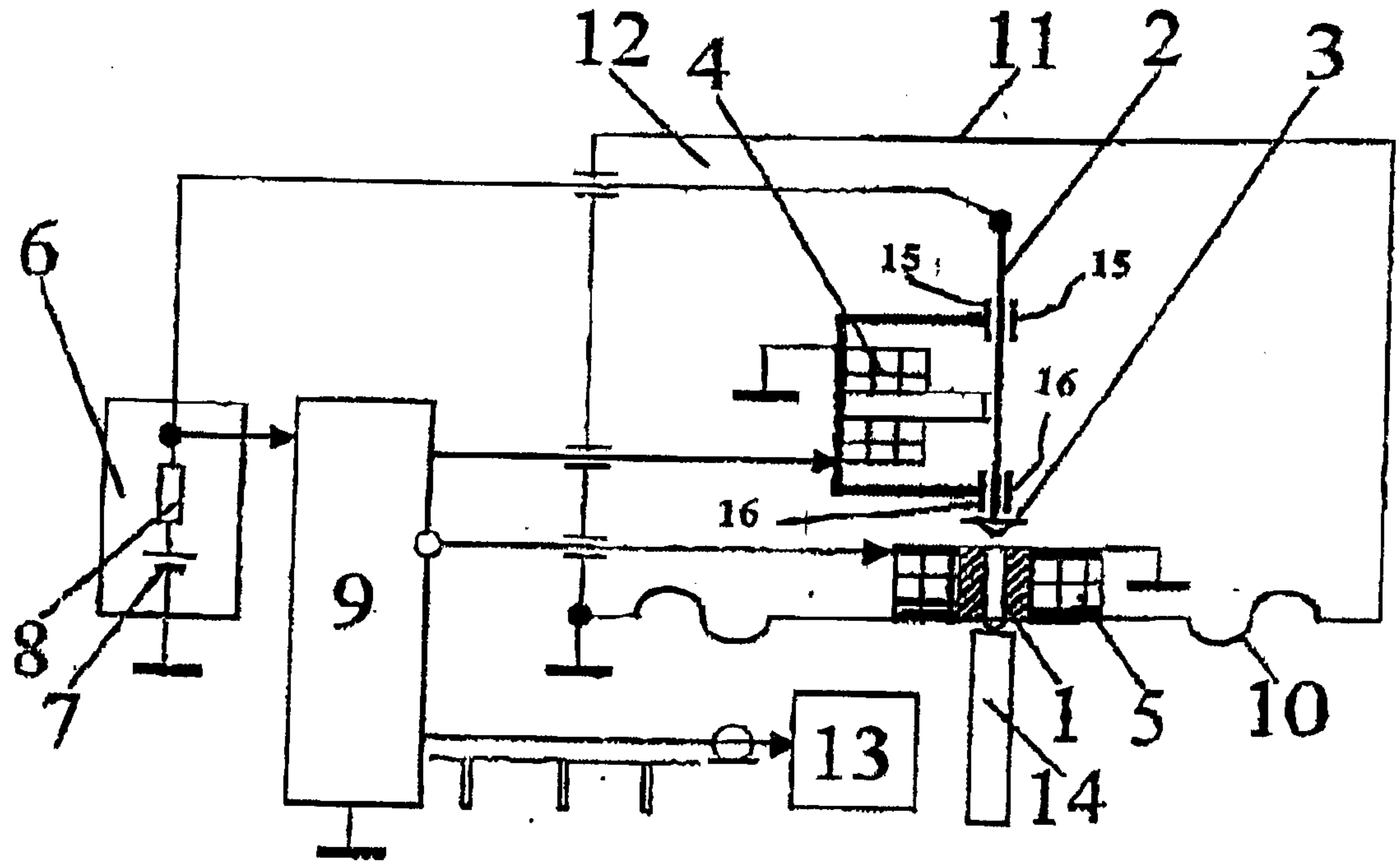
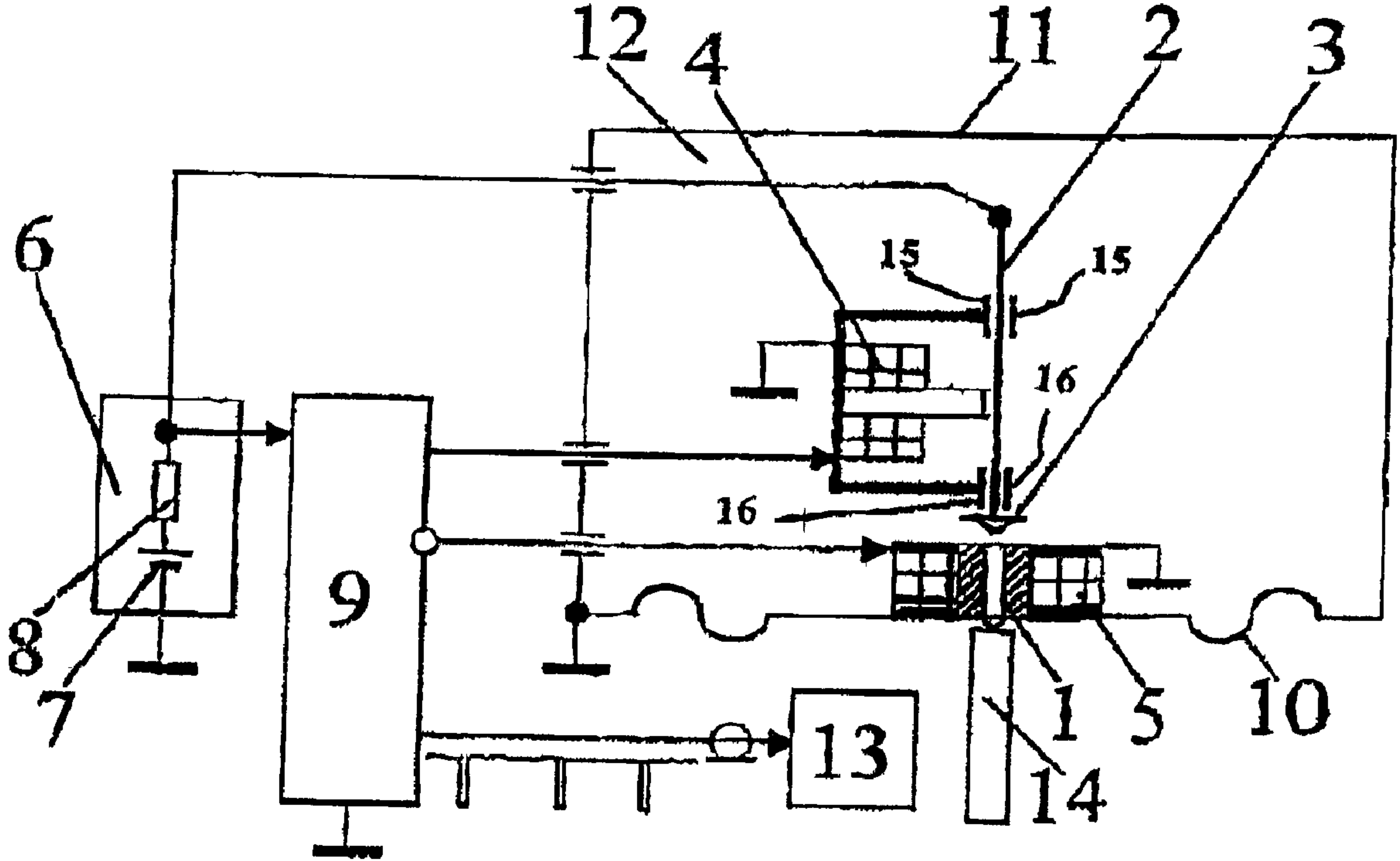


FIG. 1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