DEVICE FOR ELECTROMAGNETICALLY MAIN-TAINING OSCILLATING MOVEMENT

Peter Döme, Geneva, Switzerland, assignor to Société Suisse pour l'Industrie Horlogère S.A., Geneva, Switzerland, a firm of Switzerland

Filed June 3, 1960, Ser. No. 33,744
Claims priority, application Switzerland June 10, 1959 8 Claims. (Cl. 318—132)

The present invention relates to a device for electromagnetically maintaining the oscillating movement of the regulating member of a timepiece, comprising a magnetic flux generator and a coil, one of which two members moves integrally with the regulating member, while the other is fixed, so that the interaction of the magnetic flux and of the current flowing through the coil sets up an electromagnetic force which is intended to sustain the oscillating movement of the said regulating member.

Two types of electromagnetic sustaining devices are at present known, namely devices comprising electric contacts and transistor devices.

Contact devices, despite certain advantages which they have, for example in regard to the impulse form of the current, all have the disadvantages which are inherent in the use of contacts. This is why transistor devices are preferred. However, the latter have fairly considerable disadvantages which are due essentially to the transistor itself.

Thus, as is known, it is necessary to provide two coils, one for driving the regulating member and the other for controlling the transistor, the said coils being connected in the collector-emitter circuit and in the base-emitter circuit respectively. On the other hand, by reason of the magnitude of the inverse current of a germanium transistor, and thus the extent to which it effects the consumption of energy, it is preferable to use a silicon transistor, the inverse current of which is much weaker. Now, the latter requires that the control voltage applied to the base should exceed 0.4 to 0.5 volt, which voltage must be entirely supplied by the control coil, since a bias which would increase the consumption due to the quiescent current cannot be envisaged. In addition, having regard to the exponential characteristic of the emitter-base diode, the amplification factor of such a transistor is much lower with weak signals and varies with temperature.

Consequently, the weaker the control signal, and therefore the smaller the amplitude of the oscillations of the regulating member, the smaller is the current in the driving coil, so that the regulating member will not be driven below a certain angle of oscillation. This angle is generally much larger than the angle above which the balance wheel of a mechanical watch no longer oscillates. In order to obviate these disadvantages, use is made of a plurality of transistors, which obviously does not simplify the device in question.

It is proposed by the invention to eliminate the aforesaid disadvantages in devices of both types, utilizing bistable elements having special characteristics.

As is known, special bistable elements have been developed in recent years, these elements having a negative resistance for certain values of the feed voltage (see for example Swiss Patent No. 335,360).

The device according to the invention is distinguished from the known devices by the fact that the said coil is connected in series in an electric circuit comprising a direct-voltage source and a bistable element having a negative resistance for certain values of the voltage source, the said coil being so designed that the subtraction of the voltage induced therein as a result of the variations of the flux passing through the coil from the voltage of the said source produces the change-over of the said element from its stable state determined by its maximum resistance to its stable state determined by its minimum resistance, while the addition of the voltage induced in the coil to that of the source produces the change-over of the element from its stable state determined by its maximum resistance to its stable state determined by its minimum resistance.

One constructional form and one modified form of the device of the invention are diagrammatically illustrated by way of example in the accompanying drawings.

FIGURE 1 is a plan view with the electric circuit diagram.

FIGURE 2 is an electric circuit diagram of a modified form.

FIGURE 3 shows a number of electrical characteristics of the device.

FIGURE 4 shows a variant of a detail of the device. The electromagnetic sustaining device comprises a regulating member which in the present instance consists of a circular balance 1 connected by a cross-member 2 to a staff 3, of which the two ends are intended to pivot in bearings (not shown) provided in the fixed part of a time-piece. A spiral spring 4 attached at one end to the staff 3 and at the other end to the said fixed part is intended to maintain the balance 1 in oscillatory movement. Fixedly mounted on a flattened portion J of the periphery of the balance 1, for example by adhesive, are three permanent magnets 7, 8 and 9. These three magnets are polarised along an axis parallel to the staff 3 of the balance, in such manner that the direction of the flux passing through the center magnet 8 is opposite to the direction of the fluxes passing through the two outer magnets 7 and 9.

A pancake coil 10 is disposed in a plane perpendicular to the staff 3 and therefore parallel to the balance 1, in such manner that the magnets 7 to 9 pass across the coil during the oscillating movement of the balance. The coil 10 is fixed and is so disposed that its position in relation to the magnets 7 to 9 is that illustrated in FIGURE 1 when the balance 1 is in its position of rest or of equilibrium, in which position the action of the spring 4 is zero.

The coil 10 is connected at one end of the negative pole of a direct-voltage source 11 and at the other end to the collector C of a transistor T of p-n-p type, of which the emitter E is earthed. As will be seen, the transistor T is a special transistor, which comprises in addition to a base contact b1, which is negatively biased by a direct-voltage source 12, a second base contact b2 situated between the emitter E and a groove 13 surrounding the latter, and positively biased by means of a source 14 through a variable high resistance 15. The said transistor T is capable of operating as a bistable element by virtue of its Vc-E characteristic (collector voltage-collector current) which comprises a negative part, namely a part with which the current Ic is inversely proportional to the voltage Vc. This means that the transistor T has a negative resistance for certain values of the voltage applied to the collector C.

Such a transistor, of which the Vc-E characteristic is represented in FIGURE 3 by ODF, is described in detail in Swiss Patent No. 335,368. Owing to the groove 13, it is possible to vary by means of the space charge zone due to the potential difference between the collector C and the base B, the resistance of that part of the transistor T which electrically connects the base b1 to the emitter-base junction and to the contact b2, and consequently the current flowing between the emitter E and the contact b1, due to the bias of the latter. This current will therefore become substantially zero when the space charge zone extends as far as the groove 13.

The operation of the transistor T will be clearly apparent from the description hereinafter given of the operation of the whole device according to the invention. However, before this description is given, it is necessary to give a
number of particulars regarding the conditions which must be satisfied in the design of various component parts of the device. The voltage of the source 11, which is applied to the collector C through the charge resistance formed by the coil 10, must be at least higher than the voltage necessary in order that the space charge zone may be defined as far as the groove 13, and that the current path between the contact b1 on the one hand and the contact b2 and the emitter E on the other hand may be interrupted. The control current of the transistor will thus be interrupted and the transistor will be blocked.

It is to be noted that there is no consumption of electrical energy when the transistor T is in the blocked condition.

On the other hand, the resistance of the coil 10 must be made such that the V-I characteristic of the latter, represented by the line GH in FIGURE 3, has substantially the same slope as the negative part DF of the characteristic of the transistor. Finally, the magnetic and electric circuits formed by the magnets 7 to 9 and by the coil 10 respectively must be so designed that, for a very small angle of oscillation of the balance, the voltage induced in the coil is higher than the voltage difference existing between the voltage of the source 11 and the voltage of the collector at which the said base charge zones reach the groove 13.

It is further to be noted that the slope of the negative part DF of the characteristic curve of the transistor is obtained by choosing an appropriate voltage for the source 12. The positive bias of the contact b2 permits of varying the value of the voltage which must be applied to the collector in order that the space charge zone may be extended as far as the groove 13.

The device described and illustrated operates in the following manner:

It will be assumed that the balance is in one of its two extreme positions, for example in the extreme right-hand position, in relation to the reader of the drawing. Since the flux of the magnets 7 to 9 does not pass through the coil 10, no voltage is induced therein. The voltage applied to the collector C is therefore equal to the voltage of the source 11 and the transistor T is blocked. The electrical operating point is therefore situated at G (FIGURE 3). Under the action of the spring 4, the balance will carry out a return movement towards its position as shown in the drawing, i.e. towards the coil 10. When the magnetic flux passes through the latter, the variation of the said flux, produced by the passage of the magnets mounted on the balance, will cause an alternating voltage V1 to be induced in the coil (see FIGURE 3). The voltage V1 is therefore superimposed on the voltage of the source 11. Thus, since the positive half-cycle of the voltage V1 is superimposed on the negative voltage of the source, it will produce a reduction of the voltage Vc applied to the collector and the movement of the operating point will be from F to E. When the voltage V1 reaches a value below that corresponding to the point F, the transistor will change over into its other stable state, that is, into the conductive state, and the operating point will be located on the part OD of the characteristic. The oscillogram of the current Iφ, represented by the right-hand part of FIGURE 3, shows the variation of the current I as a function of a positive half-cycle of the voltage V1 (at the bottom of FIGURE 3). The current Iφ will therefore flow through the coil 10, which will result in the creation of a Laplace force, resulting from the presence of a conductor having a current flowing therethrough in a magnetic field, which force will drive the balance in the direction of its movement.

The change of polarity of the induced voltage V1, and thus the change from the positive half-cycle to the negative half-cycle, will result in the superimposition of the induced negative voltage V1 on the voltage of the source 11 and consequently in an increase of the negative voltage Vc applied to the collector. As soon as the voltage Voc exceeds the value corresponding to the point D, the transistor will change over at the point L and will again be blocked. At the end of the negative half-cycle, the operating point will again be at G.

A further positive half-cycle will cause the transistor to change over into the conductive state and will thus result in a further impulse of the current I in the coil, and so on.

Owing to the form of the magnetic circuits 7 to 9 and of the electric circuit 10 (described in detail in Swiss patent application No. 59,880), the voltage V1 induced in the latter at a half-oscillation of the balance is composed of two G to E or from F2 to D (see FIGURE 3) is sufficient for the change-over of the transistor. The transistor may therefore consist of silicon. On the other hand, since the space charge zone is not sensitive to temperature variations, the sensitivity of the transistor is not influenced by the latter. This thermal stability also makes it possible for the distance GF (FIGURE 3) to be made very small in relation to the induced voltage V1 and consequently to reduce to a minimum the angle of oscillation of the balance for which the electromagnetic maintenance would not take place.

Finally, the current Iφ, namely the current passing through the driving coil, does not depend upon the amplification factor of the transistor T, that is, upon the value of the control signal. Owing to the internal negative feedback of the transistor, substantially the same form of driving current impulse is obtained both for very weak signals and for stronger signals.

It will be obvious that the present invention is not limited to the constructional form of the device polyethylene before described and illustrated. Thus, in a modification, the transistor T could be replaced by any other bistable element having a negative resistance for certain feed voltage values. For example, the same transistor as
that illustrated in FIGURE 1 could be employed, but without the contact b2. It is obvious that in this case the value of the voltage of the collector at which the emitter-base current is substantially zero would be chosen once for all.

The transistor T could be replaced by a transistor comprising, instead of the groove 13, other means for varying within wide limits, by means of the space charge zone, the potential difference between the collector and the base, the electrical resistance of that part of the base by which the contact b1 is electrically connected to the emitter-base junction.

FIGURE 2 shows a circuit diagram of a modified form of the device according to the invention, wherein the transistor T is replaced by another bistable element. As will be seen, the latter consists of a conventional transistor T1, of which the collector C1 is connected through the coil 10 to the negative pole of the source 11, the positive pole of the latter being earthed, as also is the emitter E1 of the transistor T1. The contact b1 of the transistor T1 is connected to a contact 10, which is provided at one of the ends of the fieldistor F1, the contact 21 provided at the other end of the fieldistor F1 being connected to the negative pole of the source 12. The zone Z of the fieldistor F1 is connected to the collector C1.

It will readily be seen that the emitter-base current intended to control the transistor is itself controlled by a variable resistance formed of the fieldistor F1, this resistance being controlled by the voltage applied to the collector C1, with which it increases and vice versa. It is obvious that the voltage of the source 11 must be at least higher than the voltage necessary in order that the space charge zone of the zone Z may extend as far as the surface of the fieldistor so as to interrupt the current flowing therein.

It is obvious that the magnetic flux generator consisting of the magnets 7 to 9 in the example given could be of any other form. The same is the case with regard to the arrangement of the magnetic members and of the coil. The latter could be movable and the magnetic members fixed.

Finally, the transistors T and T1 could be of the n-p-n type, which would obviously involve a reversal of the polarities of the various voltage sources.

What I claim is:

3. A timepiece comprising an oscillating regulating member and a device for electromagnetically maintaining the oscillating movement of said regulating member, said device comprising a magnetic flux generator and a coil, one of which two members moves integrally with said regulating member, while the other is stationary, so that the interaction of the magnetic flux and of the current flowing through said coil sets up an electromagnetic force maintaining movement of said regulating member of the timepiece, an electric circuit in which said coil is connected in series, a direct-voltage source in said circuit, and a transistor in said circuit and including a collector, an emitter, a base and a base contact, said base having a space charge zone varying with differences in potential of said collector and base to vary the electrical resistance between the base contact and the emitter, said transistor constituting a bistable element having a negative resistance for certain values of the voltage of the said source, and said transistor being so designed that subtraction of the voltage induced in said coil as a result of variations of the flux passing through the coil from the voltage of the said source produces change-over of said element from its stable state determined by its maximum resistance to its stable state determined by its minimum resistance, while addition of the voltage induced in the coil to that of the source produces the change-over of the element from its stable state determined by its minimum resistance to its stable state determined by its maximum resistance.

4. A timepiece as claimed in claim 3, in which the base of said transistor comprises a second contact situated between said groove and said emitter and biased by means of a voltage of opposite sign to the voltage by which the said first contact is biased, the biasing of said second contact being effected through a variable resistance, so that the value of the potential difference between the collector and the base at which said space charge zone must reach the said groove may be varied.

5. A timepiece comprising an oscillating regulating member and a device for electromagnetically maintaining the oscillating movement of said regulating member, said device comprising a magnetic flux generator and a coil, one of which two members moves integrally with said regulating member, while the other is stationary, so that the interaction of the magnetic flux and of the current flowing through said coil sets up an electromagnetic force maintaining movement of said regulating
member of the timepiece, an electric circuit in which said coil is connected in series, a direct-voltage source in said circuit, and a transistor in said circuit having a collector and a base, a fieldistor through which said base of the transistor is biased, said fieldistor being controlled by the voltage applied to the collector of said transistor in such manner that resistance of the fieldistor increases with resistance of the transistor and vice versa, said transistor constituting a bistable element having a negative resistance for certain values of the voltage of the said source, said transistor and fieldistor being so designed that the subtraction of the voltage induced in said coil as a result of variations of the flux passing through the coil from the voltage of the said source produces change-over of said bistable means from its stable state determined by its minimum resistance, while addition of the voltage induced in the coil to that of the source produces change-over of said element from its stable state determined by its maximum resistance, while the addition of the voltage induced in the coil to that of the source produces change-over of said element from its stable state determined by its minimum resistance to its stable state determined by its maximum resistance.

6. In a timepiece comprising an oscillating regulating member and a device for electromagnetically maintaining the oscillating movement of said regulating member, said device comprising a magnetic flux generator and a coil, one of which two members moves integrally with the said regulating member, while the other is stationary, so that the interaction of the magnetic flux and of the current flowing through said coil sets up an electromagnetic force maintaining movement of said regulating member of the timepiece, an electric circuit in which said coil is connected in series, a direct-voltage source in said circuit, and bistable means in said circuit having a negative resistance for certain values of the voltage of said source, the voltage of said source being at least higher than the voltage at which the resistance of said bistable means reaches its maximum value, said bistable means being so designed that subtraction of the voltage induced in said coil as a result of variations of the flux passing through the coil from the voltage of said source produces change-over of said bistable means from its stable state determined by its maximum resistance, while addition of the voltage induced in the coil to that of the source produces change-over of said bistable means from its stable state determined by its minimum resistance to its stable state determined by its maximum resistance.

7. In a timepiece comprising an oscillating regulating member and a device for electromagnetically maintaining the oscillating movement of said regulating member, said device comprising three magnetic members supported by said regulating member, of which at least one is a permanent magnet, said three members being polarised along axes parallel to the axis of oscillation of the regulating member and disposed in such manner that the direction of the flux in the center member is opposite to that in the two outer members, and a stationary coil, of pancake form, disposed in a plane substantially perpendicular to said axis of oscillation, so that in the oscillating movement of the regulating member the three magnetic members pass close to the coil and, as a result of the variations of the flux passing therethrough, induce an alternating voltage in said coil, an electric circuit in which said coil is connected in series, a direct-voltage source in said circuit, and a bistable means for certain values of the voltage of said source, said bistable means being so designed that subtraction of the voltage induced in said coil as a result of variations of the flux passing through the coil from the voltage of said source produces change-over of said bistable means from its stable state determined by its minimum resistance, while addition of the voltage induced in the coil to that of the source produces change-over of said bistable means from its stable state determined by its maximum resistance to its stable state determined by its maximum resistance.

References Cited in the file of this patent

UNITED STATES PATENTS

<table>
<thead>
<tr>
<th>Patent Number</th>
<th>Inventor</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,713,132</td>
<td>Matthews</td>
<td>July 12, 1955</td>
</tr>
<tr>
<td>2,806,983</td>
<td>Hall</td>
<td>Sept. 17, 1957</td>
</tr>
<tr>
<td>2,831,114</td>
<td>Van Overbeek</td>
<td>Apr. 15, 1958</td>
</tr>
<tr>
<td>2,843,742</td>
<td>Ciwen</td>
<td>July 15, 1958</td>
</tr>
<tr>
<td>2,907,000</td>
<td>Lawrence</td>
<td>Sept. 29, 1959</td>
</tr>
<tr>
<td>2,907,940</td>
<td>Beyner</td>
<td>Oct. 6, 1959</td>
</tr>
<tr>
<td>2,909,732</td>
<td>Van Overbeek</td>
<td>Oct. 20, 1959</td>
</tr>
<tr>
<td>2,934,657</td>
<td>Rack</td>
<td>Apr. 26, 1960</td>
</tr>
<tr>
<td>2,962,643</td>
<td>Kwartiroff</td>
<td>Nov. 29, 1960</td>
</tr>
<tr>
<td>3,010,075</td>
<td>Eppstein</td>
<td>Nov. 21, 1961</td>
</tr>
</tbody>
</table>