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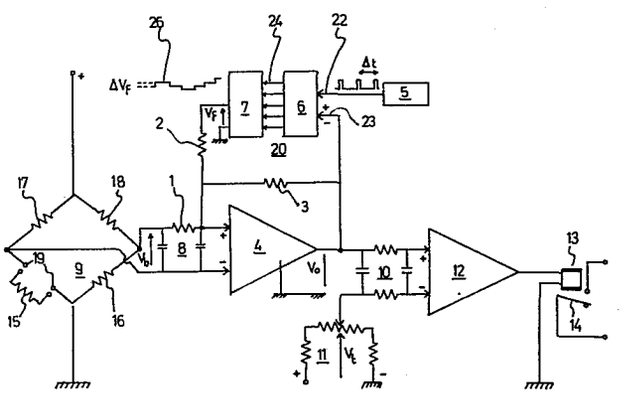
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(54) Temperature monitoring device.

(57) Device for warning against the passing of a temperature value, e.g. in case of fire, overheating or undercooling. The temperature sensor is a wire (15), made of shape memory alloy, which can be laid in a tortuous shape along the room to be watched, and this wire is coupled to a circuit responsive to the rate of change of the electrical resistance of the wire above a threshold value to generate the warning signal. This circuit includes a Wheatstone bridge (9) connected to an amplifier (4) with an integrating feedback circuit (20) with limited integrating speed. The amplifier (4) is further connected to a comparator (12) having its output connected to an alarm relay (13).



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TEMPERATURE MONITORING DEVICE

The invention relates to a device for warning against the passing of a temperature value, e.g. an undercooling or overheating warning device such as a fire alarm system or a warning system for electrical cable overheating. In certain cases it is necessary to monitor large rooms or long lengths, such as in electric cable, or rooms of tortuous shape, such as the cavities between the parts of a combustion engine, which cannot be monitored with the help of one single temperature sensor.

It is the object of the present invention to provide a device having one sensor capable of monitoring such regions.

According to the invention there is provided a temperature monitoring device comprising a wire made of shape memory alloy, and a circuit having an input coupled to said wire and being responsive to a rate of change of the electrical resistance of the wire above a threshold value to generate a warning indication of the passing of a temperature value.

Shape memory alloys have the property that their resistivity slowly rises with rising temperature, but only outside their transformation temperature range, because within that range these alloys show a steep resistivity fall over about 10 to 20 % of the value. When a measuring circuit registers a rate of resistance drop above a threshold value, this means then that the wire temperature is rising through the transformation temperature range. Conversely, the resistivity falls slowly with falling temperature outside the transformation temperature range of a shape memory allow, but shows a similar steep rise inside that range. And when a measuring circuit registers rate of resistance rise above a threshold value, this means then that

the wire temperature is falling down through the transformation temperature range.

Such range can be chosen by taking the right wire alloy and the measuring circuit consequently will produce a warning signal which can be sent to any warning instrument, such as a generator of a visual or audible alarm signal, via the necessary amplifiers and/or relays, or to a computer, etc. It is however not necessary that the whole wire be heated to obtain an alarm signal. When only one tenth is heated, the sudden rise or fall will be of 1 to 2 %, and this can also be measured for producing the alarm signal. The wire can then be laid in tunnels along lengths of 10 to 50 metres, or along electrical cables to avoid overheating, or along the parts of a combustion or other motor in tortuous forms to monitor the temperature of the different parts, and so on. As soon as a part of the wire is then overheated, the alarm signal is produced.

The invention will now be further explained with reference to the appended drawings, given by way of example, in which :

Figure 1 shows the variation of resistivity of a given shape memory alloy.

Figure 2 shows a ternary composition diagram of Cu-Al-Zn alloys with the dependence of transformation temperature range on the composition.

Figure 3 shows an example of an overheating warning signal generator according to the invention.

Shape memory alloys are alloys having a martensitic phase at lower temperature and an austenitic phase at higher temperature, with a narrow transformation range between both, of which the breadth ranges in the order of 20 to 70°C and capable of producing a shape memory effect. For these alloys it was earlier discovered that, when they are deformed in the martensitic state from an original shape to another shape, and then

heated into their austenitic state, they recover either partially or totally their original shape during the transformation from martensite to austenite, and when they are cooled down again to the martensitic state, they take again the said other shape. This shape memory effect was discovered in the 1950's with Cu-Zn, Au-Cd and Ni-Ti alloys, and others were found in later years, such as ternary and quaternary alloys with Fe, Ni, Cr, Co or Mn. Such alloys were also described in British patents Nos. 1.315.652 and 1.346.046. Ternary alloys of Cu-Al-Zn are also known with β-structure in the austenitic state, of which the content (as shown in the ternary diagram), lies inside the trapezoidal form determined by the four corners, expressed in percentages by weight of Cu, Al and Zn respectively, A (64 ; 1 ; 35), B (74 ; 5 ; 21), C (87.5 ; 12.5 ; 0) and D (86 ; 14 ; 0). Also quaternary alloys of Cu-Al-Zn are known, being the ternary alloy of the compositions above, to which a small amount in the range between 0 and 2.5 % of some other material is added, such as cobalt or nickel or boron. Such ternary or quaternary alloys are called hereinafter "shape memory Cu-Al-Zn alloys".

Figure 1 shows, as an example, the variation as a function of temperature of the resistivity of a wire, of 1.5 mm diameter and 0.738 metre length, made of an alloy No. 1222 comprising 70.3 % Cu, 24.9 % Zn, 4.4 % Al and 0.4 % Co. When the alloy is heated up from room temperature, the resistivity rises from about 0.088 micro-Ohm-metre ($\mu\Omega m$) to about 0.090 $\mu\Omega m$. The starting temperature of the transformation to Austenite (A_s-temperature) lies for this alloy at about 30°C. When the temperature further rises through the transformation range towards the finishing temperature of the transformation to Austenite (A_f-temperature), which is about 80°C in this case, then the resistivity falls rapidly down towards a minimum of about 0.076 $\mu\Omega m$, and then rises again as the A_f-temperature, the

temperature where the transformation to Austenite is finished, is passed. When cooling down from Austenite, the alloy undergoes the inverse transformation to Martensite with a certain hysteresis, starting the transformation at the M_s-temperature (in this case at about 58°C) and finishing the transformation at the M_f-temperature as shown in the drawing. The transformation range of a shape memory alloy is the range between M_f and A_f, in this case between about 20 and about 80°C, the range having in this example a breadth of about 60°C.

In dependence of the application, the temperature level of the transformation can be chosen by adapting the alloy composition as indicated in Fig.2. For instance, for the ternary Cu-Al-Zn alloys, the M_s-temperature as a function of the composition is given in Figure 2. When Ni is added, it must be taken into account that the latter slightly increases the M_s-temperature, whereas adding Co or B have less influence on this diagram. In general, for overheating warning systems, an alloy will be chosen having an M_s-temperature between 30°C and 150°C.

In dependence on the use, the wire of shape memory alloy will in general have a diameter in the range between 0.1 mm and 2.5 mm, although not exclusively. The wire need not necessarily have a circular cross-section, but the latter may be rectangular or have any other shape, including the shape between two concentric circles, the "wire" having then a tubular form. By "wire" is consequently meant any elongated form with a length dimension of larger order of magnitude than the largest dimension perpendicular thereto, e.g. at least 100 times larger. The length of the wire will depend on the order of magnitude of length of the zones where overheating or undercooling is expected, the percentage of resistance drop or rise produced by the transformation of martensite or austenite, or austenite to martensite, of the alloy, and on the sensitivity to which the measuring apparatus has been set. For instance, for a fire alarm

in a tunnel, a fire overheating length of about 3 metres can be expected, and for an alloy of e.g. 12 % resistivity-drop, and an instrument set to register a 1 % resistivity-drop in 15 seconds of transition through the transformation range, a length of 36 metres can be taken. In applications where the whole of the length is overheated, there is in principle no limit of length. In general, for applications where the overheating zone is of the order of a few centimetres, as in monitoring motor parts or short-circuits in electrical conductors, the usual wire length will range in the order of 0.5 to 3 metres. In fire alarm applications, where the overheating zone is of the order of 0.3 to about 3 metres, wire lengths in the range between 3 and 50 metres can be used, and if the circuit can be preset with a sufficiently low threshold value, but still without responding to slower drift signals, the length can even go up to 100 metres.

Figure 3 shows an example of an overheating warning signal generator. A circuit responsive to an excessive rate of resistance drop comprises an operational amplifier 4 and a wheatstone bridge 9. The output voltage V_o of the amplifier 4 is fed back to the input, on one hand via feedback resistance 3, on the other hand via a feedback circuit 20 comprising a clock-pulse generator 5, an up-down counter 6, and a digital-to-analog converter 7, delivering an output signal V_f through feedback resistance 2 back to the input of amplifier 4. This input is also connected via a noise filter 8, comprising an input resistance 1, to the Wheatstone bridge 9 which delivers an output voltage V_b towards the amplifier.

The Wheatstone bridge comprises the wire 15 made of shape memory alloy of which the extremities are connected to terminals 19 and forming a first arm of the bridge. An adjacent arm comprises preferably, but not necessarily, a monitor wire 16 of the same alloy and same dimensions, exposed to the same

ambient temperature variations as wire 15, but not exposed to the same overheating risks. The two other arms are formed by two equal resistances 17 and 18. A d.c.-supply voltage is applied between resistances 17 and 18, whereas the point between resistances 15 and 16 is connected to earth. This produces at the output of the bridge an imbalance voltage V_b.

The output of the operational amplifier 4 is connected, via noise filter 10, to a second operational amplifier 12. The positive input terminal of this amplifier is connected to the output of amplifier 4 and receives the output voltage V_o of the latter, whereas the negative terminal is connected to a potentiometer circuit 11 for adjusting the positive threshold voltage V_t . The output of amplifier 12 is connected to a polarized relay 13 which closes contact 14 when the input voltage of amplifier 12 is positive, i.e. when V_o is larger than V_t.

The clock-pulse generator 5 of the feedback circuit of the first amplifier 4 delivers pulses every Δt seconds, e.g. every 15 seconds. The output of this generator is connected to a first input 22 of the up-down counter 6 whereas the other input 23 of this counter is connected to the output of amplifier 4. The counter 6 is so arranged as to count up when the voltage V_o at input 23 is positive and down when that voltage is negative. The outputs 24 of the different binary stages of the counter are connected to the input of the digital-to analog converter 7, which is arranged to produce an output voltage V_f , which is proportional to, but has the inverse sign of the digital content of counter 6. The resulting output voltage wave form 26 is a cumulation of voltage step functions of unitary voltage value ΔV_f , i.e. the amount that the output voltage V_f of the converter 7 rises with each decrease of input value of one binary unit.

In operation, when the alloy wire 15 does not change resistance value, the output voltage V_o will be zero, and relay contact 14 remains in the open position shown in the drawing. If not zero in fact, but for instance positive, the counter 6 will accept the clock pulses and increase its binary content in response to which the converter 7 will stepwise lower its output voltage V_f, whereby, via feedback resistance 2, the input voltage of amplifier 4 comes down until output voltage V_o becomes zero.

When there is a slow variation of resistance value 15, due e.g. to slow temperature changes, or when there is slow drift of the circuit constants, then the feedback circuit will work in the same way to compensate the changes. The changes cause the output voltage to slowly deviate from zero, whereby the feedback voltage V_f is changed so that the output voltage V_o becomes zero again.

There is however a rate of voltage change $(\frac{dV_b}{dt})$ at the output of Wheatstone bridge 9, for which the feedback circuit 20 is no longer rapid enough to produce complete compensation, and when this rate of voltage change is positive, which occurs in the case of a rapid resistance fall of resistance 15, then the output voltage V_o begins to rise until it reaches threshold voltage V_t and amplifier 12 will actuate relay 13 and close relay contact 14.

When Δt is the time between two clock-pulses and ΔV_f is the correction step given by one pulse to the feedback voltage V_f, then the output voltage rise ΔV_o during one pulse period Δt is given by

$$\Delta V_o = \frac{R_3}{R_1} \cdot \frac{dV_b}{dt} \cdot \Delta t - \frac{R_3}{R_2} \cdot \Delta V_f \qquad (1)$$

in which R_1, R_2 and R_3 are the values of resistances 1, 2 and 3 respectively.

Assuming that the rate of voltage change $(dV_b/dt)_{limit}$ is the lowest limit to actuate relay 13, this means then that the circuit will need the whole duration that V_b changes from its value at rest to its maximum value, over a total difference ΔV_b, until V_o becomes equal to V_t, and that relay 14 is actuated just at the end of the change of the output of the bridge. Consequently, and assuming a linear change of V_b as a function of time, the number of pulses during this whole duration will be equal to

$$\frac{\Delta V_b}{\Delta t\,(dV_b/dt)_{limit}} \qquad (2)$$

and after such number of pulses the output voltage V_o will be given by multiplication of expression (1) by expression (2) and this is equal to the threshold value V_t or

$$\frac{R_3}{R_1}\Delta V_b - \frac{R_3}{R_2}\,\frac{\Delta V_f}{\Delta t}\,\Delta V_b \times \frac{1}{(dV_b/dt)_{limit}} = V_t$$

$$\text{or } (dV_b/dt)_{limit} = \frac{R_3}{R_2}\,\frac{\Delta V}{\Delta t}\,\Delta V_b \times 1/\left(\frac{R_3}{R_1}\Delta V - V_t\right) \qquad (3)$$

Consequently, all positive changes of V_b above a certain rate, determined by a number of constants of the circuit which can be preset, will cause the relay 13 to be actuated, and below that rate they will not. As a rapid resistance fall of wire 15 causes a rapid positive change of V_b in the bridge circuit of Figure 3, this bridge with amplifier circuit can consequently be called a circuit responsive to a rate of resistance drop above a threshold value, which can be calculated from expression (3) and which depends on circuit constants.

When analysing the function of the operational amplifier 4 above, it is clear that in fact it is an operational amplifier with an input resistance and with an integrating counter in the feedback circuit. An integration in the feedback circuit makes, as well known, the amplifier to work as a differentiator. But because of the limited integrating speed of the

integrating counter, which is equal to $\Delta V_f / \Delta t$ volts per second, the amplifier acts as a differentiator until a threshold value is reached. It is clear that in the feedback circuit other equivalents can be designed for an integrator with limited integrating speed, by analog or digital means.

It is also clear that a circuit responsive to a rate of resistance drop above a threshold value need not necessarily be designed in the form of an operational amplifier with an integrator with limited integrating speed in the feedback circuit. It is also possible to design such circuit in the form of a differentiator, e.g. an operational amplifier with capacitive input impedance and resistive feedback, the output of the differentiator being connected to one input of a threshold circuit, which is adapted to deliver an output signal when the input voltage at that input exceeds a preset voltage, applied at a second input of said threshold circuit.

The input voltage V_b for the operational amplifier need not necessarily be taken from a Wheatstone bridge circuit. The simplest way is to feed with d.c. voltage a series connection of the alloy wire and another resistance, and take the input voltage V_b over the extremities of the wire. But other passive networks may be used, supplied with a supply voltage, where the voltage V_b is taken from two points in the network, adapted to deliver a voltage V_b changing in response to the resistance change of said wire, such as across the diagonal points of a Wheatstone bridge. This is consequently meant by "coupling" the wire to the input of the circuit.

As an example for the use of the circuit of Figure 3, a fire-alarm system can be designed, in which a round wire 15 is used of 7.6 m length and 2 mm diameter of an alloy 1287 (71.2 % Cu ; 23.6 % Zn ; 4.6 % Al and 0.4 % Co) ; the resistance 15 falls from about 260 milli-ohms to about 225 milli-ohms between about 60°C and about 90°C. When the bridge

is supplied with a voltage of 1.5 volts and resistances 17 and 18 are of 10 Ohms each, then the total voltage deviation ΔV_b of the bridge, when only one tenth is heated, is of the order of 0.525 millivolts. With a threshold value V_t of zero and $R_1 = R_2$ expression (3) gives for instance

$$\left(\frac{dV_b}{dt}\right)_{limit} = \frac{\Delta V_f}{\Delta t}$$

If it is wished that the circuit produces an alarm above the limit of the 0.525 millivolts rise in 2 minutes for a fire, and each step ΔV_f of the digital-to-analog converter is of the order of 0.05 millivolts, then the frequency of the clock-pulse generator can be set at about one pulse per 12 seconds. It is however clear that other circuit constants can be taken, which will need other presettings.

Although this circuit example of Figure 3 relates to an overheating signal generator, it is clear that an analogous circuit can be designed for generating an undercooling alarm signal.

CLAIMS :

1. A temperature monitoring device comprising a wire made of shape memory alloy, and a circuit having an input coupled to said wire and being responsive to a rate of change of the electrical resistance of the wire above a threshold value to generate a warning indication of the passing of a temperature value.

2. A device according to claim 1, in which said circuit responsive to a rate of change of resistance above a threshold value comprises a passive electrical network in which said wire is included, a differentiator circuit of which the input is connected to two points of said network adapted to deliver a voltage changing in response to a change of resistance of said wire, and a threshold circuit of which the input is connected to the output of said differentiator.

3. A device according to claim 1, in which said circuit responsive to a rate of change of resistance above a threshold value comprises a passive electrical network in which said wire is included, an amplifier of which the input is connected by resistive means to two points of said network adapted to deliver a voltage changing in response to a resistance change of said wire, the output of said amplifier being fed back towards the input via an integrator having a limited integrating speed.

4. A device according to claim 3, in which said integrator with limited integrating speed comprises a generator of clock pulses, an up-down counter for counting the clock pulses at one input up or down according as the voltage at a second input is positive or negative, and a digital-to-analog

converter of which the input is connected to the output of said counter.

5. A device according to any one of the preceding claims, in which said shape memory alloy is a Cu-Al-Zn shape memory alloy.

6. A device for monitoring overheating according to any one of the preceding claims, in which said circuit responsive to a rate of change of resistance is responsive to a rate of drop of resistance.

7. A device according to any one of the preceding claims, in which said alloy has an M_s temperature in the range between 30°C and 150°C.

8. A device according to any one of the preceding claims, in which the wire has a circular cross-section of a diameter in the range between 0.1 mm and 3 mm and a length in the range from 0.5 to 100 metres.

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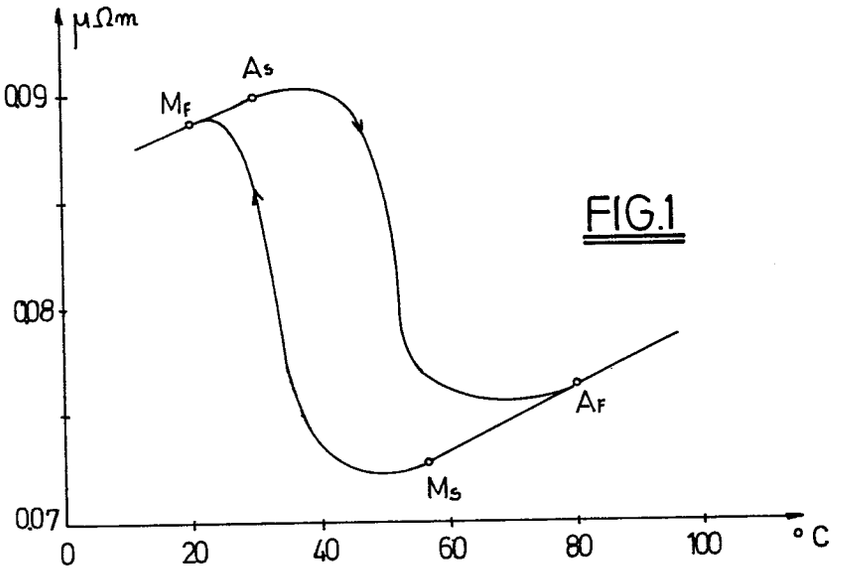


FIG.1

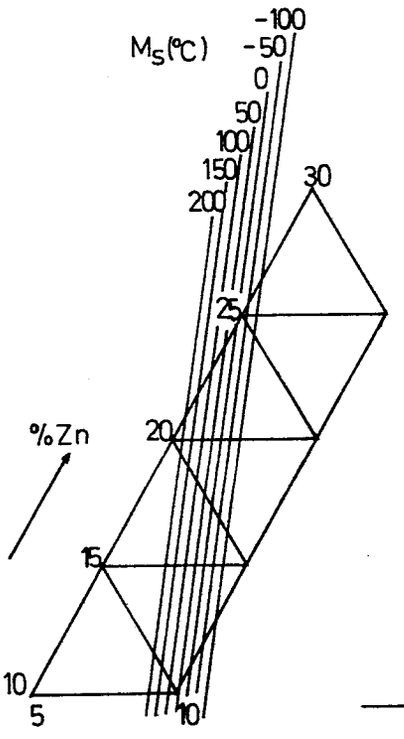


FIG.2

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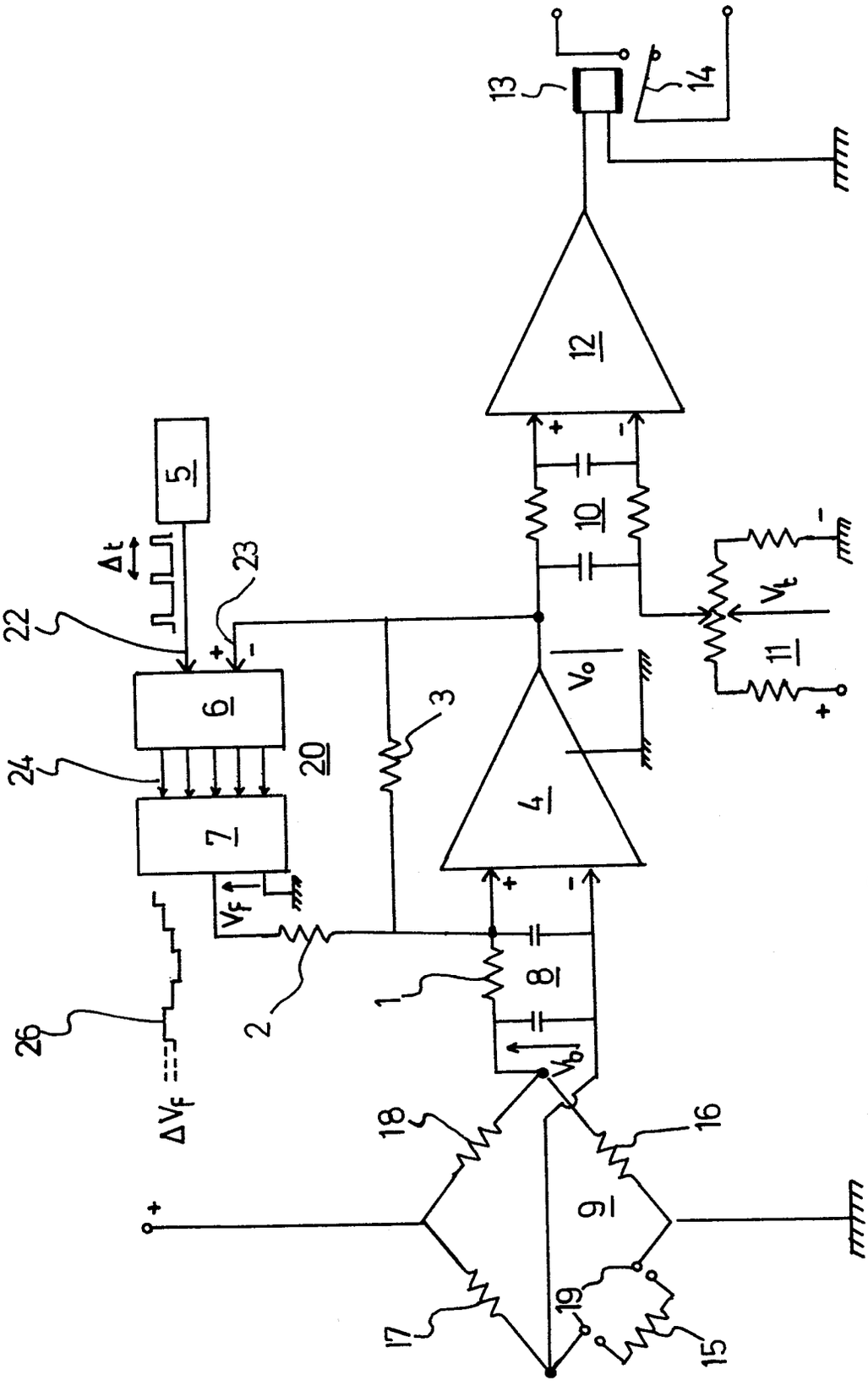


FIG.3

European Patent Office

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Application number

EP 84 20 0654

EUROPEAN SEARCH REPORT

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)
A	US-A-3 516 082 (COOPER) * Claims *	1	G 08 B 17/06
A	GB-A-1 589 870 (E.M.I.) * Claims 1,2 *	1	
A	US-A-3 044 050 (ABROMAITIS) * Claim 1 *	1,2	
A	US-A-3 643 245 (JONES et al.) * Claims 1-7 *	1,2,6	
A	FR-A-1 230 121 (LEMAIRE) * Abstract *	1,2	
A	US-A-4 356 478 (MUGGLI et al.) * Claims 1-6 *	1	TECHNICAL FIELDS SEARCHED (Int. Cl. ³) G 08 B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	29-08-1984	REEKMANS M.V.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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E : earlier patent document, but published on, or after the filing date
D : document cited in the application
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