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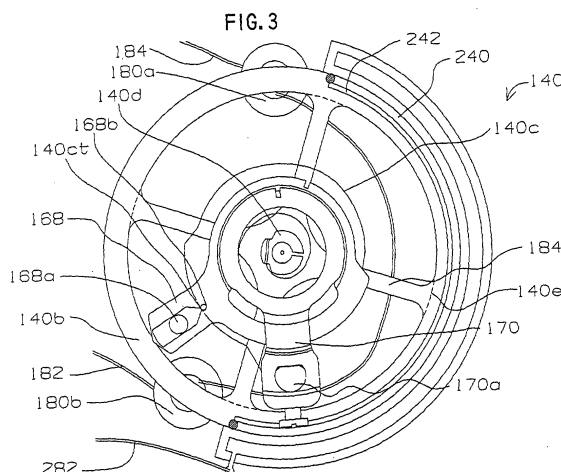
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(54) **MECHANICAL TIMEPIECE WITH ELECTROSTATIC CAPACITY TYPE DETECTING PART AND BRAKING PART**

(57) In a mechanical timepiece of the present invention, a movement 200 includes a barrel complete 120, a center wheel and pinion 124, a third wheel and pinion 126, a fourth wheel and pinion 128, a balance with hair-spring 140, an escape wheel and pinion 130 and a pallet fork 142. Coils 180a, 180b are attached on a front surface of a main plate in a manner facing a surface of a balance wheel 140b close to the main plate. A balance magnet 140e is attached on a surface of the balance wheel 140b close to the main plate in a manner facing a front surface of the main plate 102.

The mechanical timepiece of the invention has a detector section 276 provided to detect a swing angle of the balance with hairspring by detecting a change of electrostatic capacitance between a balance electrostatic capacitor electrode portion 240 and a detecting electrostatic capacitor electrode 250 varying corresponding to an operating state of the balance with hairspring 140, and a brake section 146 structured to apply such a force as suppressing rotation of the balance with hairspring 140 to the balance with hairspring 140 when a swing angle of the balance with hairspring 140 detected by the detector section 276 is greater than a previously-set set angle.



Description

[TECHNICAL FIELD]

[0001] The present invention relates to a mechanical timepiece having an electrostatic capacitor type detector section and brake section, which is structured to apply such a force as suppressing rotation of the balance with hairspring to a balance with hairspring based on a detection result of a swing angle of the balance with hairspring.

[BACKGROUND OF THE INVENTION]

[0002] In a conventional mechanical timepiece, as shown in Fig. 13 and Fig. 14, a mechanical-timepiece movement 1100 (mechanical body) has a main plate 1102 constituting a base plate for the movement. A hand setting stem 1110 is rotatably assembled in a hand-setting-stem guide hole 1102a of the main plate 1102. A dial 1104 (shown by the virtual line in Fig. 14) is attached to the movement 1100.

[0003] Generally, of the both sides of a main plate, the side having a dial is referred to as a "back side" of the movement and the opposite side to the side having the dial is referred to as a "front side" of the movement. A train wheel assembled on the "front side" of the movement is referred to as a "front train wheel" and the train wheel assembled on the "back side" of the movement is as a "back train wheel".

[0004] The hand setting stem 1110 is determined in axial position by a switch device including a setting lever 1190, a yoke 1192, a yoke spring 1194 and a back holder 1196. A winding pinion 1112 is rotatably provided on a guide axis portion of the hand setting stem 1110. When the hand setting stem 1110 is rotated in a state that the hand setting stem 1110 is set in a first hand-setting-stem position closest to an inward of the movement along a rotation axis direction (0 stage), the winding pinion 1112 rotates through rotation of a clutch wheel. A crown wheel 1114 rotates due to rotation of the winding pinion 1112. A ratchet wheel 1116 rotates due to rotation of the crown wheel 1114. By rotating the ratchet wheel 1116, a mainspring 1122 accommodated in a barrel complete 1120 is wound up. A center wheel and pinion 1124 rotates due to rotation of the barrel complete 1120. An escape wheel and pinion 1130 rotates through rotation of a fourth wheel and pinion 1128, a third wheel and pinion 1126, and the center wheel and pinion 1124. The barrel complete 1120, the center wheel and pinion 1124, the third wheel and pinion 1126, and the fourth wheel and pinion 1128 constitute a front train wheel.

[0005] An escapement/speed-control device for controlling rotation of the front train wheel includes a balance with hairspring 1140, the escape wheel and pinion 1130, and a pallet fork 1142. The balance with hairspring 1140 includes a balance stem 1140a, a balance wheel 1140b and a stud mainspring 1140c. Based on rotation

of the center wheel and pinion 1124, an hour pinion 1150 rotates simultaneously. A minute hand 1152 attached on the hour pinion 1150 indicates "minute". The hour pinion 1150 is provided with a slip mechanism for the center wheel and pinion 1124. Based on rotation of the hour pinion 1150, an hour wheel 1154 rotates through rotation of a minute wheel. An hour hand 1156 attached on the hour wheel 1154 indicates "hour".

[0006] The barrel complete 1120 is rotatably supported relative to the main plate 1102 and a barrel bridge 1160. The center wheel and pinion 1124, the third wheel and pinion 1126, the fourth wheel and pinion 1128 and the escape wheel and pinion 1130 are rotatably supported relative to the main plate 1102 and a train wheel bridge 1162. The pallet fork 1142 is rotatably supported relative to the main plate 1102 and a pallet fork bridge 1164. The balance with hairspring 1140 is rotatably supported relative to the main plate 1102 and a balance bridge 1166.

[0007] The stud mainspring 1140c is a thin leaf spring in a spiral (helical) form having a plurality of turns. The stud mainspring 1140c at an inner end is fixed to a stud ball 1140d fixed on the balance stem 1140a, and the stud mainspring 1140c at an outer end is fixed by screwing through a stud support 1170a attached to a stud bridge 1170 fixed on the balance bridge 1166.

[0008] A regulator 1168 is rotatably attached on the balance bridge 1166. A stud bridge 1168a and a stud rod 1168b are attached on the regulator 1168. The stud mainspring 1140c has a portion close to the outer end positioned between the stud bridge 1168a and the stud rod 1168b.

[0009] Generally, in the conventional representative mechanical timepiece, as shown in Fig. 15, the torque on the mainspring decreases while being rewound as the sustaining time elapses from a state the mainspring is fully wound (full winding state). For example, in the case of Fig. 15, the mainspring torque in the full winding state is about 27 g·cm, which becomes about 23 g·cm at a lapse of 20 hours from the full winding state and about 18 g·cm at a lapse of 40 hours from the full winding state.

[0010] Generally, in the conventional representative mechanical timepiece, as shown in Fig. 16, the decrease of mainspring torque also decreases a swing angle of the balance with hairspring. For example, in the case of Fig. 16, the swing angle of the balance with hairspring is approximately 240 to 270 degrees when the mainspring torque is 25 to 28 g·cm, while the swing angle of the balance with hairspring is approximately 180 to 240 degrees when the mainspring torque is 20 to 25 g·cm.

[0011] Referring to Fig. 17, there is shown a transition of an instantaneous watch error (numeral value indicative of timepiece accuracy) against a swing angle of a balance with hairspring in the conventional representative mechanical timepiece. Here, "instantaneous watch error" refers to "a value representative of fast or slow of

a mechanical timepiece at a lapse of one day on the assumption that the mechanical timepiece is allowed to stand while maintaining a state or environment of a swing angle of a balance with hairspring upon measuring a watch error". In the case of Fig. 17, the instantaneous watch error delays when the swing angle of the balance with hairspring is 240 degrees or greater or 200 degrees or smaller.

[0012] For example, in the conventional representative mechanical timepiece, as shown in Fig. 17, the instantaneous watch error is about 0 to 5 seconds per day (about 0 to 5 seconds fast per day) when the swing angle of the balance with hairspring is about 200 to 240 degrees while the instantaneous watch error becomes about -20 seconds per day (about 20 seconds slow per day) when the swing angle of the balance with hairspring is about 170 degrees.

[0013] Referring to Fig. 18, there is shown a transition of an instantaneous watch error and a lapse time upon rewinding the mainspring from a full winding state in the conventional representative mechanical timepiece. Here, in the conventional mechanical timepiece, the "watch error" indicative of timepiece advancement per day or timepiece delay per day is shown by an extreme thin line in Fig. 18, which is obtainable by integrating over 24 hours an instantaneous watch error against a lapse time of rewinding the mainspring from the full winding.

[0014] Generally, in the conventional mechanical timepiece, the instantaneous watch error slows down because the mainspring torque decreases and the balance-with-hairspring swing angle decreases as the sustaining time elapses with the mainspring being rewound from a full winding state. Due to this, in the conventional mechanical timepiece, the instantaneous watch error in a mainspring full winding state is previously put forward in expectation of timepiece delay after lapse of a sustaining time of 24 hours, thereby previously adjusting plus the "watch error" representative of timepiece advancement or delay per day.

[0015] For example, in the conventional representative mechanical timepiece, as shown by an extreme thin line in Fig. 18, the instantaneous watch error in a full winding state is about 3 seconds per day (3 seconds fast per day). However, when 20 hours elapse from the full winding state, the instantaneous watch error becomes about -3 seconds per day (about 3 seconds slow per day). When 24 hours elapse from the full winding state, the instantaneous watch error becomes about -8 seconds per day (about 8 seconds slow per day). When 30 hours elapse from the full winding state, the instantaneous watch error becomes about -16 seconds per day (about 16 seconds slow per day).

[0016] Incidentally, as a conventional balance-with-hairspring swing angle adjusting device there is a disclosure, for example, in Japanese Utility Model Laid-open No. 41675/1979 of one having a swing angle adjuster plate to generate over-current each time a magnet

of the balance with hairspring approaches by swinging and give brake force to the balance with hairspring.

[0017] Furthermore, it is an object of the present invention to provide an accurate mechanical timepiece less in change of watch error even after a lapse of time from a full winding state.

[DISCLOSURE OF THE INVENTION]

[0018] The present invention is, in a mechanical timepiece structured having a mainspring constituting a power source for the mechanical timepiece, a front train wheel rotating due to rotational force given upon rewinding the mainspring and an escapement/speed-control device for controlling rotation of the front train wheel, the escapement/speed-control device being structured including a balance with hairspring alternately repeating right and left rotation, an escape wheel and pinion rotating based on rotation of the front train wheel and a pallet fork controlling rotation of the escape wheel and pinion based on operation of the balance with hairspring, the mechanical timepiece characterized by comprising: a detector section provided for detecting a swing angle of the balance with hairspring by detecting an electrostatic capacitance varying corresponding to an operating state of the balance with hairspring; and a brake section structured to apply to the balance with hairspring such a force as suppressing rotation of the balance with hairspring when a swing angle of the balance with hairspring detected by the detector section is equal to or greater than a set angle previously set.

[0019] In the mechanical timepiece of the invention, a balance electrostatic capacitor electrode part is preferably provided on the balance with hairspring to measure rotational operation of the balance with hairspring, and the detector section including a detecting electrostatic capacitor electrode arranged with a constant spacing to the balance electrostatic capacitor electrode part and arranged on a main plate through an insulating part.

[0020] Also, in a mechanical timepiece of the invention, the balance electrostatic capacitor electrode part is preferably fixed on an outer periphery side surface of a balance wheel through a balance insulating part for insulating between the balance with hairspring and the balance electrostatic capacitor electrode part.

[0021] Also, in a mechanical timepiece of the invention, the balance electrostatic capacitor electrode part is preferably fixed on an outer periphery side surface of the balance wheel.

[0022] Also, in a mechanical timepiece of the invention, the balance electrostatic capacitor electrode part is preferably arranged on an underside of a balance arm part on a main plate side through a balance insulating part for insulating between the balance with hairspring and the balance electrostatic capacitor electrode part.

[0023] Also, in a mechanical timepiece of the invention, the balance electrostatic capacitor electrode part

may be arranged on an underside of a balance arm part on a main plate side.

[0024] Also, in a mechanical timepiece of the invention, the brake section preferably includes a coil to damp operation of a balance magnet provided on the balance with hairspring.

[0025] By using the detector and brake sections thus configured, the mechanical timepiece can be effectively controlled in rotation angle of the balance with hairspring thereby improving the accuracy for the mechanical timepiece.

[0026] Also, a mechanical timepiece of the invention preferably comprises a balance-rotation detecting circuit configured to control voltage applied to the balance electrostatic capacitor electrode part, an electrostatic capacitance detecting circuit provided to measure a change of an electrostatic capacitance between the balance electrostatic capacitor electrode part and the detecting electrostatic capacitor electrode, and a balance-rotation control circuit configured to input a signal concerning a change of an electrostatic capacitance between the balance electrostatic capacitor electrode part and the detecting electrostatic capacitor electrode outputted by the electrostatic capacitance detecting circuit and calculate a swing angle of the balance with hairspring based on a measurement result of a change of an electrostatic capacitance between the balance electrostatic capacitor electrode part and the detecting electrostatic capacitor electrode; wherein the balance-rotation control circuit is configured not to energize the coil where the swing angle of the balance with hairspring is smaller than a certain constant threshold, but to energize the coil where the swing angle of the balance with hairspring is equal to or greater than the certain constant threshold.

[0027] Also, a mechanical timepiece of the invention is preferably structured by further comprising a storage battery section to operate the balance-rotation detecting circuit, the electrostatic capacitance detecting circuit and the balance-rotation control circuit.

[0028] Also, a mechanical timepiece of the invention, preferably, further comprises a power generator section to charge the storage battery section.

[0029] Furthermore, the present invention is, in a mechanical timepiece having a mainspring constituting a power source for the mechanical timepiece, a front train wheel rotating due to rotational force given upon rewinding the mainspring and an escapement/speed-control device for controlling rotation of the front train wheel, the escapement/speed-control device being structured including a balance with hairspring alternately repeating right and left rotation, an escape wheel and pinion rotating based on rotation of the front train wheel and a pallet fork controlling rotation of the escape wheel and pinion based on operation of the balance with hairspring, the mechanical timepiece characterized by comprising: a storage battery section constituting a power source; a power generator section for charging the storage battery

section; a speed control section including a balance with hairspring and a balance magnet provided on the balance with hairspring and a balance electrostatic capacitor electrode part provided on the balance with hairspring; a detector section including a detecting electrostatic capacitor electrode arranged with a constant gap to the balance electrostatic capacitor electrode part and provided to detect a swing angle of the balance with hairspring by detecting an electrostatic capacitance varying corresponding to an operating state of the balance with hairspring; a brake section including a coil arranged to damp operation of a balance magnet provided on the balance with hairspring; and an IC including a balance-rotation detecting circuit configured to control voltage applied to the balance electrostatic capacitor electrode part, an electrostatic capacitance detecting circuit provided to measure a change of an electrostatic capacitance between the balance electrostatic capacitor electrode part and the detecting electrostatic capacitor electrode, and a balance-rotation control circuit configured to input a signal concerning a change of an electrostatic capacitance between the balance electrostatic capacitor electrode part and the detecting electrostatic capacitor electrode outputted by the electrostatic capacitance detecting circuit and calculate a swing angle of the balance with hairspring based on a measurement result of a change of an electrostatic capacitance between the balance electrostatic capacitor electrode part and the detecting electrostatic capacitor electrode.

[0030] The balance-rotation control circuit for the mechanical time piece of this invention is configured not to energize the coil where the swing angle of the balance with hairspring is smaller than a certain constant threshold, but to energize the coil where the swing angle of the balance with hairspring is equal to or greater than the certain constant threshold.

[0031] By this structure, it is possible to provide an accurate mechanical timepiece less in change of watch error even after lapse of time from the full winding state.

[BRIEF DESCRIPTION OF THE DRAWINGS]

[0032]

Fig. 1 is a plan view showing a schematic form of a movement front side in an embodiment of a mechanical timepiece of the present invention (in Fig. 1, parts are partly omitted and bridge members are shown by virtual lines).

Fig. 2 is a magnified fragmentary sectional view showing a schematic form of a train wheel and escapement/speed-control section in the embodiment of the mechanical timepiece of the invention.

Fig. 3 is a magnified fragmentary sectional view showing a schematic form of a balance with hairspring part in the embodiment of the mechanical timepiece of the invention.

Fig. 4 is a magnified fragmentary sectional view

showing a schematic form of speed control and detector sections in a state that the balance with hair-spring is not rotated in the embodiment of the mechanical timepiece of the invention.

Fig. 5 is a magnified fragmentary sectional view showing a schematic form of the speed control and detector sections in the embodiment of the mechanical timepiece of the invention.

Fig. 6 is a magnified fragmentary sectional view showing a schematic form of the speed control and detector sections in a state that the balance with hairspring is rotated by 90 degrees in the embodiment of the mechanical timepiece of the invention.

Fig. 7 is a magnified fragmentary sectional view showing a schematic form of speed control and detector sections in a state that the balance with hair-spring is not rotated in another embodiment of the mechanical timepiece of the invention.

Fig. 8 is a magnified fragmentary sectional view showing a schematic form of the speed control and detector sections in the other embodiment of the mechanical timepiece of the invention.

Fig. 9 is a magnified fragmentary sectional view showing a schematic form of the speed control and detector sections in a state that the balance with hairspring is rotated by 90 degrees in the other embodiment of the mechanical timepiece of the invention.

Fig. 10 is a perspective view showing a schematic form of a balance-with-hairspring magnet used in the embodiment of the mechanical timepiece of the invention.

Fig. 11 is a block diagram showing a schematic configuration of the mechanical timepiece of the invention.

Fig. 12 is a flowchart showing operation of the mechanical timepiece of the invention.

Fig. 13 is a plan view showing a schematic form of a movement front side of a conventional mechanical timepiece (in Fig. 13, parts are partly omitted and bridge members are shown by virtual lines).

Fig. 14 is a schematic fragmentary sectional view showing the movement of the conventional mechanical timepiece (in Fig. 14, parts are partly omitted).

Fig. 15 is a graph schematically showing a relationship between a lapse time of rewinding from full winding and a mainspring torque in the mechanical timepiece.

Fig. 16 is a graph schematically showing a relationship between a swing angle of the balance with hair-spring and a mainspring torque in the mechanical timepiece.

Fig. 17 is a graph schematically showing a relationship between a swing angle of the balance with hair-spring and an instantaneous watch error in the mechanical timepiece.

Fig. 18 is a graph schematically showing a relation-

ship between a lapse time of rewinding from full winding and an instantaneous watch error in the mechanical timepiece of the invention and conventional mechanical timepiece.

[BEST MODE FOR CARRYING OUT THE INVENTION]

[0033] Hereunder, embodiments of a mechanical timepiece of the present invention will be explained based on the drawings.

(1) Structure of Switch Device and Winding Section

[0034] Referring to Fig. 1 to Fig. 3, in an embodiment of a mechanical timepiece of the invention, a movement (mechanical body) 200 of the mechanical timepiece has a main plate 102 structuring a base plate for the movement. A hand setting stem 110 is rotatably assembled in a winding-stem guide hole 102a of the main plate 102. A dial 104 (see Fig. 2) is attached on the movement 200.

[0035] The hand setting stem 110 has a squared portion and a guide shaft portion. A clutch wheel (not shown) is assembled on the squared portion of the hand setting stem 110. The clutch wheel has a same rotation axis as a rotation axis of the hand setting stem 110. That is, the clutch wheel is provided having a squared hole and rotating based on rotation of the hand setting stem 110 by fitting the squared hole on the squared portion of the hand setting stem 110. The clutch wheel has teeth A and teeth B. The teeth A are provided in the clutch wheel at an end close to a center of the movement. The teeth B are provided in the clutch wheel at an end close to an outside of the movement.

[0036] The movement 200 is provided with a switch device to determine an axial position of the hand setting stem 110. The switch device includes a setting lever 190, a yoke 192, a yoke spring 194 and a setting lever jumper 196. The hand setting stem 110 is determined in rotational axial position based on rotation of the setting lever. The clutch wheel is determined in rotation-axis position based on rotation of the yoke. The yoke is to be determined at two positions in rotational direction.

[0037] A winding pinion 112 is rotatably provided on the guide shaft portion of the hand setting stem 110. When the hand setting stem 110 is rotated in a state that a first hand setting stem 110 is positioned at a firsthand-setting stem position closest to a movement inner side along the rotation axis direction (in a 0 stage), the winding pinion 112 is structurally rotated through rotation of the clutch wheel. A crown wheel 114 is structured to rotate due to rotation of the winding pinion 112. A ratchet wheel 116 is structured to rotate due to rotation of the crown wheel 114.

(2) Structure of Power source and Train Wheel

[0038] The movement 200 has as a power source a mainspring 122 accommodated in a barrel complete

120. The mainspring 122 is made of an elastic material having springiness, such as iron. The mainspring 122 is structured for rotation due to rotation of the ratchet wheel 116.

[0039] A center wheel and pinion 124 is structured for rotation due to rotation of the barrel complete 120. A third wheel and pinion 126 is structured rotatable based on rotation of the center wheel and pinion 124. A fourth wheel and pinion 128 structured rotatable based on rotation of the third wheel and pinion 126. An escape wheel and pinion 130 is structured for rotation due to rotation of the fourth wheel and pinion 128. The barrel complete 120, the center wheel and pinion 124, the third wheel and pinion 126 and the fourth wheel and pinion 128 constitute a front train wheel.

(3) Structure of Escapement/Speed control Device

[0040] The movement 200 has an escapement/speed control device to control rotation of the front train wheel. The escapement/speed control device includes a balance with hairspring 140 to repeat right and left rotation with a constant period, an escape wheel and pinion 130 to rotate based on rotation of the front train wheel, and a pallet fork 142 to control rotation of the escape wheel and pinion 130 based on the operation of the balance with hairspring 140.

[0041] The balance with hairspring 140 includes a balance stem 140a, a balance wheel 140b and a stud mainspring 140c. Four balance arm portions 140f (referred to as "amida") are provided to couple the balance stem 140a and the balance wheel 140b. The number of balance arm portions 140f may be two or three, or four or more.

[0042] The stud mainspring 140c is made of an elastic material having springiness, such as "elinvar". That is, the stud mainspring 140c is made of a metallic conductive material.

[0043] Based on rotation of the center wheel and pinion 124, an hour pinion 150 simultaneously rotates. The hour pinion 150 is structured having a minute hand 152 to indicate "minute". The hour pinion 150 is provided with a slip mechanism having predetermined slip torque to the center wheel and pinion 124.

[0044] Based on rotation of the hour pinion 150, a minute wheel (not shown) rotates. Based on rotation of the minute wheel, an hour wheel 154 rotates. The hour wheel 154 is structured having an hour hand 156 to indicate "hour".

[0045] The barrel complete 120 is supported for rotation relative to the main plate 102 and a barrel bridge 160. The center wheel and pinion 124, the third wheel and pinion 126, the fourth wheel and pinion 128 and the escape wheel and pinion 130 are supported for rotation relative to the main plate 102 and a train wheel bridge 162. The pallet fork 142 is supported for rotation relative to the main plate 102 and a pallet fork bridge 164.

[0046] The balance with hairspring 140 is supported

for rotation relative to the main plate 102 and a balance bridge 166. That is, the balance stem 140a has an upper tenon 140a1 supported for rotation relative to a balance upper bearing 166a fixed on the balance bridge 166.

The balance upper bearing 166a includes a balance upper hole jewel and a balance upper bridge jewel. The balance upper hole jewel and the balance upper bridge jewel are formed of an insulating material such as ruby.

[0047] The balance stem 140a has a lower tenon 140a2 supported for rotation relative to a balance lower bearing 102b fixed on the main plate 102. The balance lower bearing 102b includes a balance lower hole jewel and a balance lower bridge jewel. The balance lower hole jewel and the balance lower bridge jewel are made of an insulating material such as ruby.

[0048] The stud mainspring 140c is a thin leaf spring in a spiral (helical) form having a plurality of turns. The stud mainspring 140c at an inner end is fixed to a stud ball 140d fixed on the balance stem 140a, and the stud mainspring 140c at an outer end is screwed through a stud support 170a attached to a stud bridge 170 rotatably fixed on the balance bridge 166. The balance bridge 166 is made of a metallic conductive material such as brass. The stud bridge 170 is made of a metallic conductive material such as iron.

(4) Structure of Detector Section

(4.1) Detector section structure in embodiment of the mechanical timepiece of the invention

[0049] Next, explanation will be made on a detector section structure of the mechanical timepiece of the invention.

[0050] Referring to Fig. 1 to Fig. 5, a balance electrostatic capacitor electrode part 240 is provided on the balance with hairspring 140 in order to measure rotational operation of the balance with hairspring 140. The balance electrostatic capacitor electrode part 240 is fixed on an outer peripheral side surface of the balance wheel 140b through a balance insulation part 242. The balance insulation part 242 is provided to insulate between the balance electrostatic capacitor electrode part 240 and the balance wheel 140b. The balance electrostatic capacitor electrode part 240 is formed of a conductive material, such as copper, for example. The balance insulation part 242 is formed, for example, of a plastic material such as polycarbonate. A balance electrostatic capacitor electrode part 240b is put in electric conduction to the balance wheel 140b through soldering or the like.

[0051] In this case, it is preferred to form the balance electrostatic capacitor electrode part 240b to be put in electric conduction with the balance wheel 140b through soldering, followed by previous adjustment to eliminate weight deviation in the balance with hairspring 140.

[0052] As a modification, the balance electrostatic capacitor electrode portion 240b may be fixed in an outer peripheral side surface of the balance wheel 140b with-

out providing a balance insulating portion 242b.

[0053] The angle of providing the balance electrostatic capacitor electrode portion 240 is preferably, for example, 150 to 210 degrees with reference to a rotation center of the balance with hairspring 140. The angle of providing the balance electrostatic capacitor electrode portion 240 is more preferably 180 degrees with reference to the rotation center of the balance with hairspring 140.

[0054] In order to measure rotational operation of the balance with hairspring 140, a detecting electrostatic capacitor electrode 250 is provided on the main plate 102. The detecting electrostatic capacitor electrode 250 is fixed to the main plate 102 through a main plate insulating portion 252. That is, the detecting electrostatic capacitor electrode 250 constitutes a detector section. The main plate insulating portion 252 is provided in order to insulate between the detecting electrostatic capacitor electrode 250 and the main plate 102. The detecting electrostatic capacitor electrode 250 is formed, for example, of a conductive material such as copper. The main plate insulating portion 252 is formed, for example, of a plastic material such as polycarbonate.

[0055] In this structure, a speed control section 144 includes the balance with hairspring 140, the balance magnet 140e, the balance electrostatic capacitor electrode portion 240 and the balance insulating portion 242. The detail of the balance magnet 140e will be described later.

[0056] The balance electrostatic capacitor electrode portion 240 is structured to rotate with a constant gap to the detecting electrostatic capacitor electrode 250. The constant gap is, for example, 0.2 to 0.3 millimeter.

[0057] Referring to Fig. 4, when the balance with hairspring is in a non-rotation state, the balance electrostatic capacitor electrode portion 240 at its entire surface area structurally faces the detecting electrostatic capacitor electrode 250. In contrast, referring to Fig. 6, when the balance with hairspring is in a state of rotating 90 degrees, the balance electrostatic capacitor electrode portion 240 in a half of the surface area structurally faces the detecting electrostatic capacitor electrode 250.

[0058] In a state as shown in Fig. 4, i.e. in a state that the balance electrostatic capacitor electrode portion 240 at its entire surface area faces the detecting electrostatic capacitor electrode 250, an electrostatic capacitance between the balance electrostatic capacitor electrode portion 240 and the detecting electrostatic capacitor electrode 250 is approximately 0.6 pico-farad. In a state as shown in Fig. 6, i.e. in a state that the balance electrostatic capacitor electrode portion 240 in about a half of the surface area faces the detecting electrostatic capacitor electrode 250, an electrostatic capacitance between the balance electrostatic capacitor electrode portion 240 and the detecting electrostatic capacitor electrode 250 is approximately 0.3 pico-farad.

[0059] The detecting electrostatic capacitor electrode 250 is connected to an IC 234. A connecting lead wire

282 connects between a detecting terminal of the IC 234 and the detecting electrostatic capacitor electrode 250 in order to detect a change of an electrostatic capacitance between the balance electrostatic capacitor electrode portion 240 and the detecting electrostatic capacitor electrode 250.

[0060] The IC 234 includes a balance-rotation detecting circuit 272, an electrostatic capacitance detecting circuit 273 and a balance-rotation control circuit 274. The balance-rotation detecting circuit 272 is configured to control a voltage applied to the detecting electrostatic capacitor electrode 250. The electrostatic capacitance detecting circuit 273 is provided to measure a change of an electrostatic capacitance between the balance electrostatic capacitor electrode 240 and the detecting electrostatic capacitor electrode 250. The balance-rotation control circuit 274 is configured to input a signal concerning an electrostatic capacitance change outputted from the electrostatic capacitance detecting circuit 273 and calculate a swing angle of the balance with hairspring 140 based on a result of measurement of an electrostatic capacitance change between the balance electrostatic capacitor electrode portion 240 and the detecting electrostatic capacitor electrode 250.

(4.2) Detection of swing angle of balance with hairspring

[0061] The balance-rotation control circuit 274 previously stores an initial value of an electrostatic capacitance between the balance electrostatic capacitor electrode portion 240 and the detecting electrostatic capacitor electrode 250, and an after-change value of an electrostatic capacitance between the balance electrostatic capacitor electrode portion 240 and the detecting electrostatic capacitor electrode 250 and a swing angle of the balance with hairspring 140. Consequently, the swing angle of the balance with hairspring 140 can be calculated using an after-change value of an electrostatic capacitance between the balance electrostatic capacitor electrode portion 240 and the detecting electrostatic capacitor electrode 250.

[0062] That is, a value of an electrostatic capacitance between the balance electrostatic capacitor electrode portion 240 and the detecting electrostatic capacitor electrode 250 (referred to as a balance capacitor) is given as C1, and a value of an electrostatic capacitance of a reference electrostatic capacitor built in the balance-rotation control circuit 274 (referred to as a built-in capacitor) is as C2. A voltage applied to respective ends of series connection of the balance capacitor and built-in capacitor when the balance capacitor and the built-in capacitor are connected in series is as V, a terminal voltage of the balance capacitor when applied by this voltage V is as V1, and a terminal voltage of the built-in capacitor is as V2.

[0063] Here, the part connecting the balance capacitor and the built-in capacitor in series determines a value of a capacitor electrostatic capacitance, constituting an

electrostatic capacitance part to detect a swing angle of the balance with hairspring 140.

[0064] The charge Q to be stored on the balance capacitor and built-in capacitor is given as:

$$Q = C1 * V1 = C2 * V2,$$

and the voltage V to be applied across the electrostatic capacitance part (series connection part of the balance capacitor and built-in capacitor) is given as:

$$V = V1 + V2.$$

[0065] For example, given are $C1 = 0.28$ [pF], $C2 = 1.00$ [pF], $V = 1.5$ [V] (minus 1.5 volts with reference to a potential on the balance electrostatic capacitor electrode portion 240).

[0066] In the state that the balance electrostatic capacitor electrode portion 240 in about a half surface area faces the detecting electrostatic capacitor electrode 250 (when the swing angle of the balance with hairspring 140 is 180 degrees), $V2 = 328$ [mV] is provided.

[0067] This 328 [mV] can be taken as a threshold V_{th} [mV] of a reference voltage corresponding to the balance with hairspring 140 when having a swing angle of 180 degrees.

[0068] When the electrostatic capacitance of the balance capacitor becomes greater than 0.28 [pF], $V2$ becomes greater than V_{th} . When the electrostatic capacitance of the balance capacitor becomes smaller than 0.28 [pF], $V2$ becomes smaller than V_{th} .

[0069] By using a constant voltage circuit built in the balance-rotation control circuit 274, $V = 1.5$ [V] can be controlled with accuracy.

[0070] Similarly, if a voltage $V2$ is calculated as being at another angle of the balance with hairspring 140 or this relationship is determined according to an experiment, the swing angle of the balance with hairspring 140 can be accurately determined by determining a voltage $V2$ corresponding to a change in the electrostatic capacitance between the balance electrostatic capacitor electrode portion 240 and the detecting electrostatic capacitor electrode 250.

[0071] In the mechanical timepiece of the invention, the balance-rotation control circuit 274 previously stores a relationship between a electrostatic capacitance value between the balance electrostatic capacitor electrode portion 240 and the detecting electrostatic capacitor electrode 250 and a voltage $V2$ value.

(4.3) Structure of detector section in another embodiment of mechanical timepiece of the invention

[0072] Next, explanation will be made on a detector section structure of another embodiment of the mechanical timepiece of the invention.

[0073] Referring to Fig. 7 and Fig. 8, a balance electrostatic capacitor electrode portion 240b is arranged on the balance with hairspring 140 in order to measure rotational operation of the balance with hairspring 140.

5 The balance electrostatic capacitor electrode portion 240b is provided on a part of an underside surface of the balance arm portion 140f on a side of the main plate 102 through a balance insulating part 242b. The balance insulating part 242b is provided to insulate between the balance electrostatic capacitor electrode portion 240b and the balance arm portion 140f. The balance electrostatic capacitor electrode portion 240b is put in electric conduction with the balance arm portion 140f through soldering.

15 **[0074]** As a modification, the balance electrostatic capacitor electrode portion 240b may be arranged on the balance with hairspring 140 without providing the balance insulating portion 242b.

[0075] The angle of providing the balance electrostatic capacitor electrode portion 240b is preferably, for example, 150 to 210 degrees with reference to a rotation center of the balance with hairspring 140. The angle of providing the balance electrostatic capacitor electrode portion 240b is more preferably 180 degrees with reference to the rotation center of the balance with hairspring 140.

[0076] In order to measure rotational operation of the balance with hairspring 140, a detecting electrostatic capacitor electrode 250b is provided on the main plate 102. The detecting electrostatic capacitor electrode 250b is fixed to the main plate 102 through a main-plate insulating portion 252b. That is, the detecting electrostatic capacitor electrode 250b constitutes a detector section. The main-plate insulating portion 252b is provided in order to insulate between the detecting electrostatic capacitor electrode 250b and the main plate 102.

[0077] In a state as shown in Fig. 7, i.e. in a state that the balance electrostatic capacitor electrode portion 240b at its entire surface area faces the detecting electrostatic capacitor electrode 250b, an electrostatic capacitance between the balance electrostatic capacitor electrode portion 240b and the detecting electrostatic capacitor electrode 250b is approximately 0.6 pico-farad. In a state as shown in Fig. 9, i.e. in a state that the balance electrostatic capacitor electrode portion 240b in about a half of the surface area faces the detecting electrostatic capacitor electrode 250b, an electrostatic capacitance between the balance electrostatic capacitor electrode portion 240b and the detecting electrostatic capacitor electrode 250b is approximately 0.3 pico-farad.

[0078] The balance electrostatic capacitor electrode portion 240b is structured to rotate with a constant gap to the detecting electrostatic capacitor electrode 250b. The constant gap, for example, is 0.2 to 0.3 millimeters.

55 **[0079]** Referring to Fig. 7, when the balance with hairspring is not in rotation, the balance electrostatic capacitor electrode portion 240b in its entire surface area structurally faces the detecting electrostatic capacitor

electrode 250b. In contrast, referring to Fig. 9, when the balance with hairspring is in a state of rotating 90 degrees, the balance electrostatic capacitor electrode part 240b in about a half of the surface area structurally faces the detecting electrostatic capacitor electrode 250b.

[0080] The other parts structures of the other embodiment of the mechanical timepiece of the invention are similar to the structures of the embodiment of the mechanical timepiece of the invention as described herein above with reference to Fig. 1 to Fig. 6.

(5) Structure of Generator and Storage Battery sections

[0081] Next, explanation will be made on structures of a generator section and a storage battery section.

[0082] A secondary battery 136 for operating the IC 234 is fixed to the main plate 102. The secondary battery 136 constitutes a storage battery section 137. That is, the storage battery section 137 constitutes a power source to operate the IC 234. The storage battery section 137 may be configured by a secondary battery or a capacitor. Otherwise, a primary battery may be utilized in place of the storage battery section 137.

[0083] In the invention, the main plate 102 is in electric conduction with one electrode of the secondary battery 136 for example, a plus electrode of the secondary battery 136. As a result, the balance wheel 140b is also in electric conduction with the plus electrode of the secondary battery 136.

[0084] A generator section 150 is provided in order to charge the storage battery section 137, i.e. the secondary battery 136. The generator section 150 may be a manual-winding generator mechanism to generate voltage due to rotation of the hand setting stem 110 or an automatic-winding generator mechanism to generate voltage due to rotation of a rotary weight.

[0085] The generator section 150 may be arranged on a "back side" of the movement 200 or on a "front side" of the movement 200.

[0086] The generator section 150 as its structure may use a similar one to a conventional structure and hence not depicted in Fig. 1.

[0087] A schematic structure that the generator section 150 is structured by a manual-winding generator mechanism is shown in Fig. 11. Referring to Fig. 11, the generator section 150 includes a winding mechanism 152 to operate due to rotation of a hand setting stem 110, a speed-up train wheel 154 to increase the speed of and transmit rotation of the winding mechanism 152, a rotor 156 to rotate due to rotation of the speed-up train wheel 154, a stator 157 having a rotor hole opposite to a rotor magnet of the rotor 156, generator coil 158 to generate electromotive force due to rotation of the rotor 156, and a rectifying circuit 160 to rectify the current generated on the generator coil 158. The current rectified by the rectifying circuit 160 flows in a secondary battery 136 constituting a storage battery section 137. In place of the secondary battery 136, a capacitor may be em-

ployed. The rectifying operation by the rectifying circuit 160 may be half-wave rectification or full-wave rectification. The rectifying circuit may be incorporated in the IC 234 or provided separately from the IC 234.

[0088] When the generator section is structured by an automatic-winding generator mechanism, the generator section includes a rotary weight, a speed-up train wheel to increase the speed of and transmit rotation of the rotary weight, a rotor to rotate due to rotation of the speed-up train wheel, a stator having a rotor hole opposite to a rotor magnet of the rotor, a power generating coil to generate electromotive force due to rotation of the rotor, and a rectifying circuit to rectify the current generated on the power generating coil. The current rectified by the rectifying circuit structurally flows to the secondary battery 136.

[0089] For example, electronic wrist watches with power generator unit are disclosed in Japanese Patent Laid-open No. 266989/1986 and Japanese Patent Laid-open No. 293143/1986, and a portable timepiece with charge function is disclosed in Japanese Patent Laid-open No. 288192/1986.

[0090] As a modification may be used a battery (primary battery) such as a silver battery or a lithium battery, thereby providing a structure without using a power generating mechanism.

(6) Structure of Brake Section

[0091] Next, explanation will be made on a brake section of the mechanical timepiece of the invention.

[0092] Referring to Fig. 1 to Fig. 3, coils 180a, 180b are attached to a front surface of the main plate 102 in a manner facing to a main-plate-side surface of the balance wheel 140b. The coils 180a, 180b constitute a control section 146. The number of coils, as shown in Fig. 1 to Fig. 3, is for example two, but may be one, two, three or four or more.

[0093] A balance magnet 140e is attached to the main-plate-side surface of the balance wheel 140b in a manner facing to the front surface of the main plate 102.

[0094] As shown in Fig. 1 and Fig. 3, in the case of arranging a plurality of coils 180a, 180b, the coils preferably have a circumferential spacing greater integer times a spacing between S and N poles of the balance magnet 140e arranged opposite to the coils 180a, 180b. However, all the coils may not have a same spacing in the circumferential direction. Furthermore, in such a structure as having a plurality of coils, the interconnection between the coils is preferably connected in series not to mutually cancel current generated on each coil due to electromagnetic induction. Otherwise, the interconnection between the coils may be connected in parallel in a manner not to mutually cancel current generated on each coil due to electromagnetic induction.

[0095] Referring to Fig. 10, the balance magnet 140e has an annular (ring-formed) shape and is alternately provided, along a circumferential direction, with magnet

portions constituted, for example, by twelve S poles 140s1 - 140s12 and twelve N poles 140n1 - 140n12 that are vertically polarized. Although the number of magnet portions arranged annular (in a ring form) in the balance magnet 140e in the example shown in Fig. 10 is twelve, it may be in a plurality of two or more. Here, it is preferred to provide the magnet portion with one bowstring length nearly equal to an outer diameter of one coil provided opposite to the magnet portion.

[0096] A gap is provided between the balance magnet 140e and the coils 180a, 180b. The gap between the balance magnet 140e and the coils 180a, 180b is determined such that the balance magnet 140e has a magnetic force capable of giving effects upon the coils 180a, 180b when the coils 180a, 180b are energized.

[0097] When the coils 180a, 180b are not energized, the magnetic force on the balance magnet 140e cannot have effects on the coils 180a, 180b. The balance magnet 140e is fixed, for example, through adhesion to the main-plate-side surface of the balance wheel 140b in such a state that one surface is in contact with a ring rim of the balance wheel 140b and the other surface facing to the front surface of the main plate 102.

[0098] A first lead wire 182 is provided to connect between one terminal of the coil 180 and a first coil terminal of the IC 234. A second lead wire 184 is provided to connect between one terminal of the coil 180a and a second coil terminal of the IC 234.

[0099] The stud mainspring 140c has a thickness (radial thickness of the balance with hairspring) of 0.021 millimeter, for example. The balance magnet 140e has, for example, an outer diameter of approximately 9 millimeters, an inner diameter of approximately 7 millimeters, a thickness of approximately 1 millimeter and a magnetic flux density of approximately 0.02 tesla. The coils 180a, 180b respectively have the number of turns, for example, of 8 turns and a coil diameter of approximately 25 micrometers. The gap between the balance magnet 140e and the coils 180a, 180b is, for example, approximately 0.4 millimeter.

(7) Operation of Detector and Brake Sections

[0100] Referring to Fig. 1 to Fig. 3, explanation will be made on the operation of the balance with hairspring 140 when the coils 180a, 180b are not energized, i.e. when a circuit including the coils 180a, 180b is open.

[0101] The stud mainspring 140c expands and contracts radially of the stud mainspring 140c depending on a rotation angle of rotation of the balance with hairspring 140. For example, in a state shown in Fig. 3, when the balance with hairspring 140 rotates clockwise, the stud mainspring 140c contracts in a direction toward a center of the balance with hairspring 140. Contrary to this, when the balance with hairspring 140 rotates counter-clockwise, the stud mainspring 140c expands in a direction away from the center of the balance with hairspring 140.

[0102] In case that the rotation angle (swing angle) of the balance with hairspring 140 is at a certain given threshold, e.g. less than 180 degrees, the coils 180a, 180b are structurally not energized by operation of the balance-rotation control circuit 274.

[0103] Next, explanation will be made on the operation of the balance with hairspring 140 when the coils 180a, 180b are energized, i.e. when the circuit including the coils 180a, 180b is closed. That is, the coils 180a, 180b are structurally energized when the swing angle of the balance with hairspring 140 is 180 degrees or greater.

[0104] If the swing angle of the balance with hairspring 140 is 180 degrees or greater, the coils 180a, 180b are energized by operation of the balance-rotation control circuit 274 to exert to the balance with hairspring 140 such a force as suppressing rotational motion of the balance with hairspring 140 due to an induction current caused by change of magnetic flux on the balance magnet 140e. Due to the action of the balance-rotation control circuit 274 and coils 180a, 180b and balance magnet 140e, a brake force suppressing the rotation of the balance with hairspring 140 is structurally applied to the balance with hairspring 140 thereby reducing the swing angle of the balance with hairspring 140.

[0105] When the swing angle of the balance with hairspring 140 exceeds 0 degree and decreases to a range of less than 180 degrees, the balance-rotation control circuit 274 structurally operates not to energize the coils 180a, 180b. Accordingly, in a range that the swing angle exceeds 0 degree and in a range of less than 180 degrees, the coils 180a, 180b are not energized. Thus, the balance with hairspring 140 is not applied by such a force as suppressing rotation motion of the balance with hairspring 140.

[0106] Next, explanation will be made on the operation of the detector and brake section in the mechanical timepiece of the invention.

[0107] Referring to Fig. 11 and Fig. 12, the operation of the balance-rotation detecting circuit 272 starts detection of rotation of the balance with hairspring (step S21 of Fig. 12).

[0108] The balance-rotation detecting circuit 272 determines a detection time (step S22 of Fig. 12). Determination of a detection time is made, e.g. by a counter. The set time for detecting rotation of the balance with hairspring is previously stored in the balance-rotation detecting circuit 272. The set time for performing rotation detection of the balance with hairspring is, for example, about one hour. The set time for detecting rotation of the balance with hairspring is preferably approximately 0.25 to 6 hours, more preferably approximately 0.5 to 3 hours, further preferably approximately 1 to 2 hours.

[0109] When the balance-rotation detecting circuit 272 determines a lapse of the set time, the balance-rotation detecting circuit 272 applies voltage to the electrostatic capacitor part. That is, the balance-rotation de-

detecting circuit 272 puts the detecting electrostatic capacitor electrode 250 into conduction to a detection terminal of the balance-rotation detecting circuit 272, thereby applying voltage to the electrostatic capacitor part (step S23 of Fig. 12).

[0110] This application voltage is a constant voltage, for example, of minus 1.5 volts. That is, the balance-rotation detecting circuit 272 controls the timing of applying voltage to the electrostatic capacitor part and the magnitude of application voltage.

[0111] If the balance-rotation detecting circuit 272 determines that the set time is not elapsed, the process returns to step S22 of Fig. 12 to repeat an operation of determining a detection time.

[0112] If the balance-rotation detecting circuit 272 applies voltage to the electrostatic capacitor part, the electrostatic capacitance detecting circuit 273 measures a change in electrostatic capacitance between the balance electrostatic capacitor electrode portion 240 and the detecting electrostatic capacitor electrode 250. Next, the balance-rotation control circuit 274 inputs a signal concerning the change of the electrostatic capacitance outputted by the electrostatic capacitance detecting circuit 273 and calculates a swing angle of the balance with hairspring 140 based on a measurement result of the electrostatic capacitance change between the balance-electrostatic capacitor electrode portion 240 and the detecting electrostatic capacitor electrode 250. Then, the balance-rotation control circuit 274 determines a swing angle of the balance with hairspring 140 (step S24 of Fig. 12).

[0113] Here, as stated before the balance-rotation control circuit 274 previously stores the relations with an initial value of an electrostatic capacitance between the balance electrostatic capacitor electrode portion 240 and the detecting electrostatic capacitor electrode 250, and an after-change value of the electrostatic capacitance between the balance electrostatic capacitor electrode portion 240 and the detecting electrostatic capacitor electrode 250, and a swing angle of the balance with hairspring 140. Consequently, the calculation of a swing angle of the balance with hairspring 140 is made using an after-change value of an electrostatic capacitance between the balance electrostatic capacitor electrode portion 240 and the detecting electrostatic capacitor electrode 250.

[0114] If the balance-rotation control circuit 274 determines that the swing angle of the balance with hairspring 140 is at a set angle or greater, the balance-rotation detecting circuit 272 puts off operation of applying voltage to the electrostatic capacitor part (step S25 of Fig. 12). In this case, the balance-rotation control circuit 274 energizes the coils 180a, 180b (step S26 of Fig. 12). The energization of the coils 180a, 180b causes an induction current due to change of magnetic flux of the balance magnet 140e and exerts to the balance with hairspring 140 such a force as suppressing the rotational movement of the balance with hairspring 140. Thus, the swing

angle of the balance with hairspring 140 is reduced by applying to the balance with hairspring 140 a brake force of suppressing the rotation of the balance with hairspring 140. If the balance-rotation control circuit 174 energizes the coils 180a, 180b and reduces the swing angle of the balance with hairspring 140, the process returns to the step S22 of Fig. 12 to repeat operation of determining a detection time.

[0115] The relationship between a time for energizing the coils 180a, 180b by the balance-rotation control circuit 274 and a swing angle of the balance with hairspring 140 is empirically determined beforehand, a result of which is stored in the balance-rotation control circuit 274.

[0116] The swing set angle of the balance with hairspring 140 is previously stored in the balance-rotation control circuit 274. The swing set angle of the balance with hairspring 140 is, for example, 180 degrees. The swing set angle of the balance with hairspring 140 is preferably 150 to 210 degrees.

[0117] If the balance-rotation control circuit 274 determines that the swing angle of the balance with hairspring 140 is less than the set angle, the balance-rotation detecting circuit 272 puts off the operation of applying voltage to the electrostatic capacitance part (step S27 of Fig. 12). In this case, the balance-rotation control circuit 274 does not energize the coils 180a, 180b (step S28 of Fig. 12).

[0118] Then, the process returns to the step S22 of Fig. 12 to repeat the operation of determining a detection time.

[0119] As a modification, it is satisfactory that, where the balance-rotation control circuit 274 determines the swing angle of the balance with hairspring 140 is at the set angle or greater, the balance-rotation detecting circuit 272 puts off the operation of applying voltage to the electrostatic capacitor part and the balance-rotation control circuit 274 energizes the coils 180a, 180b and applies to the balance with hairspring 140 such a force as suppressing energizing the coils 180a, 180b the rotational movement of the balance with hairspring 140 so that after that the balance-rotation control circuit 274 again determines a swing angle of the balance with hairspring 140. That is, it is possible in Fig. 12 to provide such a loop as returning to step S24 a predetermined number of times after step S26.

[0120] In this configuration, the swing angle of the balance with hairspring 140 can be adjusted with further accuracy by providing a feedback loop.

[0121] Accordingly, the mechanical timepiece of the invention can control the swing angle of the balance with hairspring 140 with accuracy and efficiency.

(8) Circuit Configuration Used in Mechanical Timepiece of the Invention

[0122] Furthermore, in the embodiment of the mechanical timepiece of the invention, various functional

circuits may be configured within an IC and the IC be a PLA-IC incorporating a program for carrying out various operations.

[0123] Also, in the embodiment of the mechanical timepiece of the invention, external elements such as resistors, capacitors, coils, diodes, transistors, etc. can be used as required together with the IC.

(9) Effect of the Invention

[0124] As explained above, the present invention is structured, in a mechanical timepiece structured including a balance with hairspring having an escapement/speed-control device repeating right and left rotation, an escape wheel and pinion rotating based on rotation of a front train wheel, and a pallet fork controlling rotation of the escape wheel and pinion based on operation of the balance with hairspring, having a detector section for detecting a swing angle of a balance with hairspring and a brake section for controlling the rotation angle of the balance with hairspring. Accordingly, it is possible to improve accuracy for the mechanical timepiece without reducing a sustaining time of the mechanical timepiece.

[0125] That is, in the invention, the swing angle is kept constant with an eye put on a correlation between an instantaneous watch error and a swing angle, thereby suppressing the variation in instantaneous watch error and making adjustment to decrease advancement and delay per day of the timepiece.

[0126] Contrary to this, in the conventional mechanical timepiece, the swing angle varies with a lapse of time due to a relationship between a sustaining time and a swing angle. Furthermore an instantaneous watch error varies with a lapse of time due to a relationship between a swing angle and an instantaneous watch error. Due to this, it has been difficult to increase a timepiece sustaining time that constant accuracy is to be maintained.

(10) Simulation on Instantaneous Watch Error

[0127] Next, explanation will be made on a result of simulation on an instantaneous watch error conducted on the mechanical timepiece of the invention developed to solve the above problem of the conventional mechanical timepiece.

[0128] Referring to Fig. 18, in the mechanical timepiece of the invention, adjustment is first made to a state the instantaneous watch error is put forward as shown by x-marked plotting and a thin line in Fig. 18.

[0129] That is, in the mechanical timepiece of the invention, as shown by the x-marked plotting and thin line in Fig. 18, the watch error in a full winding state of the mainspring is approximately 18 seconds per day (approximately 18 seconds fast per day). At a lapse of 20 hours from the full winding state, the instantaneous watch error is approximately 13 seconds per day (approximately 13 seconds fast per day). At a lapse of 30 hours from the full winding state, the instantaneous

watch error is approximately -2 seconds per day (approximately 2 seconds slow per day).

[0130] In the mechanical timepiece of the invention, when the brake section is operated, as shown by a black-dot plotting and extreme thick line in Fig. 18 the instantaneous watch error can be maintained approximately 5 seconds per day (maintaining a state of approximately 5 seconds fast per day) in a state the brake section is in operation, i.e. before lapse of 27 hours from the full winding state of the mainspring. At a lapse of 30 hours from the full winding state, the instantaneous watch error is approximately -2 seconds per day (approximately 2 seconds slow per day).

[0131] Because the mechanical timepiece of the invention having the balance-rotation angle control mechanism suppresses the timepiece instantaneous watch error from varying due to control on the swing angle of the balance with hairspring, it is possible to increase the lapse time from the full winding state in which the instantaneous watch error is approximately 0 to 5 seconds per day as compared to a conventional timepiece shown by a square plotting and virtual line in Fig. 18.

[0132] That is, the mechanical timepiece of the invention has a sustaining time of approximately 32 hours in which the instantaneous watch error is within approximately plus/minus 5 seconds per day. This sustaining time value is approximately 1.45 times a sustaining time of approximately 22 hours of the conventional mechanical timepiece wherein the instantaneous watch error is approximately within plus/minus 5 seconds per day.

[0133] Therefore, the mechanical timepiece of the present invention obtained a result of simulation that accuracy is well as compared to the conventional mechanical timepiece.

[Industrial Applicability]

[0134] The mechanical timepiece of the present invention has a simple structure and is suited for realizing an extreme accurate mechanical timepiece.

[0135] Furthermore, the mechanical timepiece of the invention has an optical detection type of a swing-angle detector section and hence is extremely easy to manufacture and watch-error adjustment for the mechanical timepiece.

Claims

1. In a mechanical timepiece structured having a mainspring constituting a power source for the mechanical timepiece, a front train wheel rotating due to rotational force given upon rewinding the mainspring and an escapement/speed-control device for controlling rotation of the front train wheel, said escapement/speed-control device being structured including a balance with hairspring alternately repeating right and left rotation, an escape wheel and

pinion rotating based on rotation of said front train wheel and a pallet fork controlling rotation of said escape wheel and pinion based on operation of said balance with hairspring, the mechanical timepiece **characterized by** comprising:

a detector section (276) provided for detecting a swing angle of said balance with hairspring (140) by detecting an electrostatic capacitance varying corresponding to an operating state of said balance with hairspring (140); and
a brake section (146) structured to apply to said balance with hairspring (140) such a force as suppressing rotation of said balance with hairspring (140) when a swing angle of said balance with hairspring (140) detected by said detector section (276) is equal to or greater than a set angle previously set.

2. A mechanical timepiece as claimed in claim 1, **characterized in that** a balance electrostatic capacitor electrode part (240) is provided on said balance with hairspring (140) to measure rotational operation of said balance with hairspring (140), and said detector section (276) including a detecting electrostatic capacitor electrode (250, 250b) arranged with a constant spacing to said balance electrostatic capacitor electrode part (240, 240b) and arranged on a main plate (102) through an insulating part (242).
3. A mechanical timepiece as claimed in claim 2, **characterized in that** said balance electrostatic capacitor electrode part (240) is fixed on an outer periphery side surface of a balance wheel (140b) through a balance insulating part (242) for insulating between said balance with hairspring (140) and said balance electrostatic capacitor electrode part (240).
4. A mechanical timepiece as claimed in claim 2, **characterized in that** said balance electrostatic capacitor electrode part (240) is fixed on an outer periphery side surface of said balance wheel (140b).
5. A mechanical timepiece as claimed in claim 2, **characterized in that** said balance electrostatic capacitor electrode part (240b) is arranged on an underside of a balance arm part (140f) on a main plate side through said balance with hairspring (140) and an insulating part (242b) for insulating between said balance with hairspring (140) and said balance electrostatic capacitor electrode part (240b).
6. A mechanical timepiece as claimed in claim 2, **characterized in that** said balance electrostatic capacitor electrode part (240b) is arranged on an underside of a balance arm part (140f) on a main plate side.

7. A mechanical timepiece as claimed in any one of claims 1 to claim 6, **characterized in that** said brake section (146) includes a coil (180a, 180b) to damp operation of a balance magnet (140e) provided on said balance with hairspring (140).
8. A mechanical timepiece as claimed in claim 7, **characterized by** having a balance-rotation detecting circuit (272) configured to control voltage applied to said balance electrostatic capacitor electrode part (240), an electrostatic capacitance detecting circuit (273) provided to measure a change of an electrostatic capacitance between said balance electrostatic capacitor electrode part (240) and said detecting electrostatic capacitor electrode (250), and a balance-rotation control circuit (274) configured to input a signal concerning a change of an electrostatic capacitance between said balance electrostatic capacitor electrode part (240) and said detecting electrostatic capacitor electrode (250) outputted by said electrostatic capacitance detecting circuit (273) and calculate a swing angle of said balance with hairspring (140) based on a measurement result of a change of an electrostatic capacitance between said balance electrostatic capacitor electrode part (240) and said detecting electrostatic capacitor electrode (250); wherein said balance-rotation control circuit (274) is configured not to energize said coil (180a, 180b) where the swing angle of said balance with hairspring (140) is smaller than a certain constant threshold, but to energize said coil (180a, 180b) where the swing angle of said balance with hairspring (140) is equal to or greater than the certain constant threshold.
9. A mechanical timepiece as claimed in claim 8, **characterized by** further comprising a storage battery section (137) to operate said balance-rotation detecting circuit (272), said electrostatic capacitance detecting circuit (273) and said balance-rotation control circuit (274).
10. A mechanical timepiece as claimed in claim 9, **characterized by** further comprising a power generator section (150) to charge said storage battery section (137).
11. In a mechanical timepiece structured having a mainspring constituting a power source for the mechanical timepiece, a front train wheel rotating due to rotational force given upon rewinding the mainspring and an escapement/speed-control device for controlling rotation of the front train wheel, said escapement/speed-control device being structured including a balance with hairspring alternately repeating right and left rotation, an escape wheel and pinion rotating based on rotation of said front train wheel and a pallet fork controlling rotation of said

escape wheel and pinion based on operation of said balance with hairspring, the mechanical timepiece **characterized by** comprising:

constant threshold.

a storage battery section constituting a power source (137);
 a power generator section (150) for charging said storage battery section (137);
 a speed control section (244) including a balance with hairspring (140) and a balance magnet (140e) provided on said balance with hairspring (140) and a balance electrostatic capacitor electrode part (240, 240b) provided on said balance with hairspring (140);
 a detector section (276) including a detecting electrostatic capacitor electrode (250, 250b) arranged with a constant gap to said balance electrostatic capacitor electrode part (240, 240b) and provided to detect a swing angle of said balance with hairspring (140) by detecting an electrostatic capacitance varying corresponding to an operating state of said balance with hairspring (140);
 a brake section (146) including a coil (180a, 180b) arranged to damp operation of a balance magnet (140e) provided on the balance with hairspring (140); and
 an IC (234) including a balance-rotation detecting circuit (272) configured to control voltage applied to said balance electrostatic capacitor electrode part (240, 240b), an electrostatic capacitance detecting circuit (273) provided to measure a change of an electrostatic capacitance between said balance electrostatic capacitor electrode part (240, 240b) and said detecting electrostatic capacitor electrode (250, 250b), and a balance-rotation control circuit (274) configured to input a signal concerning a change of an electrostatic capacitance between said balance electrostatic capacitor electrode part (240, 240b) and said detecting electrostatic capacitor electrode (250, 250b) outputted by said electrostatic capacitance detecting circuit (273) and calculate a swing angle of said balance with hairspring (140) based on a measurement result of a change of an electrostatic capacitance between said balance electrostatic capacitor electrode part (240, 240b) and said detecting electrostatic capacitor electrode (250, 250b);

wherein said balance-rotation control circuit (274) is configured not to energize said coil (180a, 180b) where the swing angle of said balance with hairspring (140) is smaller than a certain constant threshold, but to energize said coil (180a, 180b) where the swing angle of said balance with hairspring (140) is equal to or greater than the certain

Fig. 1

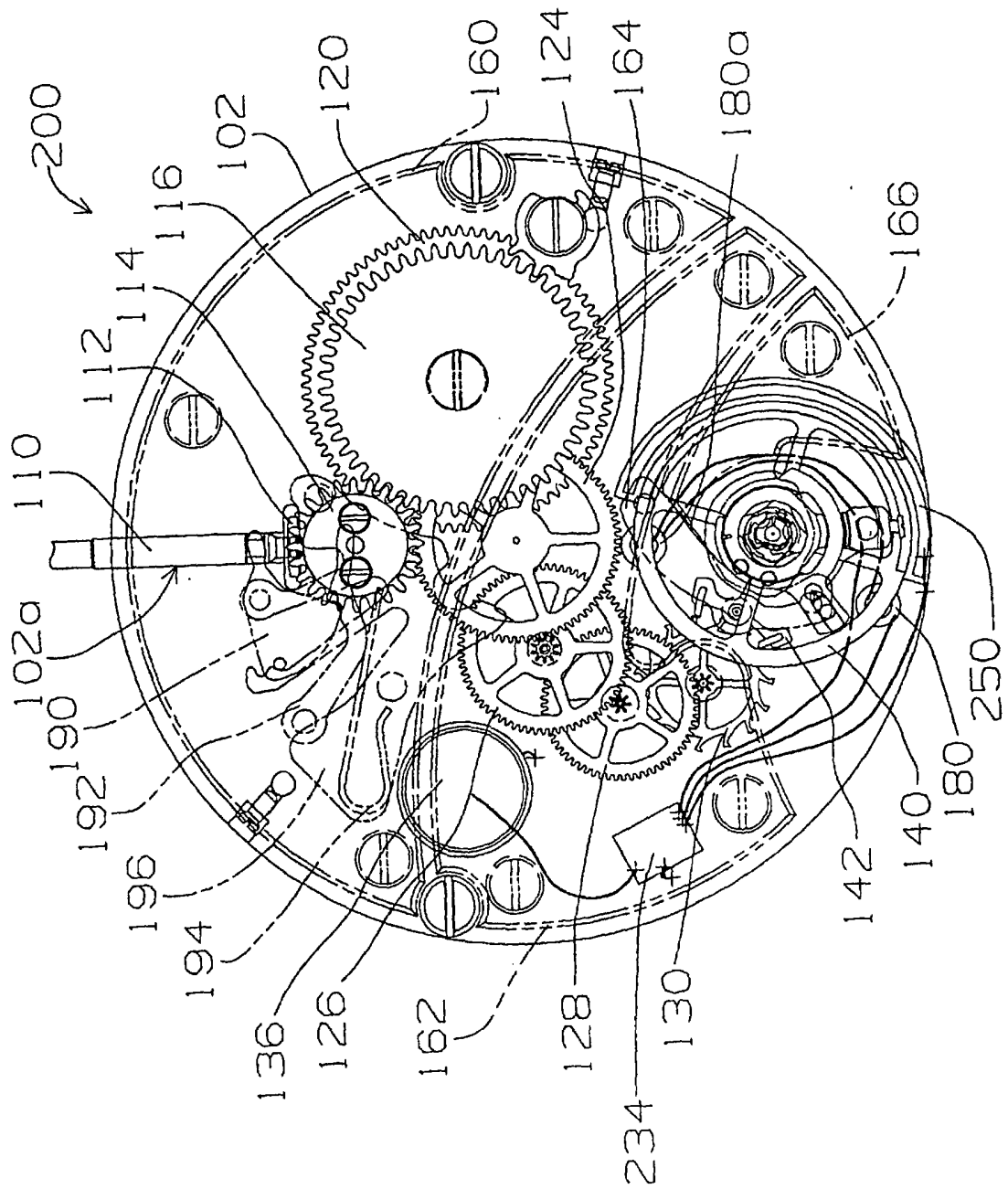


FIG. 2

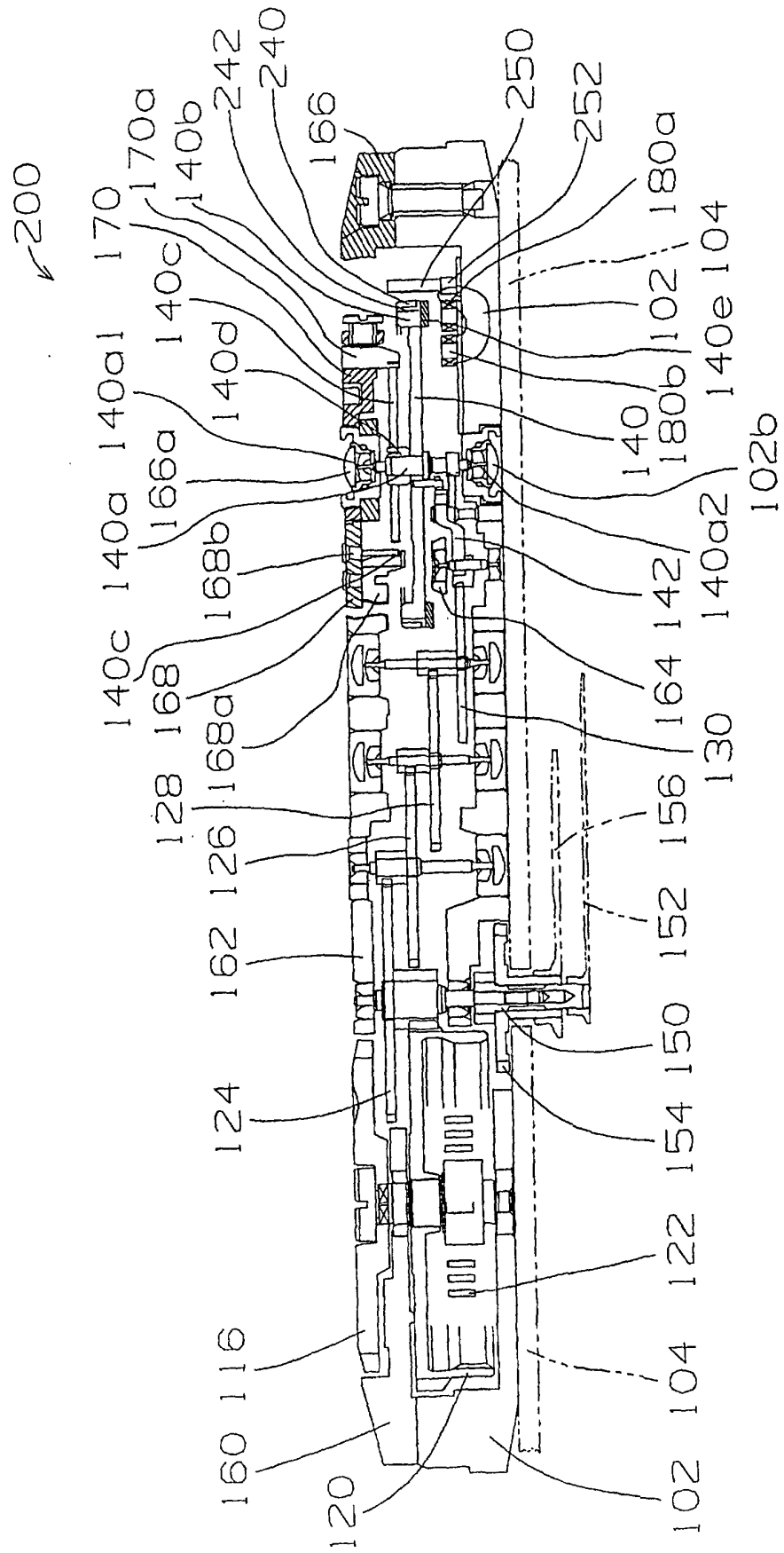


FIG. 3

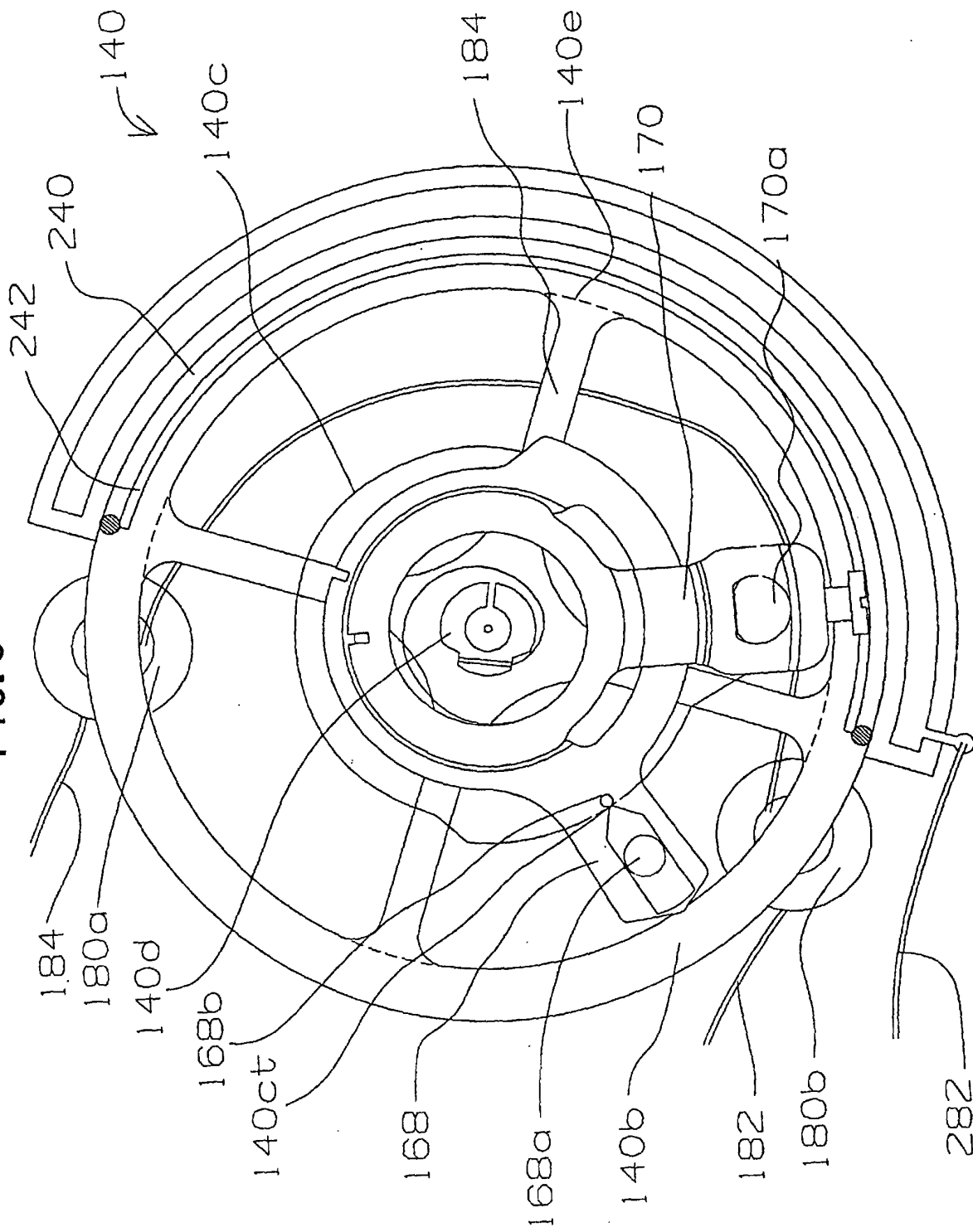
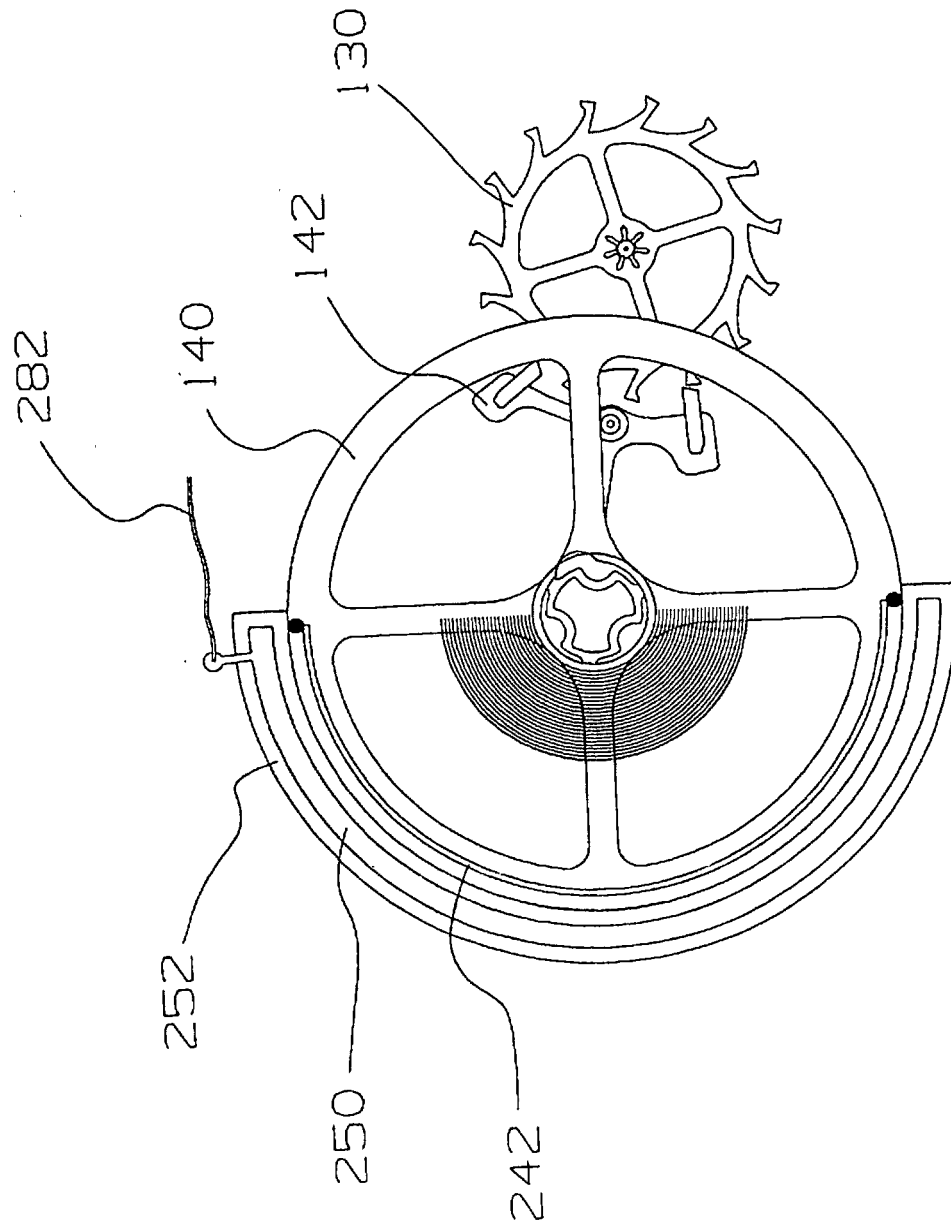


FIG. 4



56E

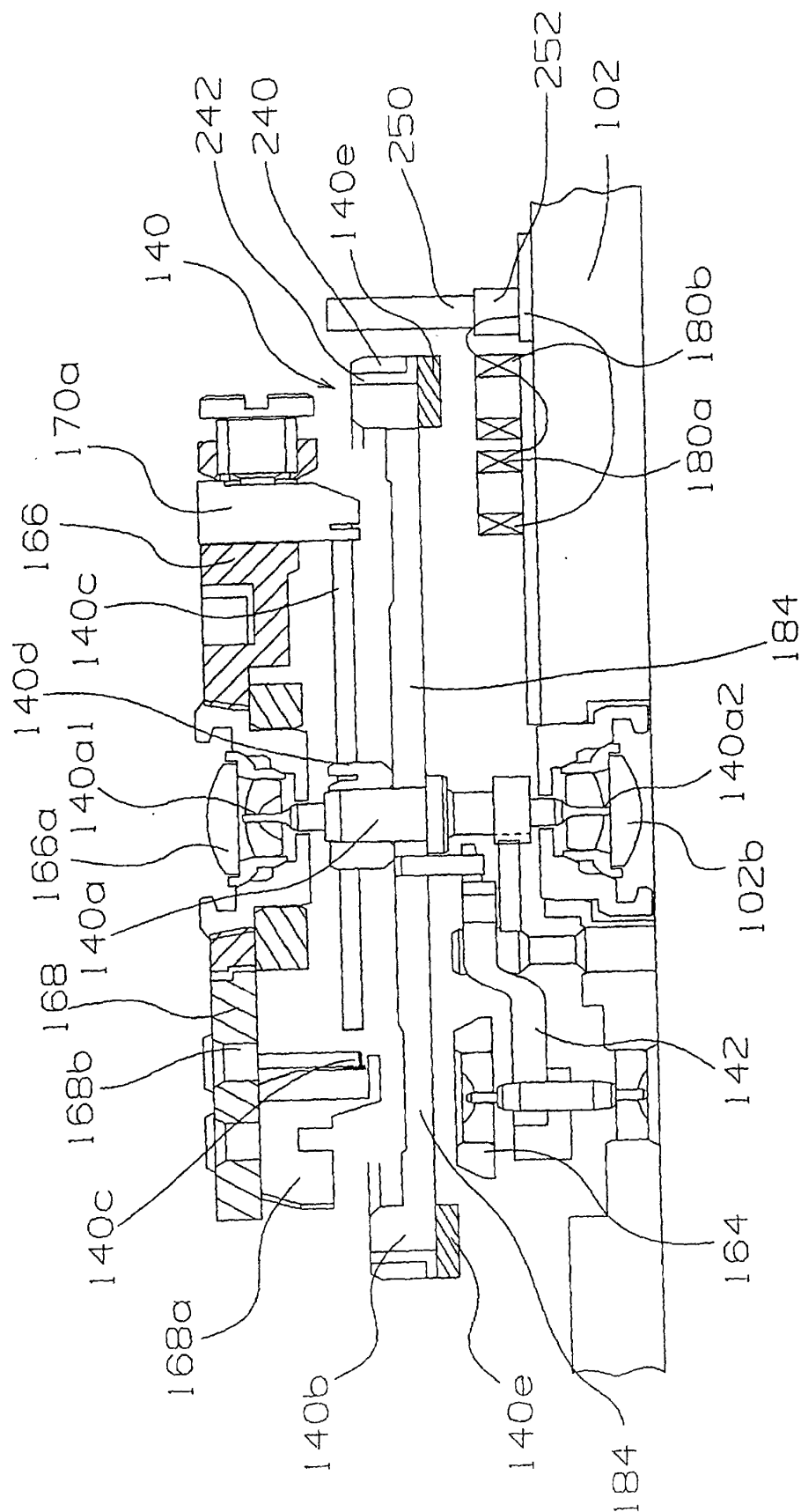


FIG. 6

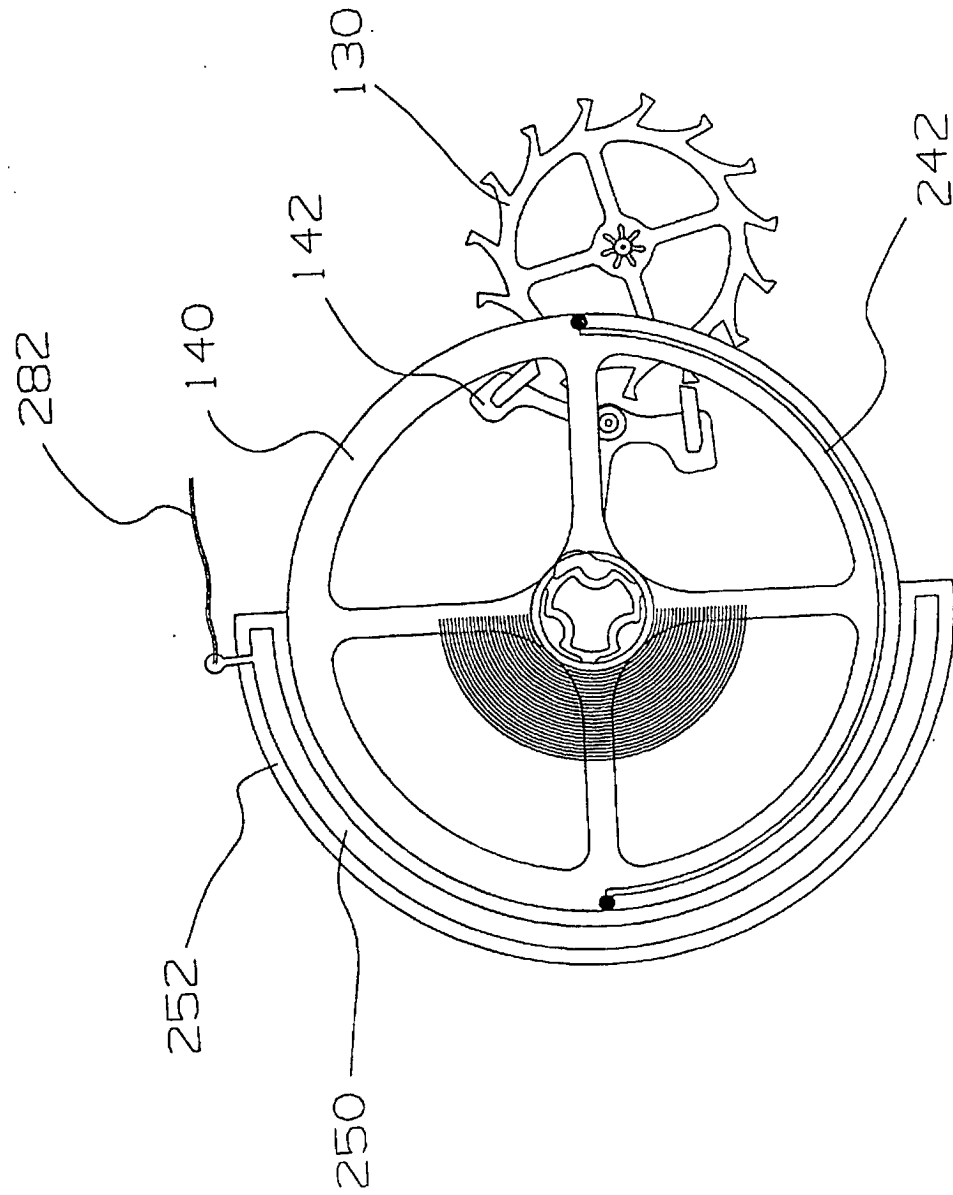


FIG. 7

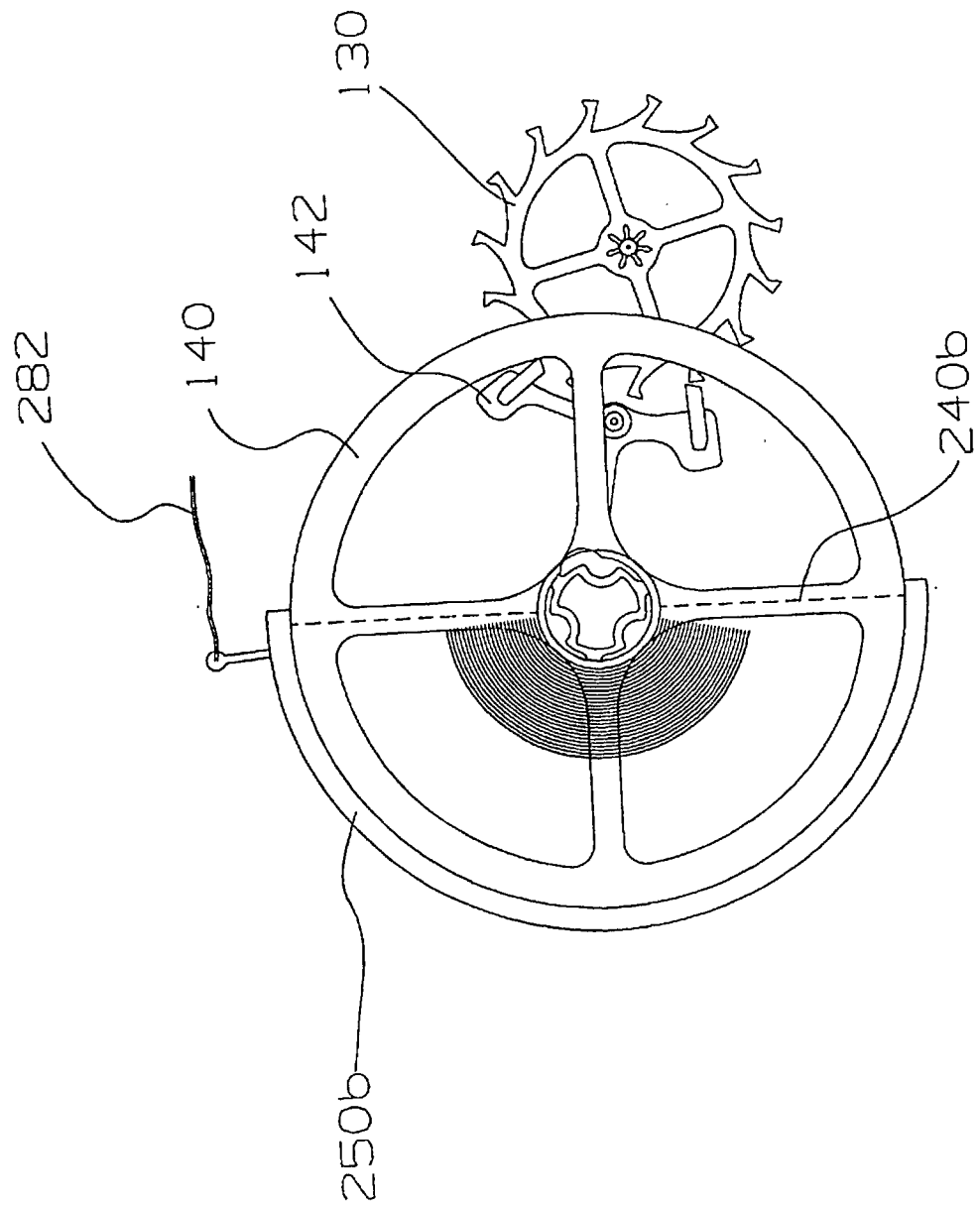


FIG. 8

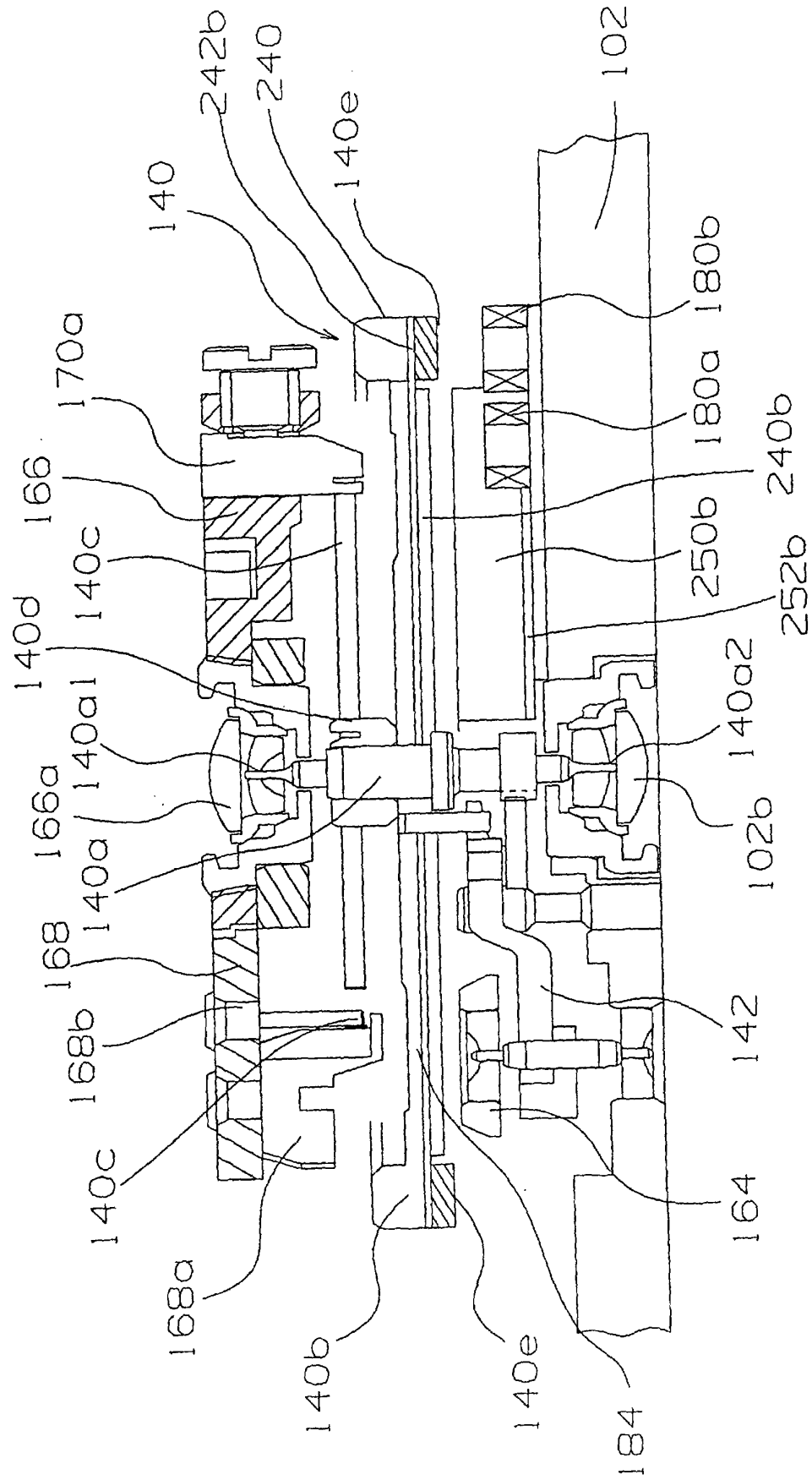


FIG. 9

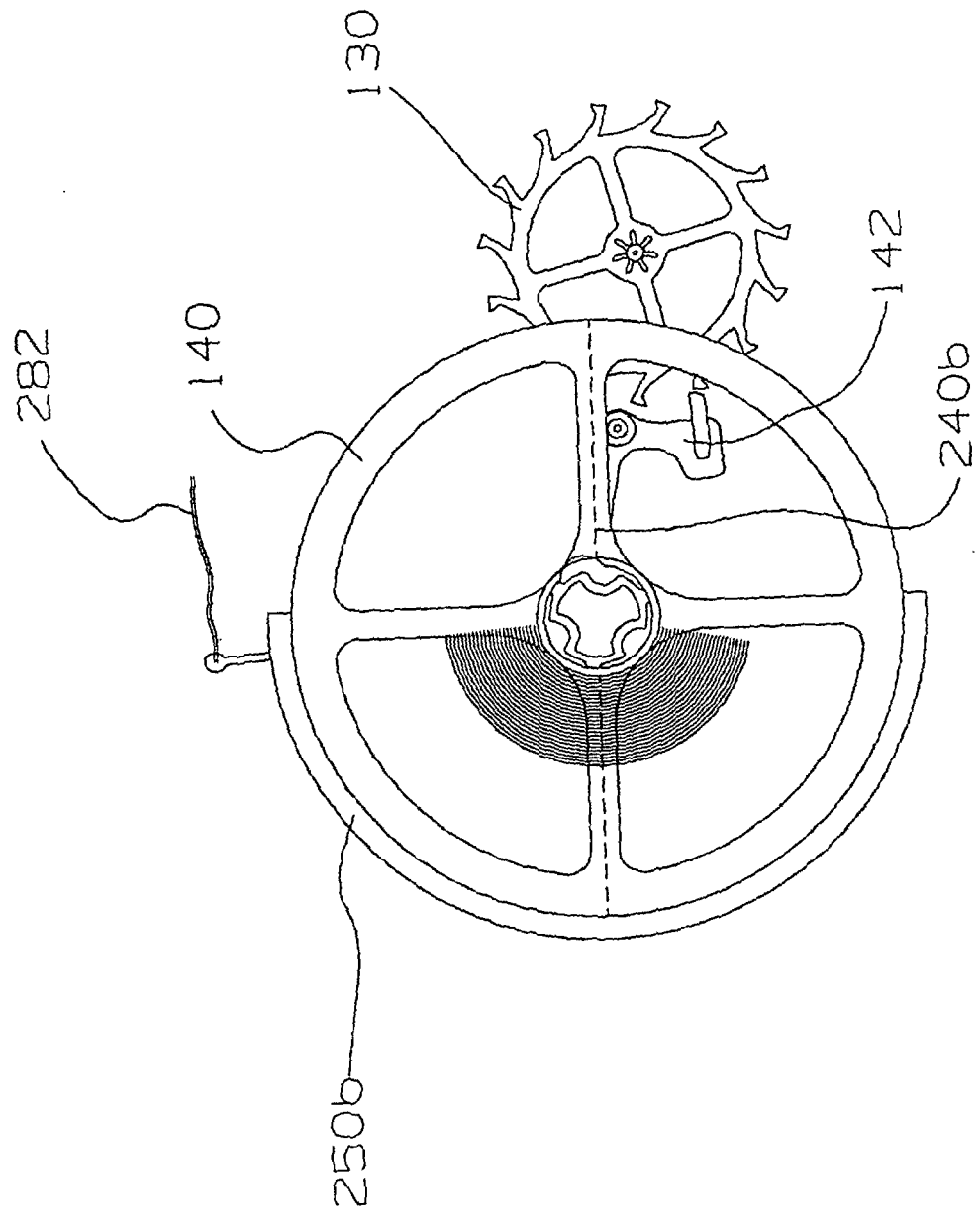


FIG. 10

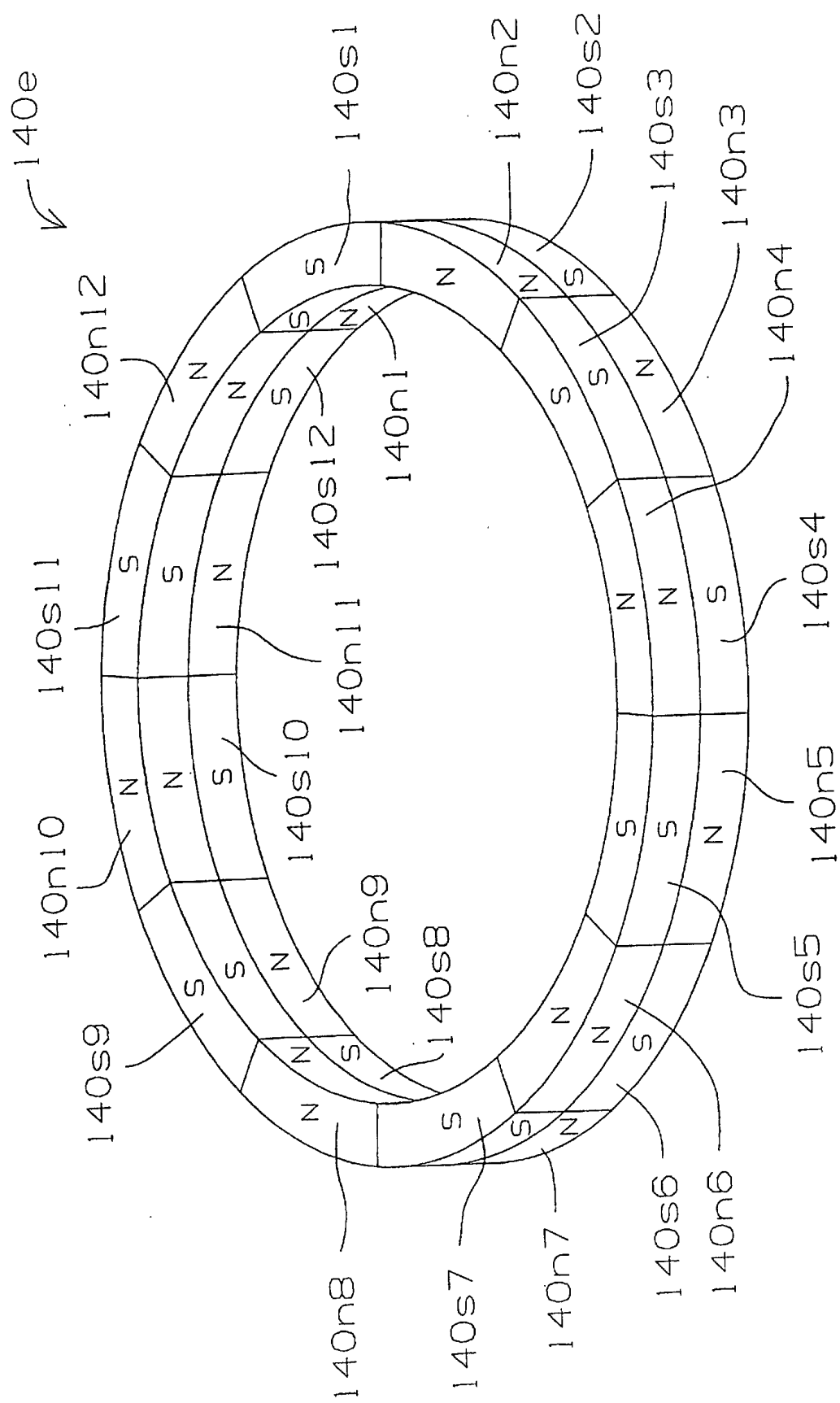


FIG.11

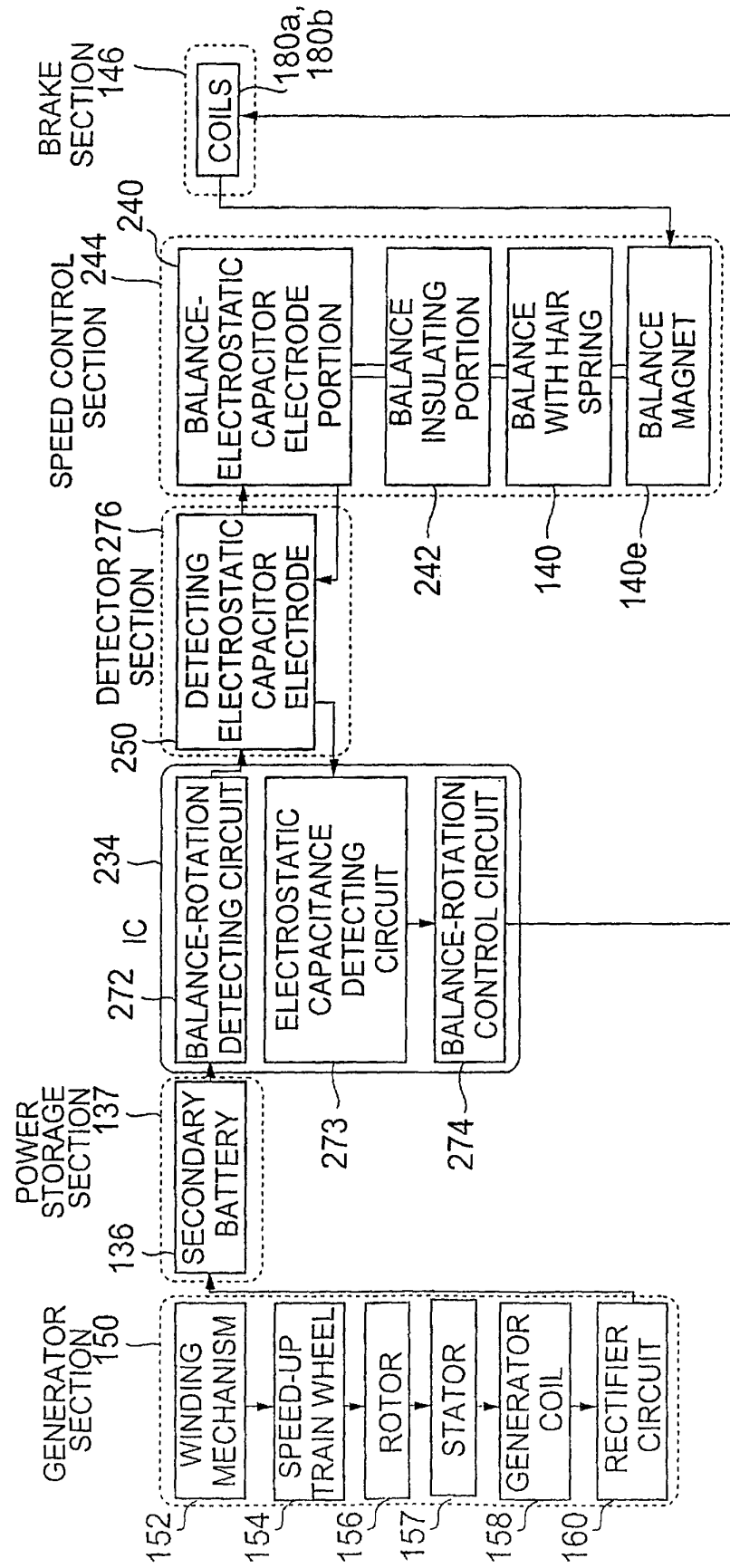


FIG.12

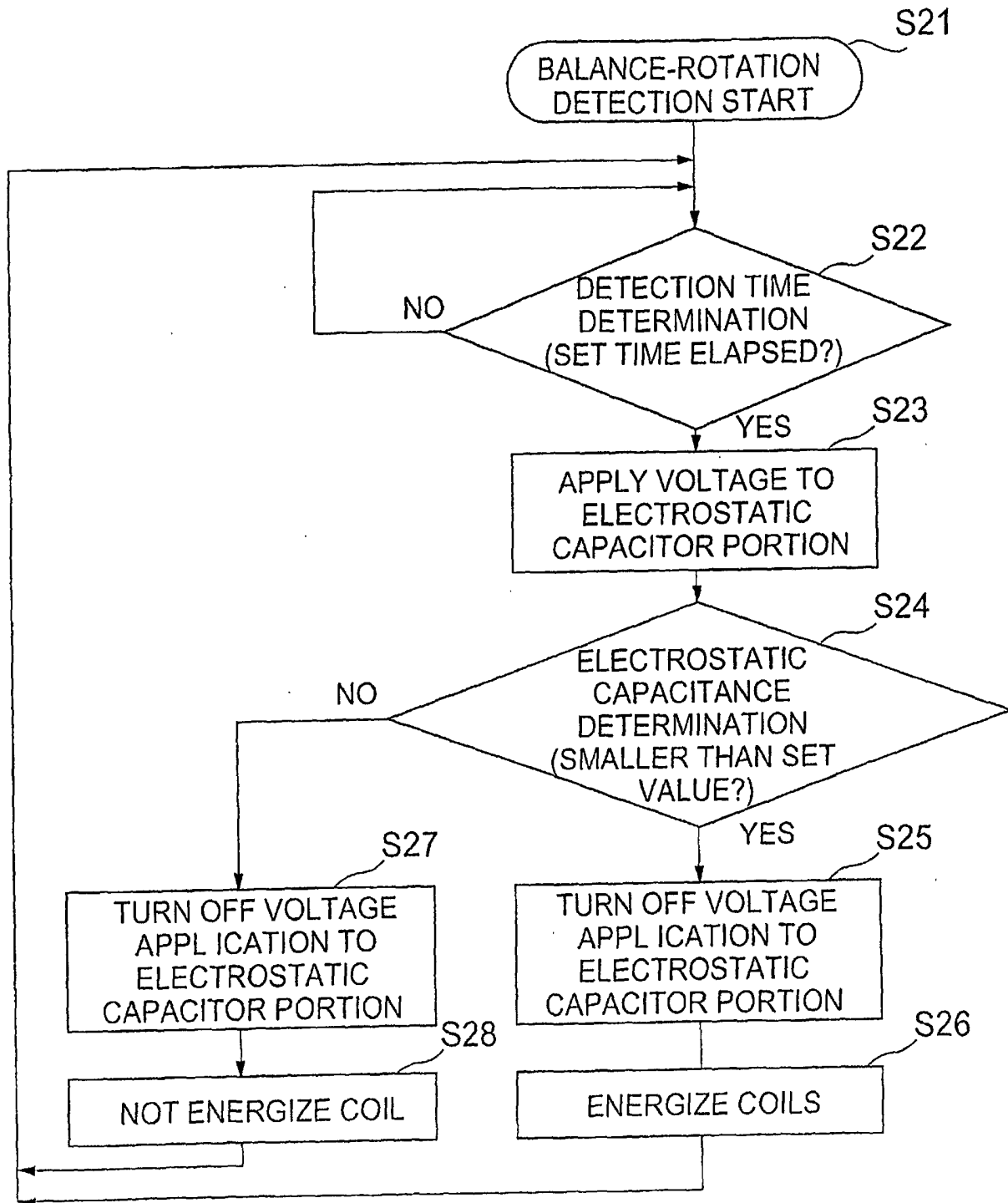


FIG. 13

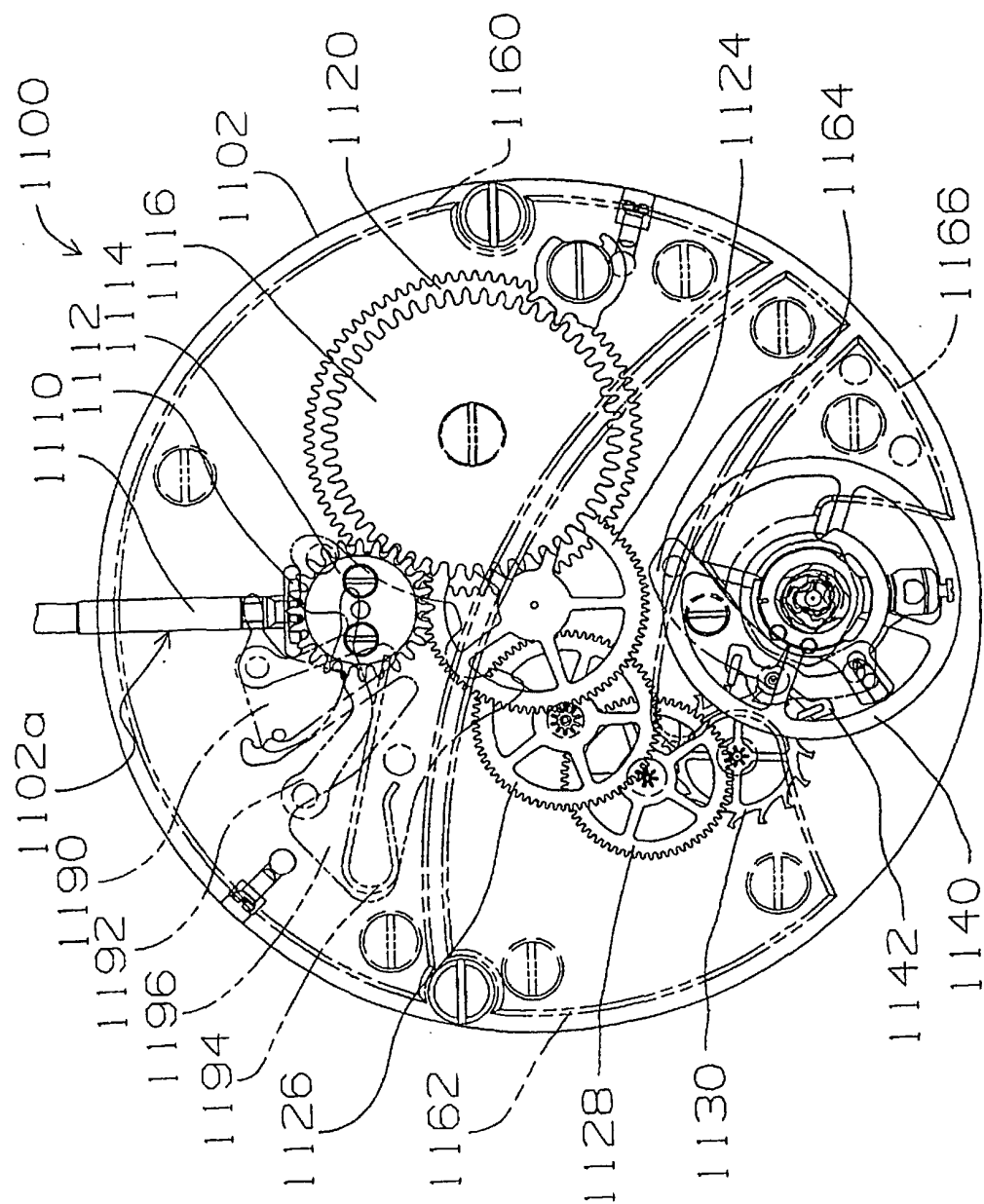


FIG. 14

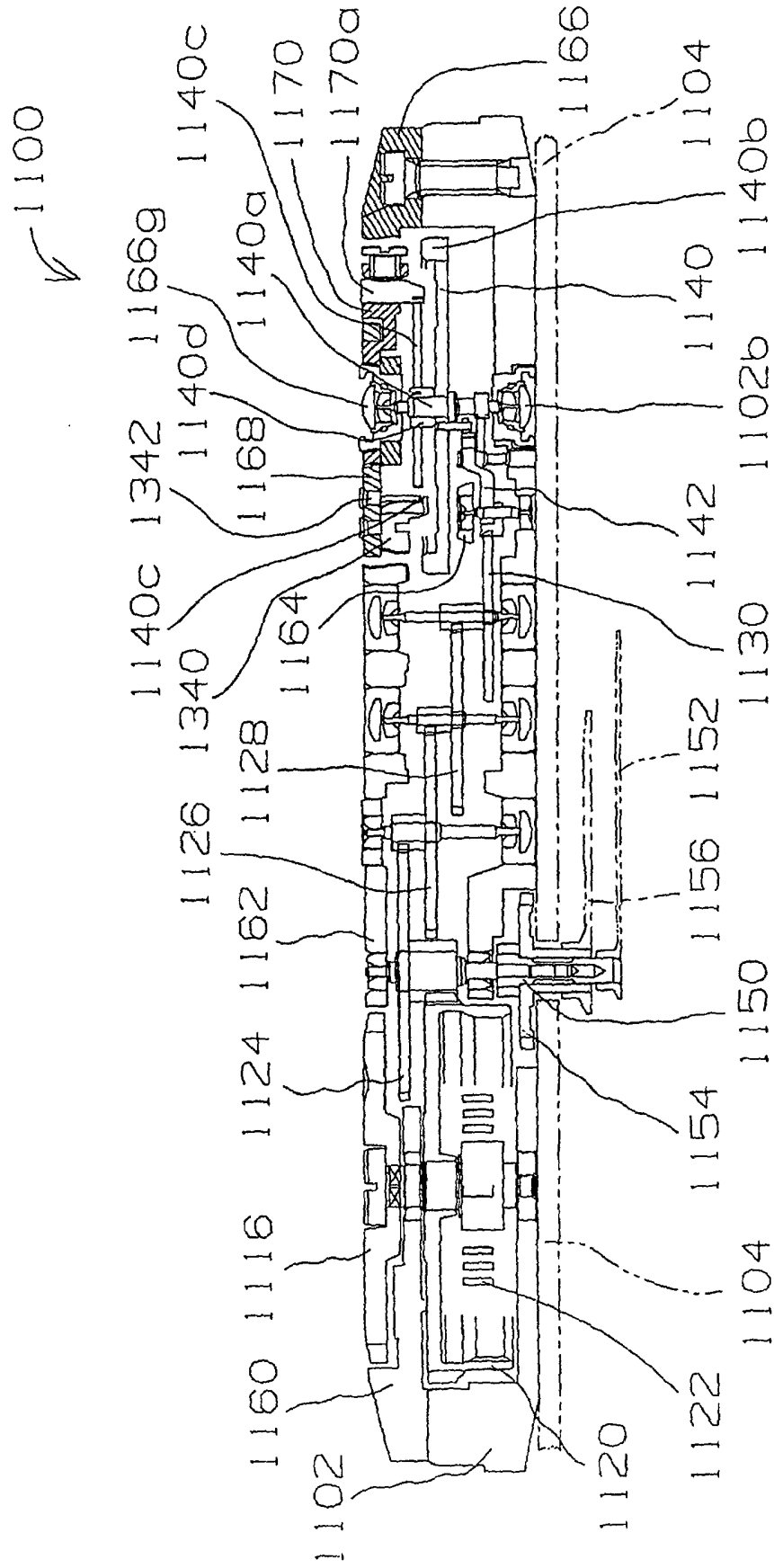


FIG. 15

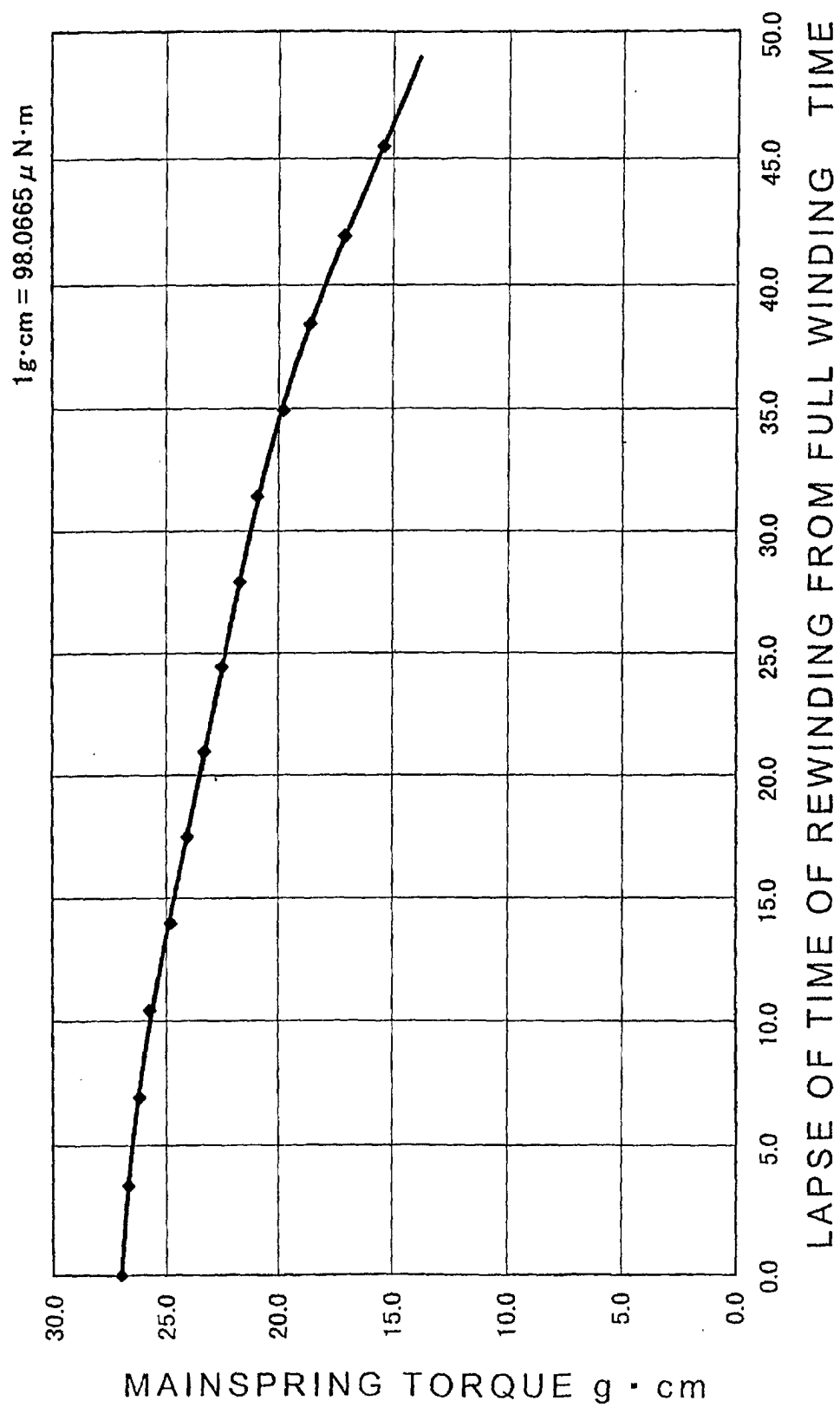


FIG. 16

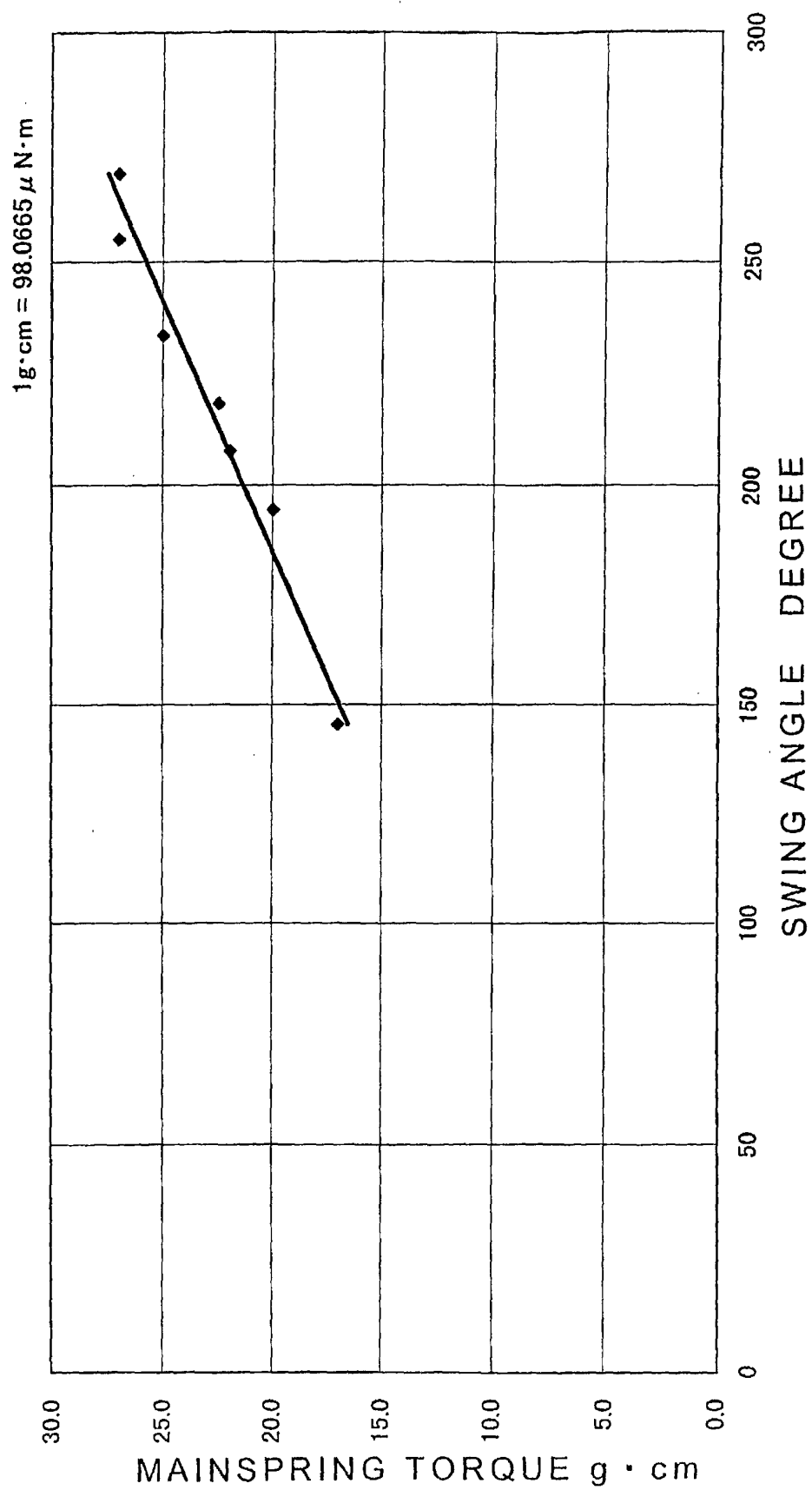


FIG. 17

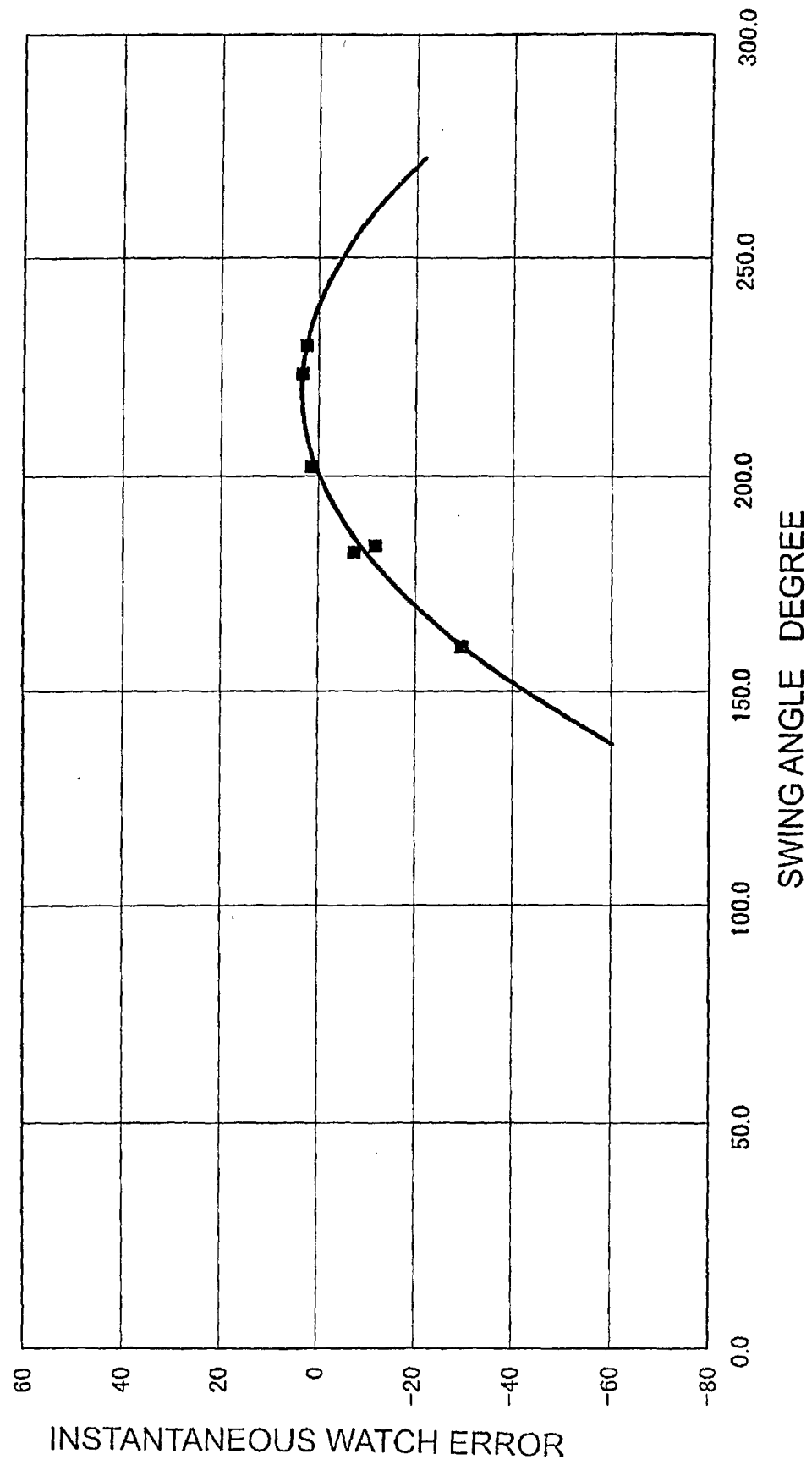
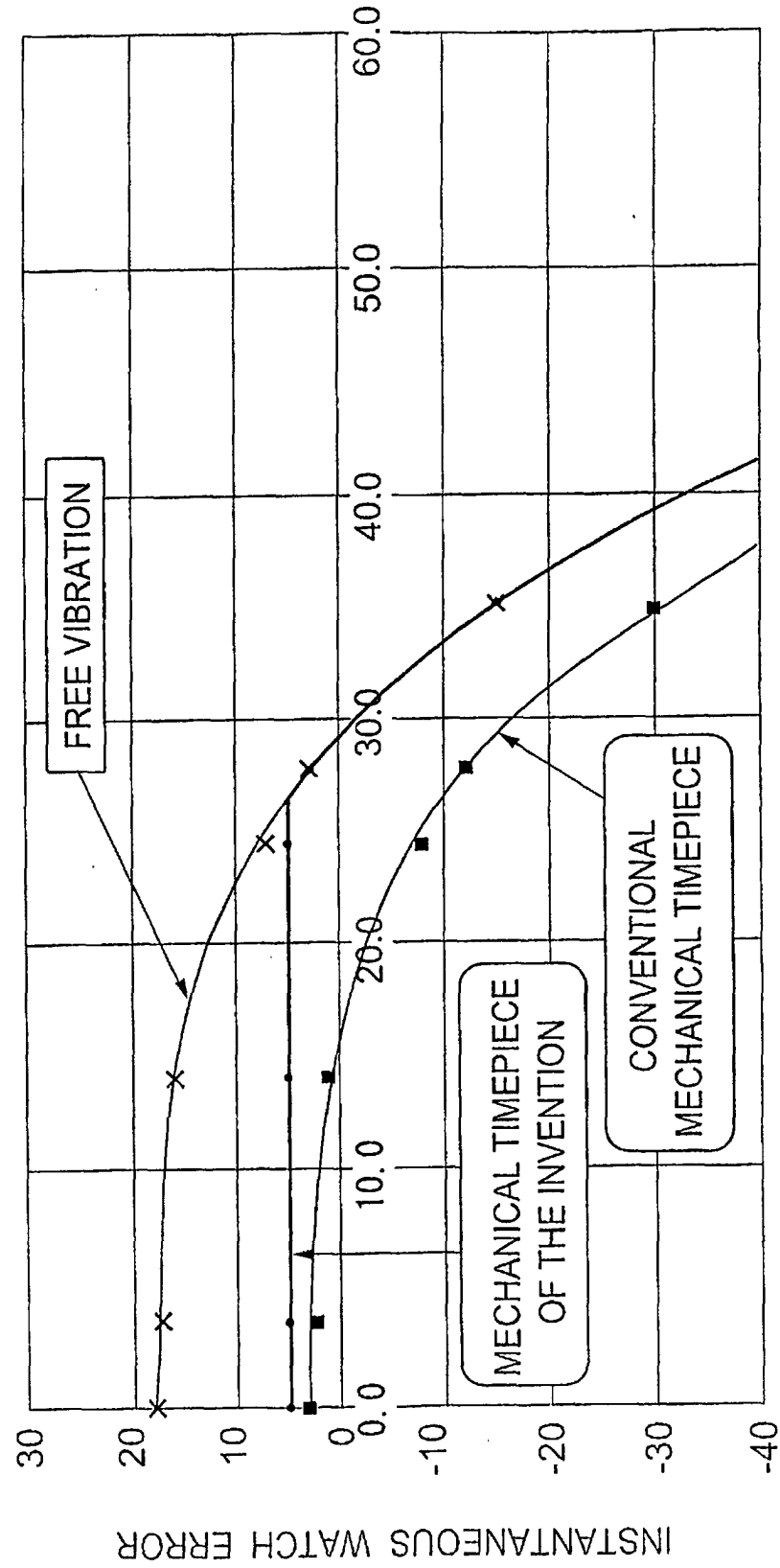


FIG.18



LAPSE OF TIME OF REWINDING FROM FULL WINDING TIME

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP00/01165

A. CLASSIFICATION OF SUBJECT MATTER Int.Cl. ⁷ G04B17/06, G04C3/04, 10/00		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) Int.Cl. ⁷ G04B17/06, 17/20, G04B18/00, G04C3/04, 10/00, G04D7/12		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Jitsuyo Shinan Koho 1922-1996 Toroku Jitsuyo Shinan Koho 1994-2000 Kokai Jitsuyo Shinan Koho 1971-2000 Jitsuyo Shinan Toroku Koho 1996-2000		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP, 39-7098, Y1 (Kabushiki Kaisha Hattori Tokeiten), 23 March, 1964 (23.03.64), Full text; Figs. 1 to 2 (Family: none)	1-11
A	Microfilm of the specification and drawings annexed to the request of Japanese Utility Model Application No.115366/1977 (Laid-open No.41675/1979) (Kabushiki Kaisha Seikosha), 20 March, 1979 (20.03.79), page 2, lines 1 to 5; page 3, lines 1 to 14; Figs. 1 to 2 (Family: none)	1-11
A	US, 3714773, A (TIMEX CORP.), 06 February, 1973 (06.02.73), Full text; Figs. 1 to 7 & JP, 48-58876, A & AU, 4831372, A & BE, 790818, A & CA, 956015, A & CH, 1594972, A & DE, 2252883, A1 & FR, 2158373, A & GB, 1358657, A & IT, 966866, A & NL, 7214761, A	1-11
☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 11 May, 2000 (11.05.00)		Date of mailing of the international search report 23 May, 2000 (23.05.00)
Name and mailing address of the ISA/ Japanese Patent Office		Authorized officer
Facsimile No.		Telephone No.

Form PCT/ISA/210 (second sheet) (July 1992)