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(54) **Timepiece**

(57) A timepiece is described that includes a mechanical power system having a mainspring and housed in a barrel that is powered by the mechanical energy provided by the mainspring. The timepiece also includes a main wheel train engaged with the barrel and including an assembly of wheels meshed to each other for transmitting a torque output of the mainspring for driving time indicating hands. The timepiece also includes an electric motor engaged with a predetermined wheel of the main wheel train through an electric motor transmission mechanism, so as to provide an additional controllable torque output to main wheel train for driving the time indicating hands, thereby a total torque that drives the timepiece includes the torque provided by the mainspring and the additional controllable torque provided by the electric motor.

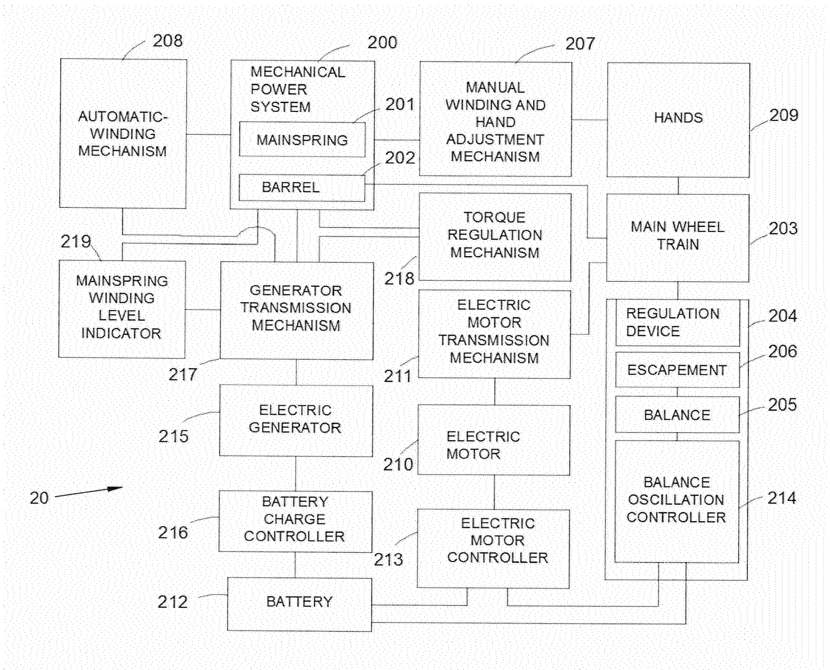


FIG. 2

EP 2 876 507 A1

Description

TECHNOLOGICAL FIELD

[0001] This invention relates generally to the field of horology, and in particular to a timepiece that has a wheel train driven by a mainspring and by an electric motor.

BACKGROUND

[0002] Generally, a conventional mechanical timepiece has a movement that includes a barrel which houses a mainspring providing a power source for the mechanical timepiece, a main (or primary) wheel train driven by the barrel, and a regulating device including a hairspring balance for controlling rotation of the wheel train. The regulating device also includes an escapement for maintaining angular oscillations of the hairspring balance of the regulating device arranged between the main wheel train and the hairspring balance. The arbors of certain wheels of the main wheel train bear indicator hands.

[0003] In modem watches, the mainspring is coiled around a barrel arbor, and is affixed to the barrel arbor at its inner end, and to the barrel at its outer end. The mainspring is wound by turning the arbor, but drives the watch movement by the barrel; this arrangement allows the mainspring to continue powering the watch while it is being wound.

[0004] Winding the watch turns the arbor, which tightens the mainspring, wrapping it closer around the arbor. The arbor has a ratchet attached to it, with a click to prevent the mainspring from turning the arbor backward and unwinding. After winding, the arbor is stationary and the pull of the mainspring turns the barrel, which has a ring of gear teeth meshing with the pinion of the center wheel of the wheel train.

[0005] The barrel usually rotates once every 8 hours, so, for example, the common 40 hour mainspring requires 5 turns to unwind completely.

[0006] **Fig. 1** illustrates a relationship between the number of turns *n* of an arbor **10** and the torque output M provided by a mainspring **11** housed in a barrel **13.** In the released state (shown by a Roman reference numeral **I**), when the mainspring **11** is completely unwound, coils **12** of the mainspring are tight near an inner wall of the barrel **13.** A torque provided by the mainspring in this state is zero. This point is indicated by an alphabetic character **A** on a curve of the dependence of a torque *M* versus a number of turns n of the arbor.

[0007] The state shown by a Roman reference numeral **II** corresponds to the first turns of the arbor. For standard spring engines, a number of turns corresponding to transition from the state **I** to the state **II** can be from 1 to 3, depending on the size of the barrel, the length and thickness of the mainspring **11.** In the state **II,** only the first and the last coils of the mainspring are located adjacent to the arbor and to the barrel, correspondingly, while the remaining coils of the mainspring are separated uniformly from each other and are retained in the concentric shape. During transition from the state **I** to the state **II,** the coils untighten from the barrel and thus create a driving torque. The coils, which remain tight to the inner wall of the barrel, do not participate in creation of the driving torque. The transition from the state **I** to the state **II** is characterized by a non-linear increase of the torque magnitude from the point **A** up to the point **B** on the curve of the dependence of the torque versus the number of turns of the arbor.

[0008] Further, during winding up the mainspring **11** from the state **II** to the state **IV** through the transitional state **III,** all coils of the mainspring are untightened from the barrel **13,** and thus participate in creation of the driving torque. During transition from the state **II** to the state **IV,** the winding is characterized by a linear increase of the torque magnitude from the point **B** up to the point **C.** Depending on the method of fastening of the mainspring to the inner wall of the barrel, the coils in the transitional state **III** can be either concentric or eccentric. In the state **IV,** the coils tighten together and are wrapped around the arbor.

[0009] Further winding up the mainspring **11** to the fully wound state **V** increases the friction between the coils that results in a sharp non-linear increase of the torque magnitude from point **C** up to point **D** on the curve of the dependence of the torque versus the number of turns of the arbor. A number of turns corresponding to transition from the state **IV** to the state **V** can be from about 1 to 2.5,

[0010] During unwinding from the state **V** to the state **IV,** a very sharp reduction of the torque magnitude from the point **D** down to the point E is monitored on the curve of the dependence of the torque versus the number of turns of the arbor. The coils wrapped around the arbor **10** become less tight. Further, during unwinding from the state **IV** to the state **II** through the state **III,** the coils are unwrapped from the arbor, and the torque output follows a linear dependence on the curve of the dependence of the torque versus the number of turns from the point **E** down to the point **G** through point **F.** The section **GE** on the curve passes below the section **BC,** owing to the hysteresis.

[0011] At the last stage of unwinding from the state **II** to the state **I,** the coils tightens near the inner wall of the arbor **10,** and the torque output of the mainspring **11** diminishes from the point **G** down to down to zero at the point **A**.

[0012] It should be noted that during unwinding in a conventional mechanical timepiece only a liner part of the dependence of the torque versus the number of turns (i.e., section **GE**) is used. In particular, the large torque output that is provided by the mainspring **11** during unwinding from the state **V** to the state **IV** is not used, because such a sudden large torque can cause damage to the regulating device controlling rotation of the main wheel train and to the escapement. Likewise, when the torque output provided by the mainspring during unwinding becomes smaller than the magnitude corresponding to the point **G,** the indicator hands gradually slow down and the timepiece stops operating, because, the torque associated with friction in the wheel train exceeds the torque output provided by the mainspring **11.**

[0013] In order to maintain a mainspring within a set torque range that usually corresponds to the linear operating regime, timepieces are usually provided with a winding-up stop mechanism and an unwinding stop mechanism that prevent winding and/or unwinding of the mainspring beyond a certain maximum number of turns during winding or minimum number of turns during unwinding.

[0014] For example, U.S. Pat. No 6,422,739 to Hara et al. describes a timepiece that drives a primary (main) wheel train by mechanical energy of a mainspring. The timepiece includes a winding-up portion that accumulates energy in the mainspring; an addition-and-subtraction wheel train driven by addition and subtraction of accumulated energy corresponding to an amount by which the mainspring is wound up and unwound, respectively. An addition-and-subtraction wheel is disposed in the addition-and-subtraction wheel train can rotate in correspondence with an amount by which the mainspring is wound up and unwound. The winding-up portion includes a lock mechanism actuated in response to the rotation of the addition-and-subtraction wheel to limit winding up and unwinding of the mainspring to a selected range of windings, and to thereby prevent transmission of torque having a value outside a set range from the mainspring to the primary wheel train.

[0015] As can be seen in the graph shown in **Fig. 1,** the torque provided by a mainspring in a conventional mechanical timepiece is not constant, but diminishes as the mainspring unwinds. In turn, as mainspring unwinds and the torque decreases on the linear section **GE** from the maximal torque M_{max} to the minimal torque M_{min}, a swing angle of the balance wheel also decreases and precision of the timepiece changes. In particular, the timepiece can be precise at a certain optimal magnitude M_{opt}, while advance or delay when the torque is greater or lower than the optimal magnitude M_{opt}, correspondingly.

[0016] Several approaches are known in the art for increasing operation time of a timepiece and improving timepiece precision.The operation time of a timepiece can, for example, be extended by increasing potential energy stored in the mainspring by using a mainspring with a greater torque. Moreover, the operation time can be extended by utilizing dedicated mechanisms reducing the torque required to drive the main wheel train. Likewise, electro-magnetic motors can be used for providing additional power to the mainspring. In turn, the timepiece accuracy can be improved by utilizing various stabilization mechanisms that stabilize the torque on the barrel and/or the swing angle of the balance.

[0017] For example, GB2349240 to Parker et al. describes a power source for automatically winding up a mechanical clock. The power source includes an electric motor, control means for the motor and means adapted to connect the output from the motor to a component of the power drive of the clock. In particular, the output shaft of the electric motor is connected by a chain and sprocket drive to a winding drum (i.e., barrel which houses a mainspring) of the clock. The control means are configured for sensing the torque at the output from the motor and controlling the supply of current to the motor in accordance with the torque sensed. When a minimum value of torque is detected the control means permits current to be supplied to the motor so that power can be transmitted to the driving drum. When adequate power has been supplied, further rotation of the winding drum is resisted by a ratchet mechanism. Consequently, if the load on the motor shaft increases beyond a predetermined maximum torque, the control means discontinues the current supply until the minimum value of torque is detected again.

[0018] U.S. Pat. No. 7,906,938 to Yang describes a timing device that utilizes hybrid power to intermittently drive a movement of the timing device. To achieve this purpose, electrical power from a power supply is timely delivered to an electro-magnetic driving unit including an electric motor that provides torque to drive the mainspring barrel through an automatic control unit manipulated by a mechanical energy storage status detection unit to produce mechanical energy.

[0019] It should be noted that winding a mainspring by an electric motor, as described in GB2349240 and U.S. Pat. No. 7,906,938, can require powerful electric motors and corresponding batteries for driving such electric motors. This requirement can result in serious difficulties in placing such powerful batteries within a limited space inside of wrist watches.

[0020] Another way to increase operation time of a timepiece can be based on the stabilization of the torque on the barrel by means of redistribution of the torque provided by the mainspring during unwinding. In operation, the maximal torque magnitude M_{max} at point **E** in the graph in **Fig. 1** can exceed the optimal magnitude M_{opt} at the point F by 15-20%. This torque excess can increase the load on the main wheel train, and if this large torque of the mainspring is not used, the energy corresponding to this torque excess is wasted. On the other hand, as the torque decreases below the optimal magnitude M_{opt}, the timepiece precision gradually drops.

[0021] U.S. Pat. No. 7,906,938 to Nagasaka describes a timepiece having a mechanism that enables accumulation of the energy corresponding to torque excess, and supplying this energy for driving the wheel train when torque magnitude is low. The timepiece includes a mainspring, an output wheel that is rotated by torque output from the mainspring, a lever that pivots synchronously to the output wheel, and a pressure member, such as a spring that pushes the lever. The pressure member pushes the lever so that the output torque of the output wheel increases as the mainspring unwinds.

[0022] The total torque that drives the timepiece is the torque combining the torque output from the mainspring and the torque applied to the output wheel by the pressure from the lever. Because the torque applied to the output wheel increases as the mainspring unwinds, this additional torque assists the decreasing torque from the mainspring as the mainspring unwinds. The problem of reduced precision resulting from the large difference between the torque output of the mainspring when the mainspring is fully wound and the torque output when the mainspring is unwound can therefore be solved, and stable timekeeping can be assured. Furthermore, because the torque applied to the output wheel increases as the mainspring unwinds, the timepiece can be driven beyond the point where the timepiece stops when the mainspring unwinds in a timepiece without such a mechanism, and the timepiece can be driven for a longer continuous operating time.

[0023] U.S. Pat. No. 7,780,342 to Takahashi et al. describes a timepiece having a mechanism that enables increasing the duration time of the mainspring by means of redistribution of the torque provided by the mainspring during unwinding on the linear part of the dependence of the torque versus the number of turns of the arbor of the mainspring. The timepiece includes a spring device having an inside-end wheel, an outside-end wheel and a torque return unit. The inside-end wheel moves in conjunction with the inside end of the mainspring. The outside-end wheel moves in conjunction with the outside end of the mainspring. The torque return unit transfers part of the output torque of the mainspring from one to the other of the inside-end wheel and outside-end wheel.

[0024] The inside-end wheel and the outside-end wheel are connected through the torque return unit only when the mainspring is wound greater than a reference number of winds so that the mainspring is wound by part of the output torque of the mainspring communicated through the drive wheel train being returned through the torque return unit to the mainspring. When the mainspring unwinds to a number of winds less than the reference number of winds, the connection between the inside-end wheel and outside-end wheel is disengaged by a torque transfer clutch unit, and all output torque from the mainspring is applied to drive the main wheel train.

[0025] As explained above, during unwinding of the mainspring, the mainspring torque and the swing angle of the balance is reduced and, accordingly, precision of the timepiece changes. European Patent Application No. 1172713 to Sasaki et al. describes a mechanical timepiece that comprises a detecting unit configured for detecting a swing angle of the hairspring balance by detecting an operational state of the balance by using light, and a braking unit configured for controlling the swing angle for adjusting the timepiece precision. The braking unit is adapted such that when the swing angle of the hairspring balance detected by the detecting unit is equal to or larger than a predetermined angle, a force of restraining rotation of the hairspring balance is exerted to the hairspring balance.

[0026] The braking unit includes a balance magnet mounted on the hairspring balance and coils arranged to be capable of braking motion of the balance magnet mounted on the hairspring balance. The braking unit also includes a balance rotation detecting circuit configured to control light emitted by the light emitting portion and a balance rotation controlling circuit constituted to measure operation of the balance arm portion and calculate a swing angle of the balance with hairspring. The balance rotation controlling circuit of the mechanical timepiece is configured to disconnect the coils from electrical power when the swing angle of the balance with hairspring is less than a certain threshold magnitude, and to feed the coils with electrical power when the swing angle of the hairspring balance is equal to or larger than the threshold magnitude.

GENERAL DESCRIPTION

[0027] Thus, there is still a need in the art for, and it would be useful to have, a novel a timepiece that can be driven for a longer continuous operating time than a conventional mechanical timepiece.

[0028] It would also be beneficial if a timepiece would have an enhanced precision.

[0029] The present invention partially eliminates the deficiencies of the prior art horology devices, and provides a novel timepiece. According to an embodiment of the present invention, the timepiece includes a mechanical power system having a mainspring associated with a ratchet and housed in a barrel that is powered by the mechanical energy provided by the mainspring. The timepiece also includes a main (primary) wheel train engaged with the barrel. The main wheel train includes an assembly of wheels meshed to each other for transmitting a torque output of the mainspring for driving time indicating hands. The timepiece also includes a timepiece regulating device having a balance engaged with the main wheel train and an escapement adapted for maintaining angular oscillations of the balance. The timepiece also includes a manual winding and hand adjustment mechanism coupled to the ratchet and to the time indicating hands.

[0030] According to an embodiment of the present invention, the timepiece further includes an electric motor engaged with a predetermined wheel of the main wheel train through an electric motor transmission mechanism, so as to provide an additional controllable torque output to main wheel train for driving said time indicating hands. Thus, a total torque that drives the timepiece includes the torque provided by the mainspring and the additional controllable torque provided by the electric motor.

[0031] According to an embodiment of the present invention, the predetermined wheel of the main wheel train that is engaged with said electric motor transmission mechanism is the third wheel when the counting starts from the barrel.

[0032] According to an embodiment of the present invention, the timepiece further includes a torque regulation mechanism coupled to the mechanical power system, and configured to control operation of the mainspring and the ratchet during winding and unwinding the mainspring.

[0033] According to an embodiment of the present invention, the torque regulation mechanism includes a ratchet wheel train coupled to the ratchet, and a ratchet lock mechanism configured for locking said ratchet wheel train for stopping rotation of the ratchet.

[0034] According to an embodiment of the present invention, the torque regulation mechanism also includes a barrel wheel train coupled to the barrel, and a barrel lock mechanism configured for stopping or allowing rotation of the barrel. The torque regulation mechanism also includes a first cam wheel coupled to the ratchet lock mechanism and to the barrel lock mechanism, and configured for activating the ratchet lock mechanism and the barrel lock mechanism to stop or enable rotation of the ratchet and the barrel during winding the mainspring, correspondingly.

[0035] According to an embodiment of the present invention, the torque regulation mechanism further includes a click lifting mechanism configured for releasing the ratchet to enable rotation of the ratchet in a direction that is reverse to the rotation of the ratchet during winding the mainspring. The torque regulation mechanism also includes a second cam wheel coupled to the click lifting mechanism, and configured for activating the click lifting mechanism. The second cam wheel can have an arbor common with the arbor of the first cam wheel and be mounted on and coupled to the first cam wheel.

[0036] According to an embodiment of the present invention, the timepiece further includes a mainspring winding level indicator. For example, the mainspring winding level indicator can include a needle affixed to the arbor of the first and second cam wheels, and a sub-dial marked with indicia.

[0037] According to an embodiment of the present invention, the timepiece further includes an electric battery for providing electrical power to the electric motor, and an electric motor controller coupled to the electric battery and to the electric motor. The electric motor controller is configured to drive the electric motor by controllably supplying electrical power from the electric battery thereto.

[0038] According to an embodiment of the present invention, the timepiece further includes an electric generator configured to generate an electrical energy for charging the electric battery, and a generator transmission mechanism.

[0039] According to an embodiment of the present invention, the generator transmission mechanism includes a ratchet torque transmission train coupled to the ratchet, and configured for transmitting a torque from the ratchet to the electric generator for driving thereof during rotation of the ratchet.

[0040] According to an embodiment of the present invention, the timepiece further includes an automatic winding mechanism coupled to the generator transmission mechanism, and configured to rotate the ratchet for winding the mainspring and to drive the electric generator for charging the electric battery.

[0041] According to an embodiment of the present invention, the timepiece regulating device includes a detecting unit and a processing unit electrically coupled to detecting unit. The detecting unit is configured for measuring rotational operation the balance for determining an oscillation period of the balance. The processing unit is configured for processing the data measured by the detecting unit, and when the measured data deviate from predetermined magnitudes, generating control signals and relaying them to the electric motor controller for driving the electric motor to provide the additional controllable torque for driving the main wheel train.

[0042] According to an embodiment of the present invention, the detecting unit includes an electromagnetic transmitter arranged at on one side of the balance and configured for irradiating an arm portion of the balance, and an electromagnetic receiver arranged at the opposite side of the balance and positioned in an optical path so that a field of view of the electromagnetic receiver ensures the capture of a part of the radiation which is transmitted by the electromagnetic transmitter and irradiated the arm portion of the balance.

[0043] According to an embodiment of the present invention, the processing unit includes a memory unit and a processor. The memory unit can, for example, store a relationship between an oscillation period of the balance and a torque driving the main train wheel. The memory unit can also store an optimal magnitude of the operating torque driving the main train wheel at which operation of the timepiece is precise. The processor can, for example, be configured for analyzing the data measured by the detecting unit, calculating the current operating torque and its deviation from the optimal magnitude, and for generating the control signals to the electric motor controller to drive electric motor, if the current operating torque deviates from the optimal torque magnitude.

[0044] There has thus been outlined, rather broadly, the more important features of the invention in order that the detailed description thereof that follows hereinafter may be better understood. Additional details and advantages of the invention will be set forth in the detailed description, and in part will be appreciated from the description, or may be learned by practice of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0045] In order to better understand the subject matter that is disclosed herein and to exemplify how it may be carried out in practice, embodiments will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

Fig. 1 illustrates schematically a relationship between the number of turns of an arbor and the torque output provided by a mainspring;

Fig. 2 illustrates a schematic block diagram of a timepiece, according to a one embodiment of the invention;

Fig. 3 illustrates a schematic plan view of a front side of the timepiece shown in **Fig. 2,** according to an embodiment of the present invention;

Fig. 4 illustrates schematic a schematic plan view of a first cam of the torque regulation mechanism of the timepiece, according to an embodiment of the present invention;

Figs. 5A and 5B illustrate a schematic view of the torque regulation mechanism in locked and unlocked states, correspondingly, according to an embodiment of the present application;

Fig. 6 illustrates schematic a schematic plan view of a second cam of the torque regulation mechanism of the timepiece, according to an embodiment of the present invention;

Fig. 7 illustrates schematic spatial relation in the torque regulation mechanism between the first cam wheel, the second cam wheel, ratchet lock lever, the barrel lock lever and the pusher lever, according to an embodiment of the present invention;

Fig. 8 illustrates a schematic perspective view of the generator transmission mechanism for driving the generator, according to an embodiment of the present invention;

Fig. 9 illustrates a perspective top view of the unidirectional coupling-clutch device of the generator transmission mechanism, according to an embodiment of the present invention; and

Fig. 10 illustrates a schematic perspective view of the electric motor transmission mechanism and the regulation device, according to a one embodiment of the present invention.

DETAILED DESCRIPTION OF EMBODIMENTS

[0046] The principles of the timepiece according to the present invention may be better understood with reference to the drawings and the accompanying description, wherein like reference numerals have been used throughout to designate identical elements. It is to be understood that these drawings, which are not necessarily to scale, are given for illustrative purposes only and are not intended to limit the scope of the invention. For example, the dimensions of some of the elements in the figures may be exaggerated relative to other elements to help improve understanding of various embodiments. In addition, the description and drawings do not necessarily require the order illustrated. It will be further appreciated that certain actions and/or steps may be described or depicted in a particular order of occurrence while those skilled in the art will understand that such specificity with respect to sequence is not actually required.

[0047] It should be noted that the blocks as well other elements in these figures are intended as functional entities only, such that the functional relationships between the entities are shown, rather than any physical connections and/or physical relationships. Those versed in the art should appreciate that many of the examples provided have suitable alternatives which may be utilized.

[0048] Referring to **Fig. 2,** a schematic block diagram of a timepiece **20** is illustrated, according to a one embodiment of the present invention. The timepiece **20** of the present invention involves integration of mechanical and electric mechanisms and devices which are indicated by block-modules in **Fig. 2,** and is not limited to a specific implementation of its components.

[0049] As shown in **Fig. 2,** the timepiece **20** includes a mechanical power system (generally indicated by a reference numeral **200** having a mainspring **201** housed in a barrel **202** that is powered by the mechanical energy provided by the mainspring **201.** The timepiece **20** also includes a main (primary) wheel train **203** engaged with the barrel **202.** The timepiece **20** also includes a timepiece regulating device **204** including a hairspring balance **205** and engaged with the main wheel train **203.** The timepiece **20** also includes an escapement **206** adapted for maintaining angular oscillations of a balance wheel (not shown) of the hairspring balance.

[0050] The mainspring **201** may be wound by one or more known winding mechanisms. Thus, the timepiece **20** includes a manual winding and hand adjustment mechanism (generally indicated by a reference numeral **207**). When desired, the timepiece **20** can also include an automatic winding mechanism **208.**

[0051] The main wheel train **203** includes an assembly of wheels (not shown) meshed to each other in the usual manner for transmitting a torque output of the mainspring **201** through the wheels with the appropriate multiplying ratios for driving time indicating hands **209** as the mainspring **201** unwinds.

[0052] According to an embodiment of the present invention, the timepiece **20** also includes an electric motor **210** engaged with the main wheel train **203** through an electric motor transmission mechanism **211,** so as to provide an additional controllable torque output for driving time indicating hands **209.** The additional controllable torque output that is provided by the electric motor **210** is applied to a predetermined wheel of the main wheel train **203** that is dedicated for this purpose, as will be described hereinbelow in detail.

[0053] Thus, the total torque that drives the timepiece **20** is the torque output combining the torque from the mainspring **201** and the torque applied to the main wheel train **203** by the electric motor **210.** Since the torque output from the mainspring **201** decreases as the mainspring unwinds, this additional torque provided by the electric motor **210** can, *inter alia,* drive the main wheel train **203** when the torque associated with the friction in the wheel train exceeds the torque provided by the mainspring (i.e., section **AG** in **Fig. 1**). As described above, conventional timepieces cannot normally operate when the torque decreases below the magnitude corresponding to point **G**

in the graph in **Fig. 1,** because below the magnitude corresponding to point **G** the hands of a conventional timepiece gradually slow down, and finally the timepiece stops operating. Thus, when the mainspring **201** is unwound beyond point **G,** the timepiece **20** can be driven by the electric motor **210;** thereby the timepiece **20** can be driven for a longer continuous operating time than a conventional timepiece.

[0054] Moreover, as will be described hereinbelow in detail, during unwinding of the mainspring, the electric motor **210** can assists to drive the main wheel train **203** also at the linear torque regime between the states **II** and **IV** in **Fig. 1,** so as to maintain the total torque that drives the timepiece at a predetermined magnitude close to a certain optimal magnitude M_{opt}. The problem of reduced precision resulting from the large difference between the torque output of the mainspring when the mainspring is wound and the torque output when the mainspring is unwound is therefore can be solved, and stable timekeeping can be assured.

[0055] As described above, the non-linear torque region between the states **IV** and **V** in **Fig. 1** is usually not used in conventional mechanical timepieces, because a large torque output in this region can cause damage to the regulating device **204** controlling rotation of the main wheel train **203** and to the escapement **206** during unwinding. On the other hand, according to an embodiment of the present invention, winding of the mainspring **201** is not ceased at point **C** at the end of the linear torque regime between states **II** and **IV** in **Fig. 1**, as it is carried out in conventional timepieces, but rather continues further within the non linear torque regime beyond state **IV** towards fully wound state **V.** For example, the winding of the mainspring **201** can be continued up to 90% of the non-linear torque region between states **IV** and **V** in **Fig. 1** or even can be continued further.

[0056] In order to control operation of the mainspring **201** during winding and unwinding, the timepiece **20** includes a torque regulation mechanism **218** that is engaged with a ratchet (not shown) of the barrel **202** and with a barrel gear (not shown) formed on the outside circumference of the barrel **202.**

[0057] According to one embodiment of the present invention, the torque regulation mechanism **218** stops rotating the barrel **202** during winding at the end of the linear torque region (point **C** in the graph in **Fig. 1**). This feature prevents damage to the regulating device **204** that controls rotation of the main wheel train **203** and to the escapement **206** during unwinding caused by a large torque output in the non-linear region. According to this embodiment, winding of the mainspring **201** can be ceased together with the stopping of the barrel, as it is usually carried out in conventional timepieces.

[0058] According to another embodiment of the present invention, the winding of the mainspring **201** is not ceased together with the stopping of the barrel, but is rather continued further until the mainspring **201** is wound up to a predetermined wound state. For example, the mainspring **201** can be wound up to 90% of the non-linear torque region or even further until the mainspring **201** reaches the fully wound state. Thus, according to an embodiment of the present invention, the torque regulation mechanism **218** is also configured for blocking rotation of a ratchet (not shown) associated with the mainspring **201** as the mainspring **201** is wound to a predetermined or fully wound state.

[0059] According to an embodiment, the present application utilizes the non-linear torque region between states **IV** and **V** in **Fig. 1** in order to charge an electric battery **212** that provides electrical power to the electric motor **210.** The electric battery **212** is electrically coupled to the electric motor **210** through an electric motor controller **213.** The electric motor controller **213** is configured to drive the electric motor **210** by controllably supplying electrical power thereto. Examples of the electric motor **210** suitable for the present invention include, but are not limited to, a bi-directional stepper motor, an AC synchronous or AC asynchronous motor, a DC synchronous or DC asynchronous motor, etc.

[0060] In operation, the electric motor **210** can be powered by a voltage generated by the electric motor controller **213.** For example, a stepper motor can be powered by a train of voltage pulses so as to provide a precisely defined increment in position of a motor shaft (not shown) and to turn the shaft by a fixed desired angle. Suitable motors for timepieces and electric motor controllers for driving such motors are widely commercially available. The construction of such motors and electric motor controllers to functionally operate in the desired manner is well within the understanding of those versed in the art.

[0061] According to an embodiment of the present invention, the timepiece regulating device **204** of the timepiece **20** includes a balance oscillation controller **214** associated with the hairspring balance **205,** and electrically coupled to the electric motor controller **213.** The balance oscillation controller **214** is configured for controlling accuracy of the timepiece **20.** In operation, the balance oscillation controller **214** can detect oscillation parameters of a balance wheel (not shown) of the balance **205,** e.g., an oscillation period of the balance **205,** an amplitude of a swing angle, etc., and generates a deviation indication signals, if the measured parameters of the balance **205** deviate from predetermined parameters of the balance **205** which correspond to a precise operation of the timepiece. For example, when during unwinding the mainspring reaches a state corresponding to point **G** in the graph in **Fig. 1** and leaves the linear operation regime, the balance oscillation controller **214** can generate a deviation indication signal indicating decrease of the oscillation period of the balance **205** and/or changes of the swing angle, and relays this signal to the electric motor controller **213.** Responsive to this signal, the electric motor controller **213** can generate a train of driving pulses for activating and driving the electric motor **210** as long as required.

[0062] Likewise, according to an embodiment of the present invention, the balance oscillation controller **214** can be configured for controlling accuracy of the timepiece **20** at the linear torque regime between the states **II** and **IV** in **Fig. 1.** In particular, the balance oscillation controller **214** can be configured for determining the current operating torque and generating a deviation indication signal, if the measured operating torque deviates from the optimal torque magnitude M_{opt} in **Fig. 1** that correspond to precise operation of the timepiece. This feature enables maintaining the total torque that drives the timepiece at a predetermined magnitude close to the optimal magnitude M_{opt}.

[0063] According to an embodiment of the present invention, the timepiece **20** includes an electric generator **215** configured to generate an electrical energy for charging the electric battery **212.** The electric battery **212** is electrically coupled to the electric generator **215** through a battery charge controller **216** configured to control the charging process. The control of the charging process can be carried out by maintaining a required charging electric current for providing an output voltage by the battery **212** within desired magnitudes.

[0064] The electric generator **215** can be driven by one or several mechanisms.

[0065] Thus, according to an embodiment of the present invention, when the user of the timepiece winds the timepiece up, the electric generator **215** can be driven by the manual winding and hand adjustment mechanism **207** that rotates a ratchet (not shown) of the barrel **202** that is associated with an arbor (not shown) of the mainspring **201** of the mechanical power system **200.** The electric generator **215** can be mechanically coupled to the mechanical power system **200** through a generator transmission mechanism **217** engaged with the ratchet.

[0066] According to another embodiment of the present invention, the electric generator **215** can also be driven by the mechanical power system **200.** According to this embodiment, the generator transmission mechanism **217** can be engaged with the ratchet associated with the mainspring **201.** Thus, the rotation of the ratchet during winding can drive the electric generator **215** when the mainspring is wound from completely unwound state (**I** in **Fig. 1**) to the state (**V** in **Fig. 1**) in which the mainspring is fully wound.

[0067] Moreover, the electric generator **215** can also be driven during unwinding the mainspring from the state (**V** in **Fig. 1**) in which the mainspring in the fully wound state (that is selected near the end of the non-linear torque region corresponding to the point **D** in the graph in **Fig. 1**) to a predetermined wound state, for example, to the state (**IV** in **Fig. 1**) that corresponds to the beginning of the linear torque region (point **E** in the graph in **Fig. 1**). This can be achieved by enabling a counterclockwise rotation of the ratchet (that is reverse to the clockwise rotation during winding) only when the mainspring **21** unwinds in the non-linear torque regime, and blocking the reverse rotation of the ratchet at the moment when the mainspring unwinds to the beginning of the linear torque region (point **E** in the graph in **Fig. 1**). This function (as will be described hereinbelow in detail) is controlled by the torque regulation mechanism **218** that is also configured for engagement of the ratchet with the generator transmission mechanism **217** for driving the electric generator **210** only during unwinding the mainspring in the non-linear torque regime.

[0068] According to a further embodiment of the present invention, when the timepiece is moved, the electric generator **215** can also be driven by the automatic winding mechanism **208.** The automatic winding mechanism **208** can be coupled to the electric generator **215** through a special part of the generator transmission mechanism **217** dedicated for this purpose.

[0069] According to an embodiment of the present invention, the timepiece **20** includes a mainspring winding level indicator **219** configured for indicating the state of the mainspring **201** during winding and unwinding.

[0070] It should be understood that numerous different embodiments of the timepiece, which are functionally described above and shown in **Fig. 2,** can be implemented without changing the timepiece function. Examples of construction of the devices and mechanisms of the timepiece **20** shown in **Fig. 2** and its operation will be described hereinbelow in detail.

[0071] **Fig. 3** illustrates a schematic plan view of a front side of the timepiece **20** shown in **Fig. 2,** according to an embodiment of the present invention. It should be understood that the present description will omit, for purpose of brevity, certain basic and very well known concepts regarding the construction of mechanisms of the timepiece. However, for purpose of supporting the claims and providing an enabling disclosure, certain important components of such known mechanisms will be briefly described or referenced throughout. For example, the basic construction of the mechanical power system (**200** in **Fig. 2**) and arrangement of the mainspring **201** in the barrel **202** is not shown in **Fig. 3** in detail as being well within the purview of a person versed in the art. In should also be noted that certain components of the timepiece **20** indicated in **Fig. 2** can be mounted on a rear side of the timepiece **20,** and therefore these components are also not shown in **Fig. 3.** The timepiece **20** can include a dial (not shown) provided with numerals or other indicia to assist in reading time.

[0072] According to the embodiment shown in **Fig. 3,** the main wheel train (**203 in Fig. 2**) of the timepiece **20** can, for example, be a known wheel train described in detail in U.S. Pat. No. 6,439,762 (the description of which is hereby incorporated in its entirety by reference). As shown in **Fig. 3,** such a wheel train includes a second wheel **316** engaged with a third wheel **317** engaged with a second hand wheel **318** engaged with a fourth wheel **319** engaged with a fifth wheel **320.** The second wheel **316** of the main wheel train **203** is engaged with the barrel **202** and configured to rotate the time indicating hands (not shown) in an ordinary manner. In particular, a minute hand, which is not shown, can be coupled to the second wheel **316** through a cannon pinion (not shown), while a second hand can be affixed to the second hand wheel **318.** An hour wheel **326** can be affixed to the cannon pinion through a minute wheel **328,** with an hour hand (not shown) being affixed to the hour wheel **326.** The basic operation of the main wheel train **203** for transmitting the mechanical energy of the mainspring to rotate the time indicating hands, will be omitted as being well within the purview of a person versed in the art.

[0073] According to the embodiment shown in **Fig. 3,** the manual winding and hand adjustment mechanism (**207** in **Fig. 2**) of the timepiece **20** can, for example, be a known manual winding and hand adjustment mechanism **207** described in detail in U.S. Pat. No. 6,439,762 (the description of which is hereby incorporated in its entirety by reference). As shown in **Fig. 3,** such a manual winding and hand adjustment mechanism has a winding-up portion **320** and a hand adjusting portion **344.**

[0074] The winding-up portion **320** includes a winding stem **301,** the winding pinion **302,** a crown wheel **303,** an intermediate ratchet wheel **304** and a ratchet **224** associated with the mainspring. The mainspring can be wound by rotating a barrel arbor **225** that is capable of rotating integrally with the ratchet **224.** The ratchet **224** meshes with a click **306** so that it can rotate clockwise and cannot rotate counterclockwise. The ratchet **224** is constructed such that when the winding stem **301,** connected to a crown (not shown), is operated, it rotates through the winding pinion **302,** the crown wheel **303,** and the intermediate ratchet wheel **304,** and causes the barrel arbor **225** to rotate in order to wind up the mainspring.

[0075] The hand adjusting portion **344** of the manual winding and hand adjustment mechanism **207** is formed by the crown, the winding stem **301,** a sliding portion **335,** a setting wheel **336,** an intermediate minute wheel **337,** a minute wheel **328,** a setting wheel **340,** a click spring **341,** and a yoke **342.** Adjustments of the minute hand and the hour hand are performed by axially moving the winding stem **301** by pulling out the crown, and by moving the sliding portion **335** towards the setting wheel **336** and engaging it therewith by the action of the setting lever **340,** the click spring **341,** and the yoke **342.** Then, the cannon pinion associated with the second wheel **316** and the hour wheel **326** are rotated through the setting wheel **336,** the intermediate minute wheel **337,** and the minute wheel **328.**

[0076] As described above, the torque regulation mechanism **218** is configured to control winding and unwinding of the mainspring for locking and unlocking the barrel **202** in order to prevent damage of the control device **205,** and for locking and unlocking the ratchet **224** to utilize the energy of the mainspring **201** when it operates at the non-liner regime.

[0077] The torque regulation mechanism **218** includes a ratchet wheel train **50a** and an barrel wheel train **50b** that can be known winding-up and unwinding wheel trains configuration and operation of which are described in detail in U.S. Pat. No. 6,439,762 (the description of which is hereby incorporated in its entirety by reference).

[0078] The torque regulation mechanism **218** also includes a first cam wheel **352,** which is designed to cooperate with the ratchet wheel train **50a** and the barrel wheel train **50b** for stopping or allowing rotation of the barrel **202** and the ratchet **224,** correspondingly.

[0079] As shown in **Fig. 3,** the ratchet wheel train **50a** are formed by consequently meshed wheels **58, 57, 56, 55, 54** and **53,** and configured for transmitting torque from the ratchet wheel to the cam wheel **352.** The barrel wheel train **50b** is formed by consequently meshed wheels **62, 61, 60, 59** and **54,** and configured for transmitting torque from the barrel **202** to the first cam wheel **352**.

[0080] Referring to **Fig. 4,** a schematic view of the first cam wheel **352** is shown, according to an embodiment of the present invention. As shown in **Fig. 4,** the first cam wheel **352** is a disk-shaped wheel that has two grooves **411** and **413** along its outer periphery separated by cam periphery regions **412** and **414.** Each grove and each cam periphery region are defined by corresponding angle sectors. The arcs of such sectors have predetermined lengths; each length corresponds to a predetermined number of rotations of the barrel **202.**

[0081] In this embodiment, the speed reduction ratio from the barrel **202** and/or from the ratchet wheel **224** to the first cam wheel **352** is set at 1/12, so that when the number of windings of the mainspring is set at six (the angle of rotation is 360 degrees x 6 = 2160 degrees), the first cam wheel **352** rotates 180 degrees.

[0082] **Figs. 5A and 5B** illustrate a schematic view of the torque regulation mechanism **218** in locked and unlocked states, correspondingly, according to an embodiment of the present application. During winding the mainspring by rotating the ratchet **224,** an amount of torque corresponding to the amount by which the mainspring is wound up is transmitted to the first cam wheel **352** through the ratchet wheel train **50a,** and is added as rotation of the first cam wheel **352** in a predetermined direction. Conversely, when the mainspring unwinds and the barrel **202** rotates, an amount of torque corresponding to the amount by which the mainspring is unwound is transmitted to the first cam wheel **352** through the barrel wheel train **50b**, and is subtracted as rotation of the first cam wheel **352** in the opposite direction.

[0083] According to an embodiment of the present invention, the torque regulation mechanism **218** also includes a ratchet lock mechanism **370** that is configured for locking the ratchet wheel train **50a** for stopping rotation of the ratchet **224.** The first cam wheel **352** is coupled to the ratchet lock mechanism **370,** and can activate the ratchet lock mechanism **370** to stop or enable rotation of the ratchet **224** during winding.

[0084] The ratchet lock mechanism **370** includes a ratchet lock lever **371** which engages the wheel **58.** The ratchet lock lever **371** can rotate around a rotation shaft **371a,** disposed between the wheel **58** and the first cam wheel **352.** The ratchet lock lever **371** can engage the wheel **58** and the first cam wheel **352.** The ratchet lock lever **371** has a stopper portion **372** having a tooth **372a,** which can engage the teeth of the wheel **58.** The ratchet lock lever **371** also has an engaging portion **373** having a cam follower **373a.** When the first cam wheel **352** rotates, the cam follower **373a** can either engage the groove **411** of the first cam wheel **352** or be pressed against the cam periphery regions **412.**

[0085] The ratchet lock lever **371** also has a spring portion **374,** which extends from the body of the lever **371** so as to form a substantially U shape. The spring portion **374** presses against a stopper pin **375.** The cam follower **373a** is pressed against the first cam wheel **352** by the action of the spring portion **374.** Therefore, when the cam follower **373a** engages the groove **411** of the first cam wheel 352, the tooth **372a** engages the wheel **58,** as shown in **Fig. 5A**. This locks the wheel **58** and stops its rotation, and thereby stops the rotation of the ratchet wheel train **50a** and the ratchet **224.** As a result the winding up of the mainspring is stopped.

[0086] Alternatively, when the cam follower **373a** of the engaging portion **373** is pressed against a location of the cam periphery regions **412** of the first cam wheel **352**, the tooth **372a,** as shown in **Fig. 5B,** is separated from the wheel **58,** allowing the ratchet **204** to be rotated and thus the mainspring to be wound up.

[0087] As mentioned above, the first cam wheel **352** is set so that it rotates 180 degrees when the ratchet **224** rotates six times. Therefore, in the case where locking of the winding operation is to be performed when the desired number of windings of the mainspring has been reached, the first cam wheel **352** is set at an angle which causes the cam follower **373a** to engage the groove **411** of the first cam wheel **352**.

[0088] According to an embodiment of the present invention, the winding of the mainspring **201** is not ceased at the end of the linear torque region (i.e., at point **C** in **Fig. 1**) that correspond to five windings of the mainspring, but is continued further until the mainspring is wound up to a predetermined wound state. For example, the mainspring can be wound up to 90% of the non-linear torque region that correspond to the number of windings of the mainspring between five and six. In this case, the groove **411** is arranged close to the position indicated by a numerical number 0(6) in **Fig. 4.**

[0089] However, when stopping the winding of the mainspring **201** (and thereby rotation of the ratchet **224**) is desired at the end of the linear torque region (i.e., at point **C** in **Fig. 1**) (that is usually carried out in conventional timepieces together with stopping rotation of the barrel), the number of windings of the mainspring can, for example, be set at about five. As described above, this number of windings is defined by location of the groove **411** on the periphery of the first cam wheel **352**.

[0090] The torque regulation mechanism **218** also includes a barrel lock mechanism **380** configured for stopping or allowing rotation of the barrel **202.** The first cam wheel **352** is coupled to the barrel lock mechanism **380,** and can activate the barrel lock mechanism **380** to stop or enable rotation of the barrel **202.**

[0091] As shown in **Figs. 5A and 5B,** the barrel lock mechanism **380** has a barrel lock lever **381** configured for locking the unwind wheel train **50b** which engages the wheel **61** that is coupled to the barrel **202** through the wheel **62.** The barrel lock lever **381** rotates about a rotation shaft **381a,** disposed between the wheel **61** and the first cam wheel **352.** The barrel lock mechanism **380** includes a stopper portion **382** having a tooth **382a,** which can engage the teeth of the wheel the wheel **61.**

[0092] The barrel lock lever **381** also has an engaging portion **383** having a cam follower **383a.** When the first cam wheel **352** rotates, the cam follower **383a** can either engage the groove **413** of the first cam wheel **352** or be pressed against the cam periphery regions **414.**

[0093] The barrel lock lever **381** also has a spring portion **384,** which extends from the body of the lever **381** so as to form a substantially U shape and presses against a stopper pin **385.** The stopper portion **382** and the engaging portion **383** press against the wheel **61** and the first cam wheel **352,** respectively, by the action of the spring portion **384.**

[0094] Accordingly, when the cam follower **383a** of the engaging portion **383** engages the groove **413** of the first cam wheel **352**, the tooth **382a** of the stopper portion **382,** as shown in **Fig. 5A**, engages the wheel **61,** thereby locking the rotation of the wheel **61,** and thus the rotation of the unwind wheel train **50b**, so that the unwinding of the rotation of the barrel **202** is stopped.

[0095] Alternately, when the cam follower **383a** of the engaging portion **383** presses against a cam periphery region **414** of the first cam wheel **352,** the tooth **382a** of the stopper portion **382,** as shown in **Fig. 5B,** is separated from the wheel **61,** allowing rotation of the unwind wheel train **50b**, and thus allowing rotation of the barrel **202.**

[0096] According to an embodiment of the present invention, the barrel lock lever **381** is set so that the tooth **382a** of the stopper portion **382** engages the groove **413** of the first cam wheel **352** to lock the winding and unwinding operations of the barrel **202,** when the desired number of winding operations has been performed. For instance, in the case when the winding of the mainspring by rotating the ratchet **224** is not ceased at the end of the linear torque region (i.e., at point **C** in **Fig. 1**), but is rather continued further at the non-linear torque region that correspond to the number of windings of the mainspring between five and six, the barrel **202** nevertheless can be stopped in this region in order to avoid damage to the regulation device (**204** in **Fig. 2**) by the large torque provided by the mainspring in the non-linear torque region (CD in **Fig. 1** that is between the states **IV** and **V** of the mainspring). For example, when the speed reduction ratio from the barrel **202** to the first cam wheel **352** is set at 1/12, the groove **413** is arranged on the first cam wheel **352** between the position indicated by a numerical number 5 and 6 in **Fig. 4** which correspond to the number of windings of the mainspring between five and six.

[0097] As mentioned above, the non-linear torque region (**CD** in **Fig. 1**) can be used for driving the electric generator (**215** in **Fig.** 2) during unwinding the mainspring from the fully wound state (**V** in **Fig. 1**) to the states (**IV** in **Fig. 1**). According to this embodiment, the electric generator **215** is driven by the ratchet **224** of mechanical power system **200** not only during winding the mainspring from completely unwound state (**I** in **Fig. 1**) to the state (**V** in **Fig. 1**) in which the mainspring is fully wound, but also during unwinding the mainspring from the fully wound state (or almost fully wound state that is selected near the end of the non-linear torque region (point **D** in the graph in **Fig. 1**)) to a predetermined wound state that is selected at the beginning of the linear torque region, e.g., at or near the point **E** in the graph in **Fig. 1.** This is achieved by enabling a reverse rotation of the ratchet only when the mainspring **201** unwinds in the non-linear torque regime, and blocking the reverse rotation of the ratchet when the mainspring unwinds to the beginning of the linear torque region (point **E** in the graph in **Fig. 1**).

[0098] In order to enable the reverse rotation of the ratchet only when the mainspring **201** unwinds in the non-linear torque regime, the torque regulation mechanism **218** includes a click lifting mechanism **390** configured for releasing the ratchet **224** and enabling rotation of the ratchet **224** in a direction that is reverse to the rotation of the ratchet **224** during winding the mainspring. Accordingly, the click lift mechanism **390** is configured for lifting the click **306** in cooperation with ratchet lock mechanism **370,** in order to release the ratchet **224** so that the ratchet **224** could rotate not only in the direct rotation (i.e., clockwise) during winding of the mainspring, but also in a reverse direction (i.e., counterclockwise), when the mainspring unwinds. The counterclockwise rotation of the ratchet can be used during the non-linear operation regime of the mainspring (i.e., region **DE** in **Fig. 1**).

[0099] According to an embodiment of the present invention, the click lifting mechanism **390** includes a click lift lever **391** configured for lifting the click **306** up, a pusher lever **396** engaged with the click lift lever **391** and with a second cam wheel **353**.

[0100] The click lift lever **391** has a first arm **391a** and a second arm **391b,** and can rotate around a rotation shaft **392.** The rotation shaft **392** can, for example, be arranged on a plate **393** disposed between the wheel **58** and the click **306.** The click lift lever **391** also has a spring portion **391c,** which extends from the body of the lever **391** so as to form a substantially U shape.

[0101] As shown in **Fig. 5A**, when the pusher lever **396** does not press the second arm **391b** of the click lift lever **391,** the spring portion **391c** has an original shape and the first arm **391a** lifts the click **306** up, thereby enabling the ratchet **224** to rotate not only in the direct direction during winding but also in the reverse direction during unwinding, e.g., during the region **DE** in **Fig. 1.**

[0102] Alternatively, as shown in **Fig. 5B,** when the pusher lever **396** presses against the second arm **391b,** the spring portion **391c** is stretched. In this state, the first arm **391a** does not press the click **306** and the click **306** lifts down and engages teeth **397** of the ratchet **224,** thereby preventing rotation of the ratchet **224** in the reverse direction during unwinding.

[0103] As shown in **Figs. 5A and 5B,** there are two stopper pins **394** and **395** which are provided on the plate **393.** The spring portion **391c** is pressed against the stopper pin **394,** while the stopper pin **395** limits displacement of the second arm **391b** when the pusher lever **396** is pressed against the second arm **391b.**

[0104] Referring to **Fig. 6,** a schematic view of the second cam wheel **353** is shown, according to an embodiment of the present invention. As shown in **Fig. 6,** the second cam wheel **353** is a disk-shaped wheel that has a projecting portion **601** along its outer periphery. The projecting portion **601** is defined by a corresponding angle sector. The arc of this sector has a predetermined length that corresponds to a predetermined number of rotations of the ratchet.

[0105] In this embodiment, the second cam wheel **353** has an arbor common with the arbor of the first cam wheel **352.** The second cam wheel **353** is mounted on and coupled to the first cam wheel **352.** Accordingly, the second cam wheel **353** can be rotated concurrently and in phase with the first cam wheel **352.** Therefore, when desired, the second cam wheel **353** can be formed integrally with the first cam wheel **352.**

[0106] A spatial relation in the torque regulation mechanism **218** between the first cam wheel **352,** the second cam wheel **353,** the ratchet lock lever **371,** the barrel lock lever **381** and the pusher lever **396** is also shown in **Fig. 7.**

[0107] As mentioned above, the total number of windings of the mainspring (e.g., six) corresponds to the angle of rotation of the first **352** and second **353** cam wheels of 180 degrees. Accordingly, this angle can be used as indication of the winding state of the mainspring.

[0108] Thus, as shown in **Fig. 7,** according to an embodiment of the present invention, the mainspring winding level indicator (**219 in Fig. 2**) includes a needle (indicated by a reference numeral **701**) that is affixed to the arbor of the first and second cam wheels **352** and **353,** and a sub-dial (not shown) marked with indicia. The indicia can, for example, correspond to the operation hours of the timepiece (**219 in Fig. 2**) until the total unwinding of the mainspring.

[0109] Referring to **Figs. 3, 5A, 5B, 6 and 7** together, the pusher lever **396** can rotate around the rotation shaft **371a,** which the pusher lever **396** shares with the ratchet lock lever **371.** The pusher lever **396** can press the click lift lever **391** and engage the second cam wheel **353.** The pusher lever **396** has a pusher portion **377,** which can press the second arm **391b** of the click lift lever **391.** The pusher lever **396** also has an engaging portion **378** having a cam follower **378a.** When the second cam wheel **353** rotates, the cam follower **378a** of the pusher lever **396** can either press the projecting portion **601** of the second cam wheel **353** or press against the cam region which is the other region on the outer periphery of the second cam wheel **353** than the projecting portion **601.**

[0110] The pusher lever **396** also has a spring portion **379,** which extends from the main body of the pusher lever **396** so as to form a substantially U shape. The spring portion **379** can press against the stopper pin **375,** which is also used to limit rotation of the pusher lever **396.**

[0111] The cam follower **378a** is pressed against the second cam wheel **353** by the action of the spring portion **374.** Therefore, when the cam follower **378a** presses the projecting portion **601** of the second cam wheel **353,** as shown in **Fig. 5A**, the pusher portion **377** does not press the second arm **391b** of the click lift lever **391.** Accordingly, as described above, the first arm **391a** of the click lift lever **391** lifts the click **306** up. As a result, the ratchet **224** is able to rotate not only in the direct direction during winding but also in the reverse direction during unwinding, e.g., during the region **DE** in **Fig. 1**.

[0112] Alternatively, when the cam follower **378a** of the of the pusher lever **396** is pressed against a region which is the other region on the outer periphery of the second cam wheel **353** than the projecting portion **601,** the pusher portion **377** of the pusher lever **396** presses against the second arm **391b.** In this state, as mentioned above, the first arm **391a** does not press the click **306** and the click **306** engages the teeth **397** of the ratchet **224.** As a result, the ratchet **224** is able to rotate only in direct direction during winding and is not able to rotate in the reverse direction during unwinding.

[0113] As mentioned above, the pusher lever **396** is set so that the cam follower **378a** presses the projecting portion **601** of the second cam wheel **353** only, when the desired number of winding operations has been performed. According to an embodiment of the present invention this number corresponds to the end of the non-linear torque regime of the mainspring due to the friction between the coils of the mainspring. For example, in the embodiment, when the number of the windings of the mainspring is set at six, the non-linear torque regime corresponds to the number of the windings between about five and six. Thus, the winding and unwinding of the mainspring in the non-linear torque regime region is carried out when the click **306** is lifted. Accordingly, the ratchet in the non-linear torque regime of the mainspring can rotate not only in the direct direction (i.e., clockwise), but also in the reverse direction (i.e., counterclockwise). As mentioned above, the clockwise rotation of the ratchet during winding and the counterclockwise rotation of the ratchet during unwinding in the non-linear torque regime of the mainspring can be used for driving the electric generator (**215** in **Fig. 2**).

[0114] As mentioned above, the electric generator (**215** in **Fig. 2**) can be driven by one or concurrently by several mechanisms that provide a power for charging the electric battery (**212** in **Fig. 2**).

[0115] Referring to **Fig. 8,** a schematic perspective view of the generator transmission mechanism **217** in **Fig. 2**) for driving the generator **215** is illustrated, according to an embodiment of the present invention. The generator transmission mechanism **217** includes a ratchet torque transmission train **810** that is coupled to the ratchet **224.** The ratchet torque transmission train **810** is configured for transmitting a torque from the ratchet **224** during rotation of the ratchet in a direct direction when the user rotates the winding crown to wind the mainspring up. Thus, the rotation of the ratchet during winding-up can drive the electric generator **215** when the mainspring is wound from completely unwound state (**I** in **Fig. 1**) to the state (**V** in **Fig. 1**) in which the mainspring is fully wound. Accordingly, in this case, the electric generator **215** can be driven by the winding-up portion (**320 in Fig. 3**) of the manual winding and hand adjustment mechanism **207** that rotates the ratchet **224** coupled to the generator through the ratchet torque transmission train **810.**

[0116] The torque from the ratchet **224** can also be transmitted to the generator **215** when the ratchet **224** rotates in a reverse direction during unwinding of the mainspring in the non-linear torque regime region from the state (**V** in **Fig. 1**) in which the mainspring in the fully wound state (that is selected near the end of the non-linear torque region corresponding to the point **D** in the graph in **Fig. 1**) to a predetermined wound state, for example, to the state (**IV** in **Fig. 1**) that corresponds to the beginning of the linear torque region (point **E** in the graph in **Fig.** 1). As described above, this is achieved by enabling a reverse rotation of the ratchet **224** only during the non-linear torque regime.

[0117] According to an embodiment of the present invention, the ratchet torque transmission train **810** includes an intermediate wheel **811** that is engaged with the ratchet **224.** The ratchet torque transmission train **810** further includes a unidirectional coupling-clutch device **812** having a coupling-clutch pinion **1** that is engaged with the intermediate wheel **811** and a coupling-clutch wheel **6.**

[0118] The unidirectional coupling-clutch device **812** is configured such that rotation of the coupling-clutch wheel **6** in a predetermined direction (e.g., clockwise) causes engagement the coupling-clutch wheel **6** with the coupling-clutch pinion **1** and driving the pinion **1** by the coupling-clutch wheel **6.** On the other hand, rotation of the coupling-clutch wheel **6** in the opposite direction (e.g., counterclockwise) results in a free rotation of the coupling-clutch wheel **6** with respect to the pinion **1** without their engagement.

[0119] According to this embodiment, the unidirectional coupling-clutch device **812** can, for example, be a unidirectional coupling-clutch runner described in detail in U.S. Pat. No. 8,337,077 (the description of which is hereby incorporated in its entirety by reference).

[0120] **Fig. 9** shows a perspective top view of this unidirectional coupling-clutch runner of Pat. No. 8,337,077. The unidirectional coupling-clutch runner includes a coaxial pinion **1** and a coupling-clutch wheel **6** which pivot relative to one another. The runner includes a first driving part **14** angularly integral with the pinion **1** having at least one elastic catch **15** with the general shape, in plan view, of a C, one branch of which is elongated and terminates with a free end; and a second driving part **17** angularly integral with the wheel **6** and which is coplanar with the first driving part **14** having an internal wolf-toothing **16.** In the neutral rest position the first and second driving parts **14, 17** do not touch one another, the end of the elastic catches **15** in the rest position which are not elastically deformed being located on a circumference whose diameter is larger than a circumference which goes through the top of the wolf-teeth **16** and smaller than a circumference going through the bottom of the toothing **16** of the second driving part.

[0121] As reported in U.S. Pat. No. 8,337,077, such a coupling-clutch runner can transmit in one direction of rotation a considerable torque grater than 1000 gr. mm without damage. It also has a resistance torque in the opposite direction of rotation less than 10 gr. mm.

[0122] The ratchet torque transmission train **810** also includes a speed increase wheel **815** that is engaged with the coupling-clutch wheel **6** and with a generator wheel **816** mounted on a rotation shaft **817** of the generator **215.** The speed increase wheel **815** is configured for transmitting a torque from the unidirectional coupling-clutch device **812** to the generator **215** with a predetermined speed increase rate.

[0123] As mentioned above, when the timepiece is moved, the electric generator **215** can also be driven by the automatic winding mechanism **208.** The automatic winding mechanism **208** can be coupled to the electric generator **215** through an automatic winding train **820** of the generator transmission mechanism **217.**

[0124] The automatic winding train **820** includes a tension wheel **821** and a reduction rate wheel **822** which are part of the automatic winding mechanism (**208** in **Fig. 2**), known to those versed in the art. The automatic winding mechanism **208** is configured for transmitting the energy associated with the movements of the timepiece wearer to the generator **215.** The automatic winding mechanism **208** uses the rotation of an oscillating weight (not shown) to transfer and store mechanical energy in the barrel **202** through the automatic winding train **820** forming a kinematic chain, which meshes with weight pinion (not shown) of the oscillating weight. Because of the shift in the centre of gravity of oscillating weight relative to its axis of rotation, the user's wrist movements cause this oscillating weight to rotate relative to the watchcase.

[0125] The rotation of oscillating weight is transferred to the ratchet **224** through the kinematic chain formed by a pair of reverser wheels (not shown) which mesh with the tension wheel **821** which meshes with the reduction rate wheel **822.** A pinion **823** of the reduction rate wheel **822** meshes with the coupling-clutch wheel **6** of the unidirectional coupling-clutch device **812.**

[0126] One of the reverser wheel meshes with the pinion of the oscillating mass so that torque from the oscillating mass is transferred through this reverser wheel directly to the tension wheel **821** during one rotation of the oscillating mass. When the direction of rotation of the oscillating mass changes, the torque from the oscillating mass is transferred through another reverser wheel. This results in rotation of the tension wheel **821** always in one direction regardless of which direction the pinion of oscillating mass turns.

[0127] When the rotation of the reduction rate wheel **822** is in the direction that causes engagement of the coupling-clutch wheel **6** with the coupling-clutch **1** pinion, the torque associated with the user's wrist movements are transferred to the ratchet **224** through the intermediate wheel **811** for winding the mainspring, and to the generator wheel **816** through the speed increase wheel **815** for driving the electric generator **215.**

[0128] According to the generator transmission mechanism **217** is of the type that only winds in one direction, owing to unidirectional coupling-clutch device **812.** Thus, the unidirectional coupling-clutch device **812** disengages the speed increase wheel **815** from the automatic winding train **820** when the ratchet is rotated in the opposite rotation to the winding rotation, because the coupling-clutch **1** pinion rotates free with respect to the coupling-clutch wheel **6.**

[0129] The electrical energy produced by the electric generator **215** is fed to the rechargeable electric battery (**212 in Fig. 2**) through the battery charge controller (**216 in Fig. 2**) configured to control the charging process. The control of the charging process can be carried out by maintaining a required charging electric current for providing an output voltage by the battery **212** within desired magnitudes. The basic construction the battery charge controller will be omitted as being well within the purview of a person versed in the art.

[0130] As mentioned above with reference to **Fig. 2,** the total torque that drives the timepiece **20** is the torque output applied to the main wheel train from the mainspring **201** combined with the torque provided by the electric motor **210.** Since the torque output from the mainspring **201** decreases as the mainspring unwinds, this additional torque provided by the electric motor **210** can, *inter alia,* drive the main wheel train **203** when the torque associated with the friction in the wheel train exceeds the torque provided by the mainspring (i.e., section **AG** in **Fig. 1**). As described above, conventional timepieces cannot normally operate when the torque decreases below the magnitude corresponding to point **G** in the graph in **Fig. 1,** because below the magnitude corresponding to point **G** the hands of a conventional timepiece gradually slow down, and finally the timepiece stops operating. Thus, according to an embodiment of the present invention, the timepiece **20** is driven by the electric motor **210** when the mainspring **201** is unwound beyond point **G.** Accordingly, the timepiece **20** can be driven for a longer continuous operating time than a conventional timepiece.

[0131] According to a further embodiment of the present invention, the electric motor **210** assists to drive the main wheel train **203** also at the linear torque regime between the states **II** and **IV** in **Fig. 1** during unwinding of the mainspring. This enables maintaining the total torque that drives the timepiece at a predetermined magnitude close to a certain optimal magnitude M_{opt}.

[0132] It should be relevant to note that employment of an electric motor for assisting in driving the main wheel train as proposed by the present application has certain advantages over the prior art techniques where electric motors were used for winding the mainspring. Indeed, a torque for winding a mainspring by an electric motor should have a magnitude significantly greater than the torque for assisting the mainspring to maintain the total torque that drives the main wheel train at a predetermined magnitude close the optimal magnitude M_{opt}. It should be understood that the provision of the present application requires less powerful electric motors, less powerful batteries for driving such electric motors, and correspondingly less space inside of the timepiece that is needed for installation of the motor and battery within a timepiece, than in the case when a powerful motor should be used for winding the mainspring. Referring to **Fig. 3 and Fig. 10** together, the electric motor **210** is engaged with the main wheel train **203** through the electric motor transmission mechanism **211,** so as to provide an additional controllable torque output for driving the time indicating hands (**209 in Fig. 2**). According to this embodiment, the electric motor **210** is coupled to the third wheel **317** of the main wheel train **203** through the electric motor transmission mechanism **211.**

[0133] There are several advantages for applying the torque provided by the electric motor to the third wheel **317.** In particular, a torque magnitude can be less when an electric motor is coupled to an intermediate wheel rather than in the case when an electric motor is coupled to the barrel or to the second (central) wheel **316.** Accordingly, less powerful electric motors and less powerful batteries for driving such electric motors can be used. Moreover, since the third wheel **317** is located in the central portion of the timepiece, the technical solutions for implementation of the electric motor transmission mechanism **211** for coupling the electric motor **210** to the main wheel train can be simplified when compared to coupling to a wheel located at the periphery. The technical solutions for implementation of a kinematic chain of the electric motor transmission mechanism **211** are determined by the configuration of the main wheel train **203,** e.g., the arrangement of a second hand (centre-mounted or provided with a sub-dial), and also by the presence of additional indicator devices, e.g., calendar, the availability of free space inside the timepiece case, etc. The number and dimension of the wheels in the electric motor transmission mechanism **211** are determined by a condition for the reduction rate coefficient of the electric motor transmission mechanism **211** to meet the rotation rate of the third wheel **317.**

[0134] According to the embodiment shown in **Figs. 3 and 10,** the electric motor transmission mechanism **211** includes an intermediate wheel **24** that meshes with a motor wheel **25** associated with a rotor shaft of the electric motor **210.** The electric motor transmission mechanism **211** also includes a reduction wheel pair **23** that is engaged with a friction clutch **22** that is engaged with the third wheel **317.** In particular, the intermediate wheel **24** meshes with one wheel **23a** of the reduction wheel pair **23,** whereas another wheel **23b** of the reduction wheel pair **23** meshes with a driving wheel **22a** of the friction clutch **22.** A driven pinion **22b** of the friction clutch **22** meshes with the third wheel **317.** A driving torque from the driving wheel **22a** of the friction clutch **22** to the driven pinion **22b** is transmitted via a spring (not shown) that can control the maximal magnitude of the torque transferred from the electric motor **210** to the third wheel **317.** In turn, the torque is further transmitted to the escapement **206** trough the wheels **318, 319** and **320.** In operation, the friction clutch **22** provides a periodic slippage between the driving wheel **22a** and the driven pinion **22b,** thereby "smoothing" the intermittent rotation of the escapement. Accordingly, implementation of the electric motor transmission mechanism **211** with such a friction clutch rather than with a regular wheel, simplifies construction of the electric motor transmission mechanism **211,** improves the reliability of its work and extends the range of types of asynchronous electric motors that can be used with the timepiece **20.**

[0135] Referring to **Figs. 2 and 10** together, in order to control operation of the electric motor **210,** the timepiece regulating device **204** of the timepiece **20** includes a balance oscillation controller **214.** According to an embodiment, the balance oscillation controller **214** includes a detecting unit **101** and a processing unit **102** electrically coupled to detecting unit **101.** The detecting unit **101** is configured for measuring rotational operation the balance **205** for determining an oscillation period of the balance **205** that is decreased when the mainspring torque is reduced. The processing unit **102** is configured for processing the data measured by the detecting unit **101,** and when the measured data deviate from predetermined magnitudes, generating control signals and relaying them to the electric motor controller **213** for driving the electric motor **210** in order to provide an additional controllable torque to the torque provided by the mainspring for driving the main wheel train **203.**

[0136] According to an embodiment, the detecting unit **101** includes an electromagnetic transmitter **103** arranged at one side of the balance **205** and configured for generating an electromagnetic radiation and irradiating an arm portion **104** of the balance **205** (i.e., the portion of the balance **205** where balance arms **105** are arranged). The electromagnetic transmitter **103** can, for example, include an optical emitter, such as a light emitting diode (LED), a laser diode, etc. However, electromagnetic transmitters that operate in other electromagnetic frequency bands are also contemplated.

[0137] The detecting unit **101** also includes an electromagnetic receiver **106** arranged at the opposite side of the balance **205** and positioned in an optical path so that a field of view of the electromagnetic receiver **106** ensures the capture of a part of the radiation which is transmitted by the electromagnetic transmitter **103** and irradiated the arm portion **104** of the balance **205.** Thus, the arm portion **104** of the balance **205** is disposed between the electromagnetic transmitter **103** and the electromagnetic receiver **105.** The electromagnetic receiver **106** can, for example, include an optical detector, such as a photodiode or other photo-receiving device, however receiving devices that operate in other electromagnetic frequency bands are also contemplated.

[0138] In operation, the balance arm portion **104** rotates between the electromagnetic transmitter **103** and the electromagnetic receiver **106.** When the balance arm **105** is disposed between the electromagnetic transmitter **103** and the electromagnetic receiver **105,** the radiation emitted by the electromagnetic transmitter **103** is blocked by the balance arm **105,** and therefore is not detected by the electromagnetic receiver **106.** On the other hand, when the balance arm **105** is not disposed between the electromagnetic transmitter **103** and the electromagnetic receiver **106,** the radiation emitted by the electromagnetic transmitter **103** is reached, and is therefore detected by the electromagnetic receiver **106.** It should be understood that the period of the radiation incident on the electromagnetic receiver **106** corresponds to the oscillation period of the balance **205.**

[0139] The electromagnetic receiver **106** generates a signal indicative of the period of the detected radiation and relays this signal to the processing unit **102.** The control processing unit **102** is typically a computing system, for example, in the form of an integrated circuit (IC), having, *inter alia,* such known utilities as a memory unit (not shown) and a processor (data acquisition and processing utility).

[0140] According to an embodiment of the present invention, the memory unit is configured for storing a relationship between an oscillation period of the balance **205** and a torque driving the main train wheel **203.** The memory unit also stores the optimal magnitude *(M_{opt}* **in Fig. 1**) of the operating torque driving the main train wheel **203** at which operation of the timepiece is precise.

[0141] According to an embodiment of the present invention, the processor is preprogrammed by a suitable software model capable of analyzing the received data (i.e., output signal of the electromagnetic receiver **106**). The analyzing the received data includes calculating the operating torque and generating a deviation indication signal (and a corresponding control signals for the electric motor controller **213**), if the calculated operating torque deviates from the optimal torque magnitude M_{opt} that correspond to precise operation of the timepiece.

[0142] In particular, since the mainspring torque during unwinding of the mainspring at the beginning and end of the linear torque regime between the states **II** and **IV** in **Fig. 1,** can deviate from the optimal magnitude M_{opt}, the balance oscillation controller **214** can generate a corresponding deviation indication signal, and relay this signal to the electric motor controller **213.** Responsive to this signal, the electric motor controller **213** can generate a train of driving pulses for activating and driving the electric motor **210** to adjust the total magnitude of the operational torque for maintaining the total torque that drives the main train wheel of the timepiece at the optimal magnitude M_{opt}.

[0143] Likewise, when during unwinding the mainspring reaches a state corresponding to point **G** in the graph in **Fig. 1** and leaves the linear operation regime, the balance oscillation controller **214** can generate a deviation indication signal indicating decrease of the oscillation period of the balance **205,** and relay this signal to the electric motor controller **213.** Responsive to this signal, the electric motor controller **213** can generate a train of driving pulses for activating and driving the electric motor **210** as long as required.

[0144] As such, those skilled in the art to which the present invention pertains, can appreciate that while the present invention has been described in terms of preferred embodiments, the concept upon which this disclosure is based may readily be utilized as a basis for the designing of other structures and processes for carrying out the several purposes of the present invention.

[0145] Also, it is to be understood that the phraseology and terminology employed herein are for the purpose of description and should not be regarded as limiting.

[0146] It is important, therefore, that the scope of the invention is not construed as being limited by the illustrative embodiments set forth herein. Other variations are possible within the scope of the present invention as defined in the appended claims. Other combinations and sub-combinations of features, functions, elements and/or properties may be claimed through amendment of the present claims or presentation of new claims in this or a related application. Such amended or new claims, whether they are directed to different combinations or directed to the same combinations, whether different, broader, narrower or equal in scope to the original claims, are also regarded as included within the subject matter of the present description.

Claims

1. A timepiece comprising:

   a mechanical power system (200) having a mainspring (201) associated with a ratchet (224) and housed in a barrel (202) that is powered by the mechanical energy provided by the mainspring;

   a main wheel train (203) engaged with the barrel (202) and including an assembly of wheels meshed to each other for transmitting a torque output of the mainspring (201) for driving time indicating hands (209);

   a timepiece regulating device (204) including a balance (205) engaged with the main wheel train (203) and an escapement (206) adapted for

maintaining angular oscillations of the balance (205);
a manual winding and hand adjustment mechanism (207) coupled to the ratchet (224) and to the time indicating hands (209);
characterized by comprising an electric motor (210) engaged with a predetermined wheel of the main wheel train (203) through an electric motor transmission mechanism (211), so as to provide an additional controllable torque output to main wheel train (203) for driving said time indicating hands (209), thereby a total torque that drives the timepiece includes the torque provided by the mainspring (201) and said additional controllable torque provided by the electric motor (210).

2. The timepiece of claim 1, **characterized in that** said predetermined wheel of the main wheel train (203) that is engaged with said electric motor transmission mechanism (211) is a third wheel (317) when the counting starts from the barrel.

3. The timepiece of claim 1, **characterized by** further comprising a torque regulation mechanism (218) coupled to the mechanical power system (200) and configured to control operation of the mainspring (201) and the ratchet (224) during winding and unwinding the mainspring (201).

4. The timepiece of claim 3, **characterized in that** said torque regulation mechanism (218) comprises:

a ratchet wheel train (50a) coupled to the ratchet (224);
a ratchet lock mechanism (370) configured for locking said ratchet wheel train (50a) for stopping rotation of the ratchet (224);
a barrel wheel train (50b) coupled to the barrel (202);
a barrel lock mechanism (380) configured for stopping or allowing rotation of the barrel (202); and
a first cam wheel (352) coupled to the ratchet lock mechanism (370) and to the barrel lock mechanism (380), and configured for activating the ratchet lock mechanism (370) and the barrel lock mechanism (380) to stop or enable rotation of the ratchet (224) and the barrel (202) during winding the mainspring, correspondingly.

5. The timepiece of claim 4, **characterized in that** said torque regulation mechanism (218) further comprises a click lifting mechanism (390) configured for releasing the ratchet (224) to enable rotation of the ratchet (224) in a direction that is reverse to the rotation of the ratchet (224) during winding the mainspring.

6. The timepiece of claim 5, **characterized in that** said torque regulation mechanism (218) further comprises a second cam wheel (353) coupled to said click lifting mechanism (390), and configured for activating said click lifting mechanism (390).

7. The timepiece of claim 6, **characterized in that** said second cam wheel 353 has an arbor common with the arbor of the first cam wheel (352) and is mounted on and coupled to the first cam wheel (352).

8. The timepiece of claim 7, **characterized by** further comprising a mainspring winding level indicator (219) having a needle (701) affixed to the arbor of the first and second cam wheels (352) and (353), and a sub-dial marked with an indicia.

9. The timepiece of claim 1, **characterized by** further comprising:

an electric battery (212) for providing electrical power to the electric motor (210); and
an electric motor controller (213) coupled to the electric battery (212) and to the electric motor 210, and configured to drive the electric motor 210 by controllably supplying electrical power from the electric battery thereto.

10. The timepiece of claim 9, **characterized by** further comprising an electric generator (215) configured to generate an electrical energy for charging the electric battery (212).

11. The timepiece of claim 10, **characterized by** further comprising:

a generator transmission mechanism (217) having a ratchet torque transmission train coupled to the ratchet (224) and configured for transmitting a torque from the ratchet (224) to the electric generator (215) for driving thereof during rotation of the ratchet.

12. The timepiece of claim 11, **characterized by** further comprising an automatic winding mechanism (208) coupled to the generator transmission mechanism (217) and configured to rotate the ratchet (224) for winding the mainspring and to drive the electric generator (215) for charging the electric battery (212).

13. The timepiece of claim 9, **characterized in that** said timepiece regulating device (204) comprises:

a detecting unit (101) configured for measuring rotational operation the balance (205) for determining an oscillation period of the balance (205); and
a processing unit (102) electrically coupled to

detecting unit (101) and configured for processing the data measured by the detecting unit (101), and when the measured data deviate from predetermined magnitudes, generating control signals and relaying them to the electric motor controller (213) for driving the electric motor (210) to provide said additional controllable torque for driving the main wheel train (203).

14. The timepiece of claim 13, **characterized in that** said detecting unit (101) comprises:

an electromagnetic transmitter (103) arranged at on one side of the balance (205) and configured for irradiating an arm portion (104) of the balance (205); and
an electromagnetic receiver (106) arranged at the opposite side of the balance (205) and positioned in an optical path so that a field of view of the electromagnetic receiver (106) ensures the capture of a part of the radiation which is transmitted by the electromagnetic transmitter (103) and irradiated the arm portion (104) of the balance (205).

15. The timepiece of claim 13, **characterized in that** said processing unit (102) comprises:

a memory unit configured for storing a relationship between an oscillation period of the balance (205) and a torque driving the main train wheel (203) and an optimal magnitude of the operating torque driving the main train wheel (203) at which operation of the timepiece is precise; and
a processor configured for analyzing the data measured by the detecting unit (101), calculating the current operating torque and its deviation from said optimal magnitude and generating said control signals to the electric motor controller (213), if the current operating torque deviates from the optimal torque magnitude.

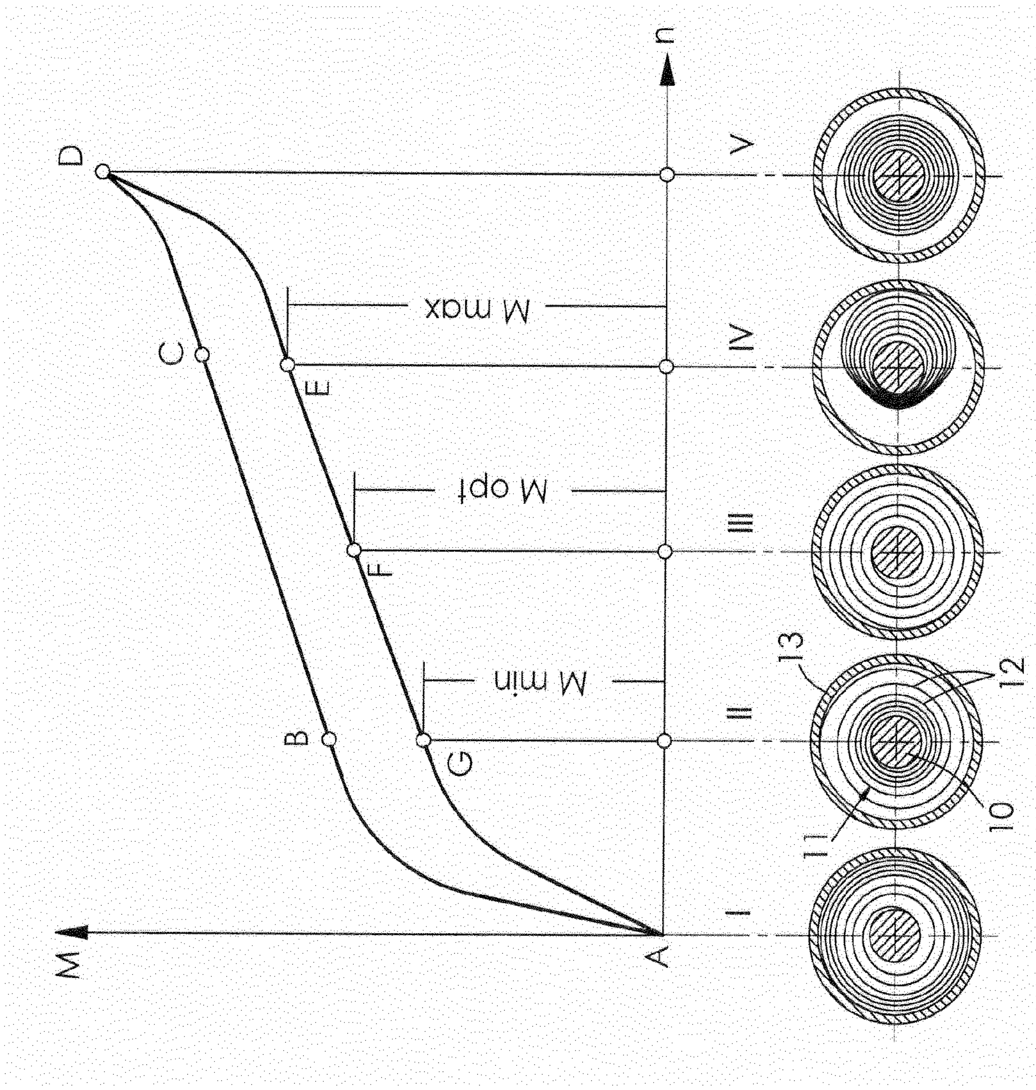
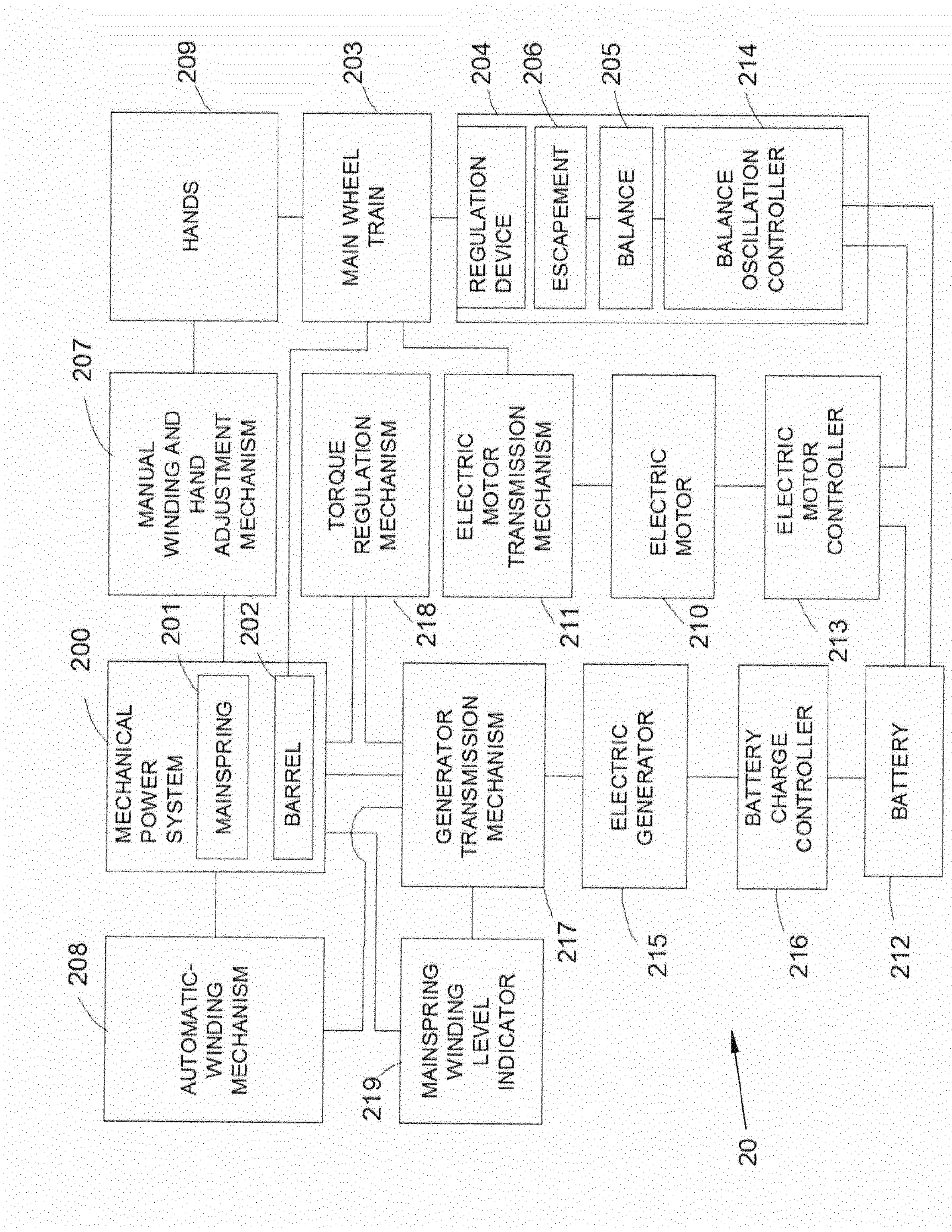


FIG. 1


HANDS
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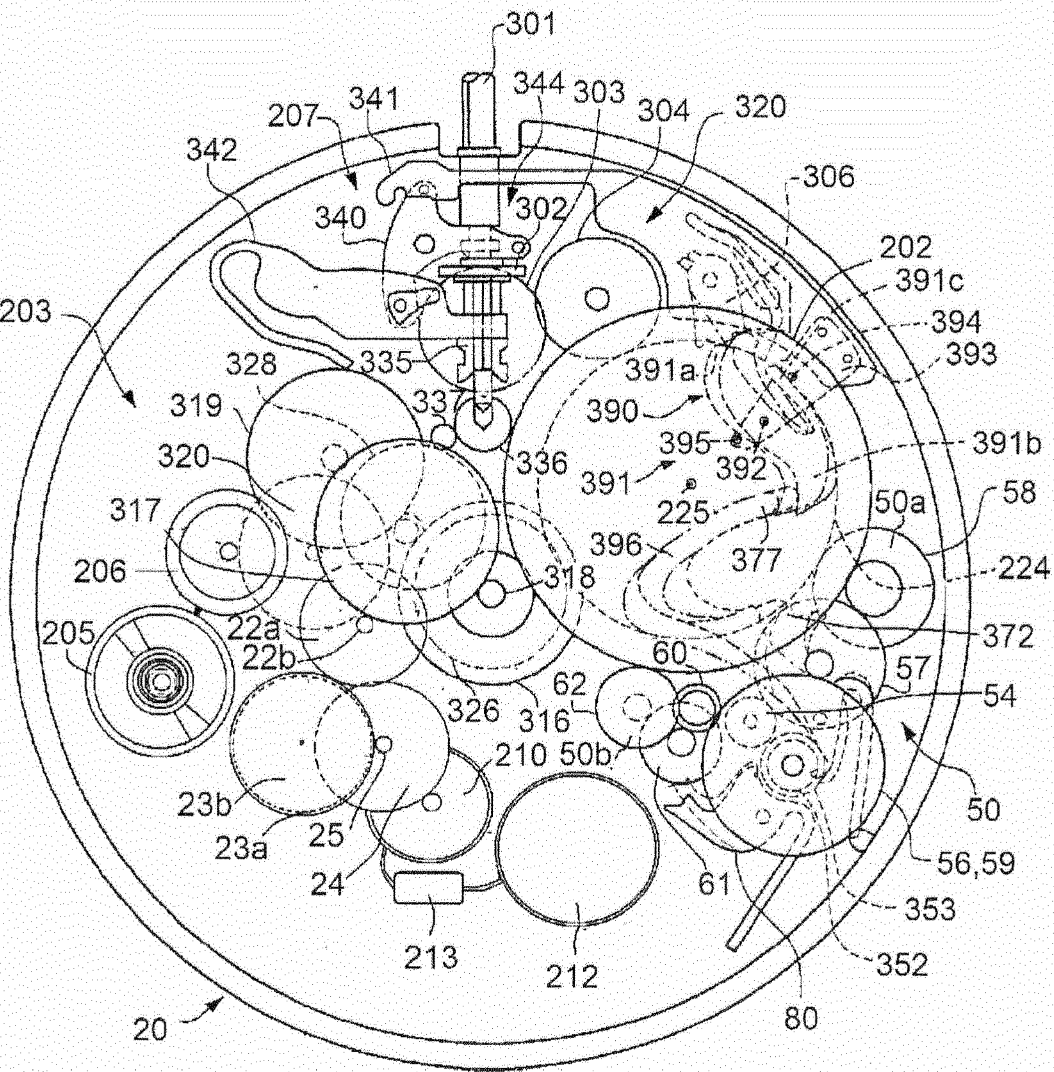
203
REGULATION DEVICE
204
ESCAPEMENT
206
BALANCE
205
BALANCE OSCILLATION CONTROLLER
214
MANUAL WINDING AND HAND ADJUSTMENT MECHANISM
207
TORQUE REGULATION MECHANISM
218
ELECTRIC MOTOR TRANSMISSION MECHANISM
211
ELECTRIC MOTOR
210
ELECTRIC MOTOR CONTROLLER
213
MECHANICAL POWER SYSTEM
200
MAINSPRING
201
BARREL
202
GENERATOR TRANSMISSION MECHANISM
217
ELECTRIC GENERATOR
215
BATTERY CHARGE CONTROLLER
216
BATTERY
212
AUTOMATIC-WINDING MECHANISM
208
MAINSPRING WINDING LEVEL INDICATOR
219
20

FIG. 2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395
392
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391
320
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50a
58
317
396
377
224
206
318
22a
372
205
22b
60
57
62
54
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316
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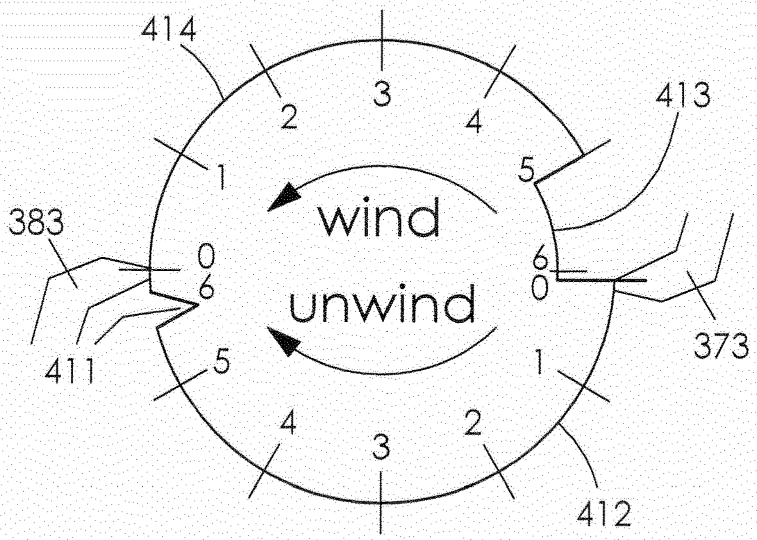
56,59
23a
24
61
353
213
212
352
20
80

FIG. 3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4
413
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wind
383
6
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6
unwind
373
411
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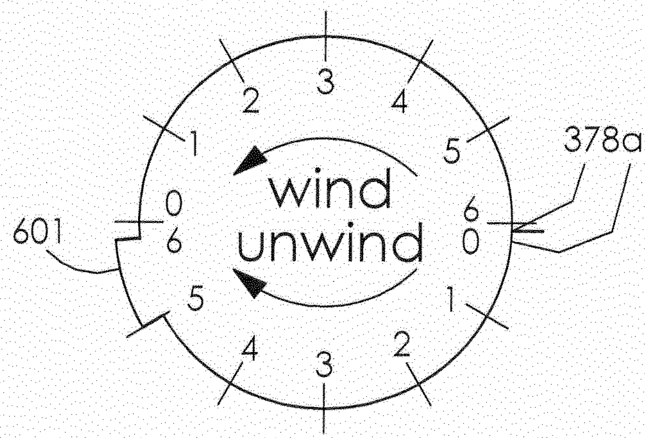
2
3
412

FIG. 4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601
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unwind
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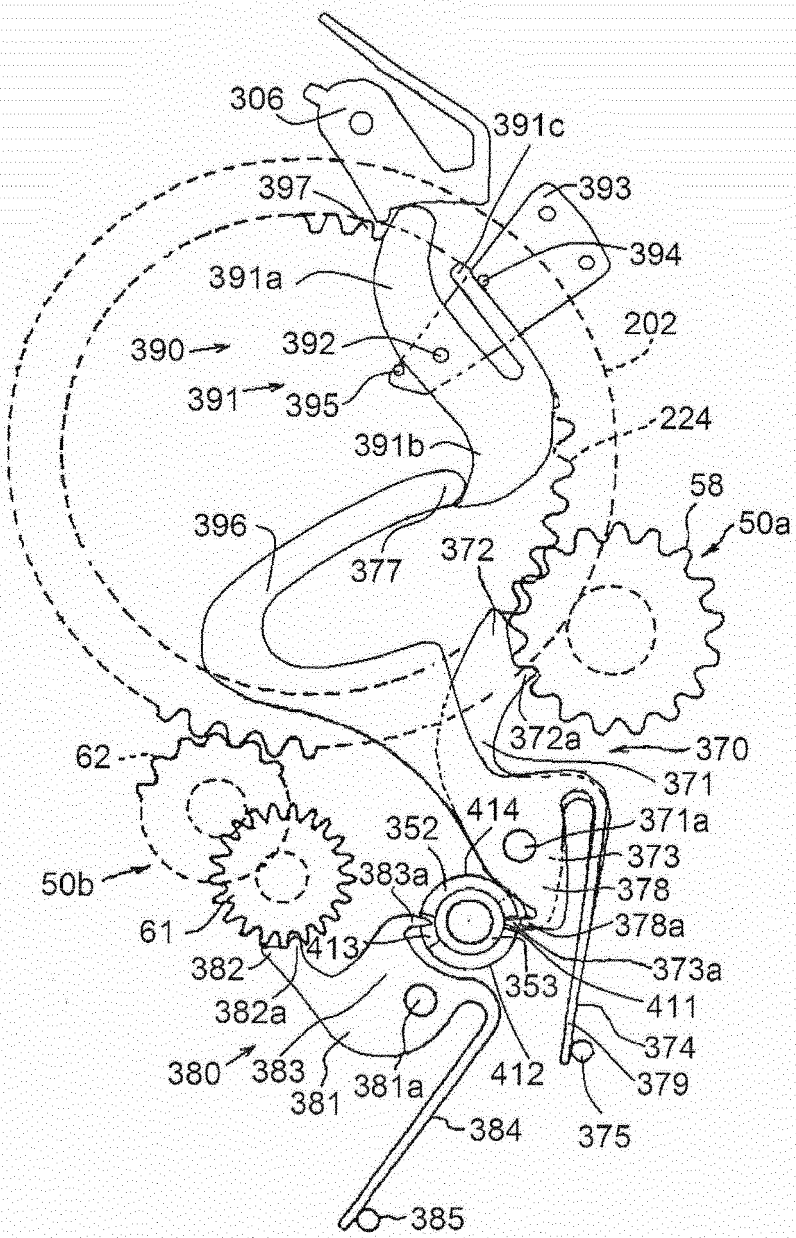
3
2

FIG. 6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383a
378a
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381
381a
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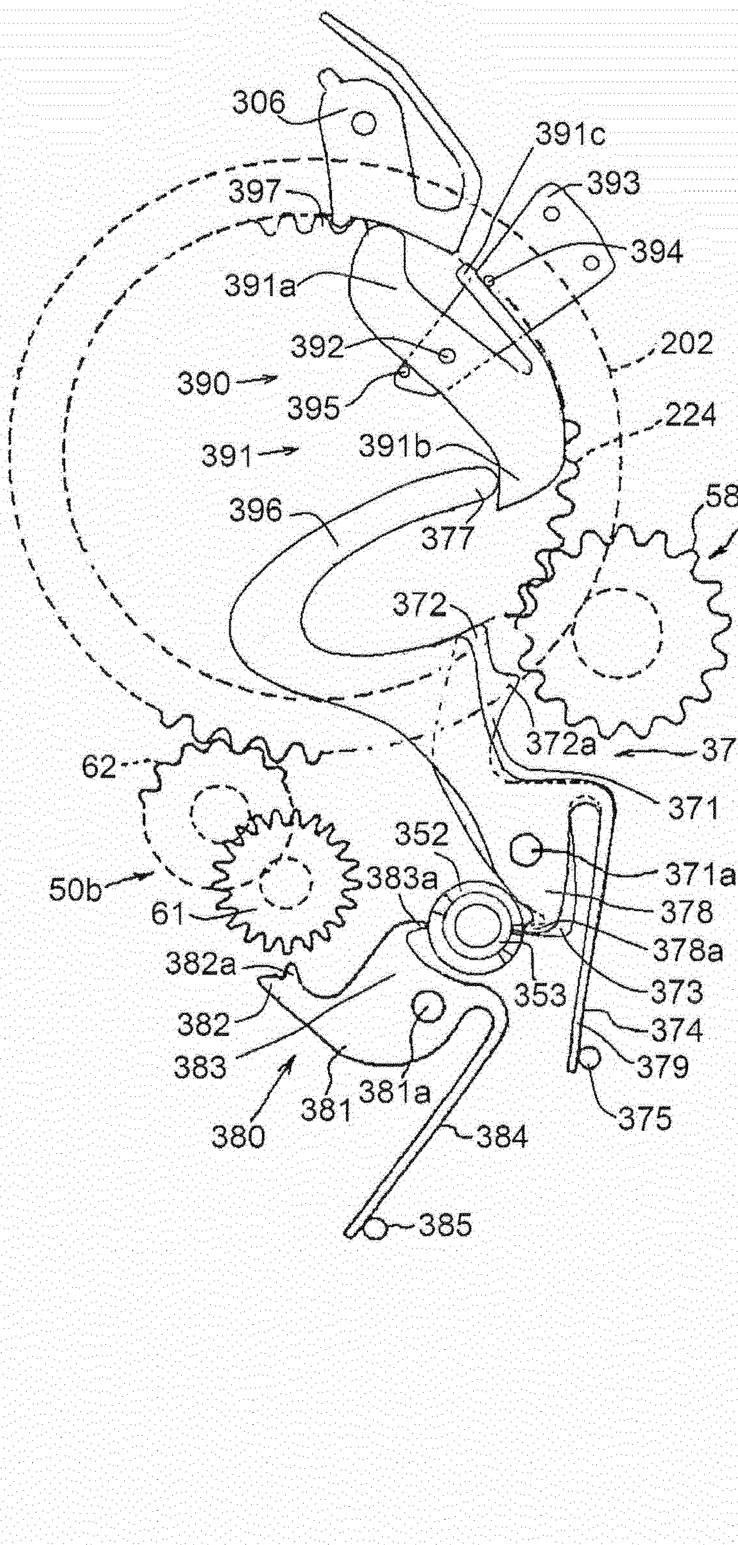
375
385

FIG. 5A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62
371
352
371a
50b
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381a
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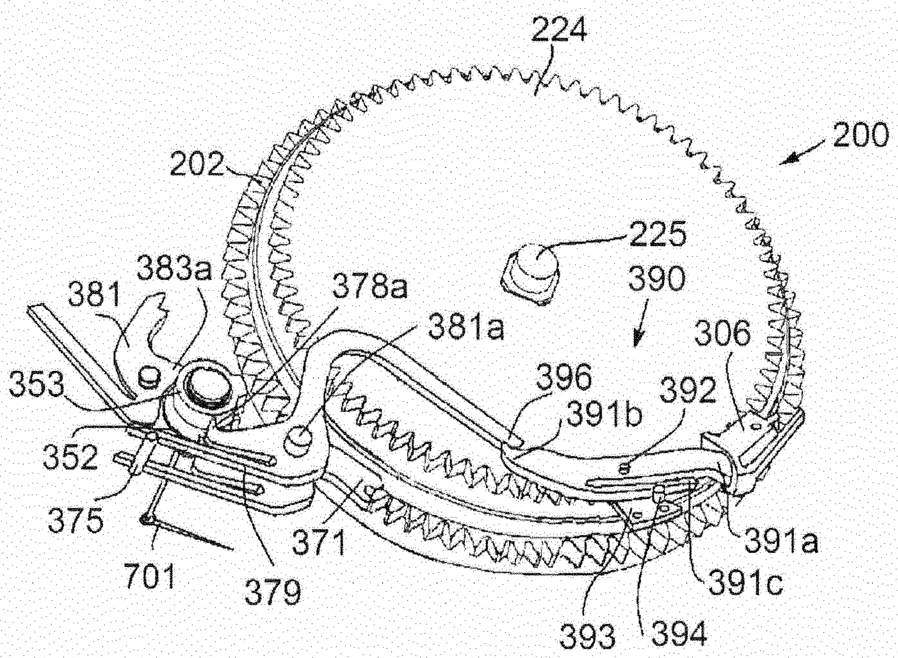
384
385

FIG. 5B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392
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391c
393
394

FIG. 7

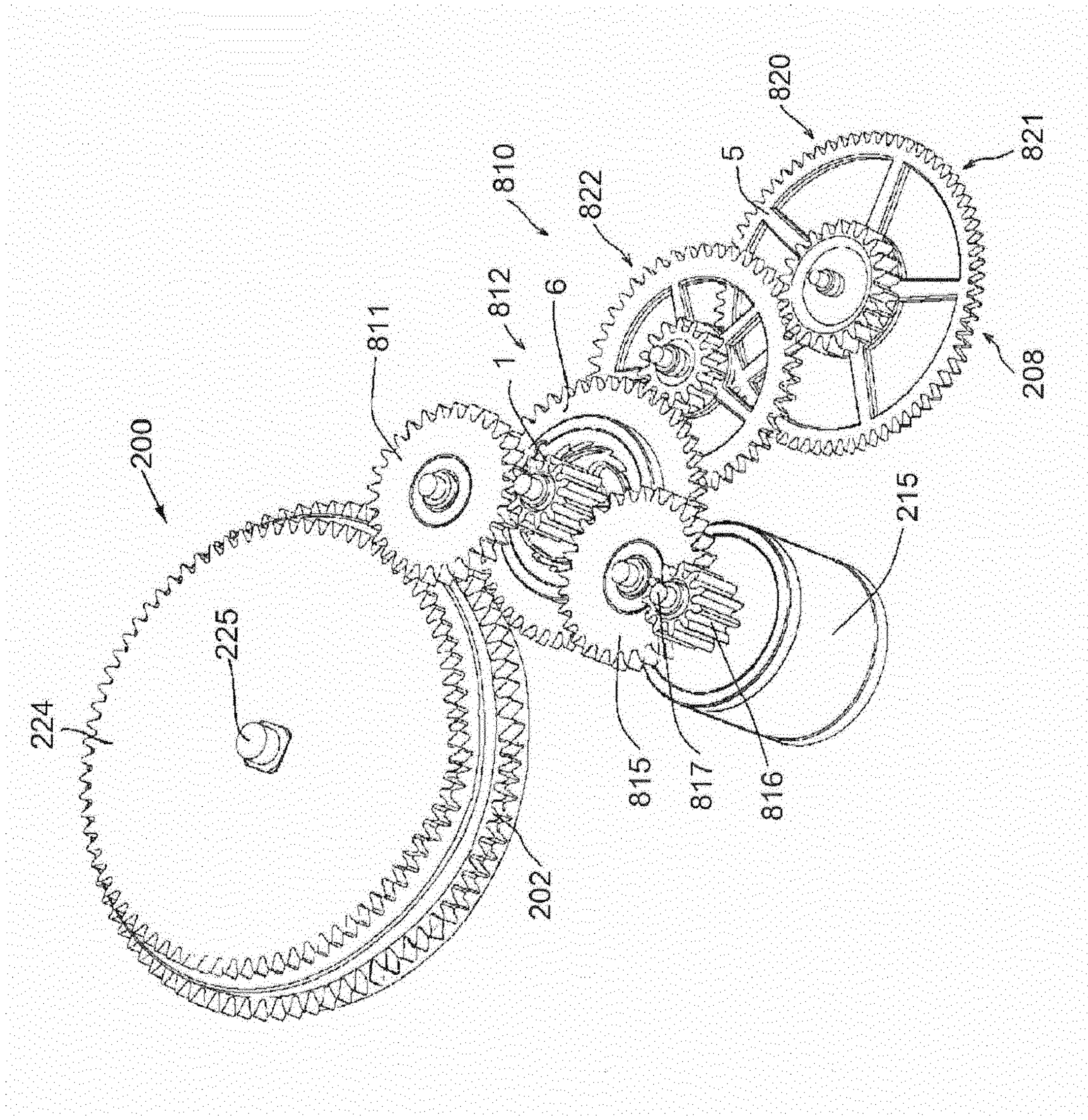


FIG. 8

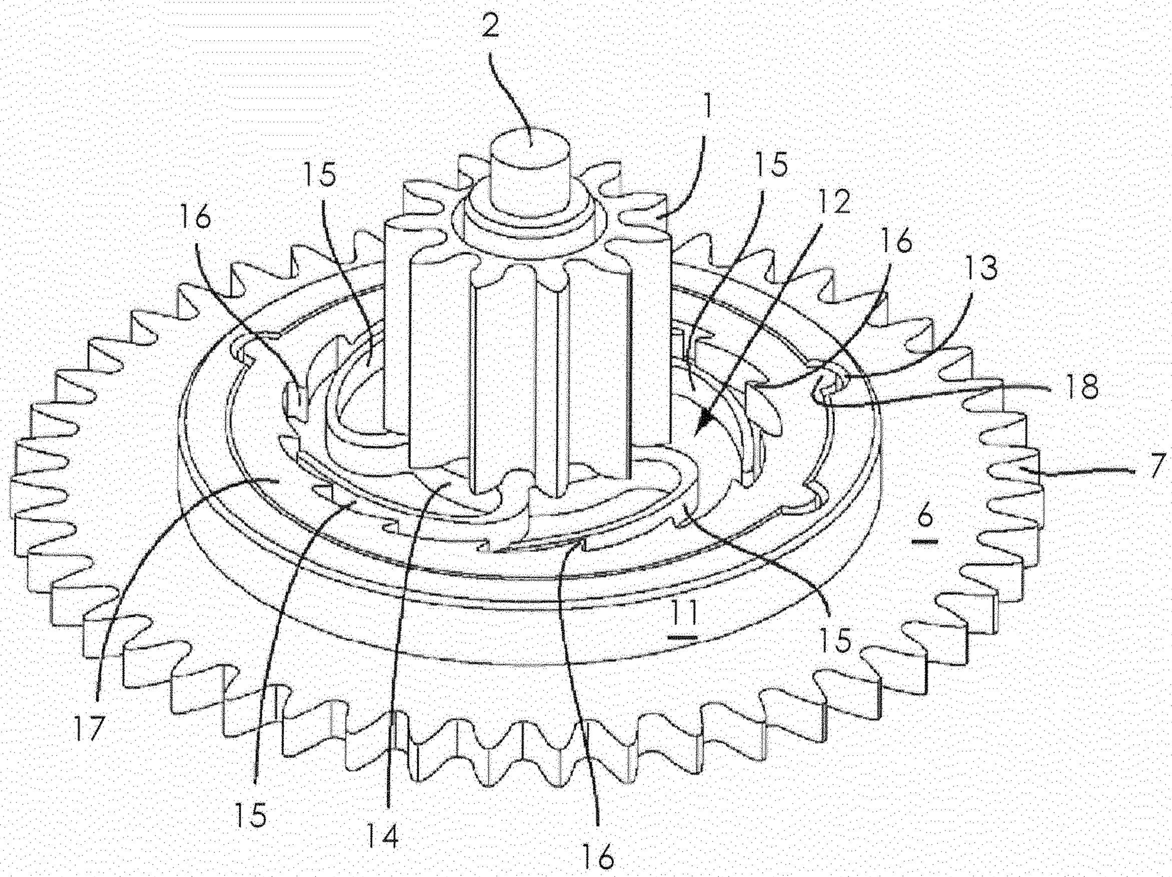
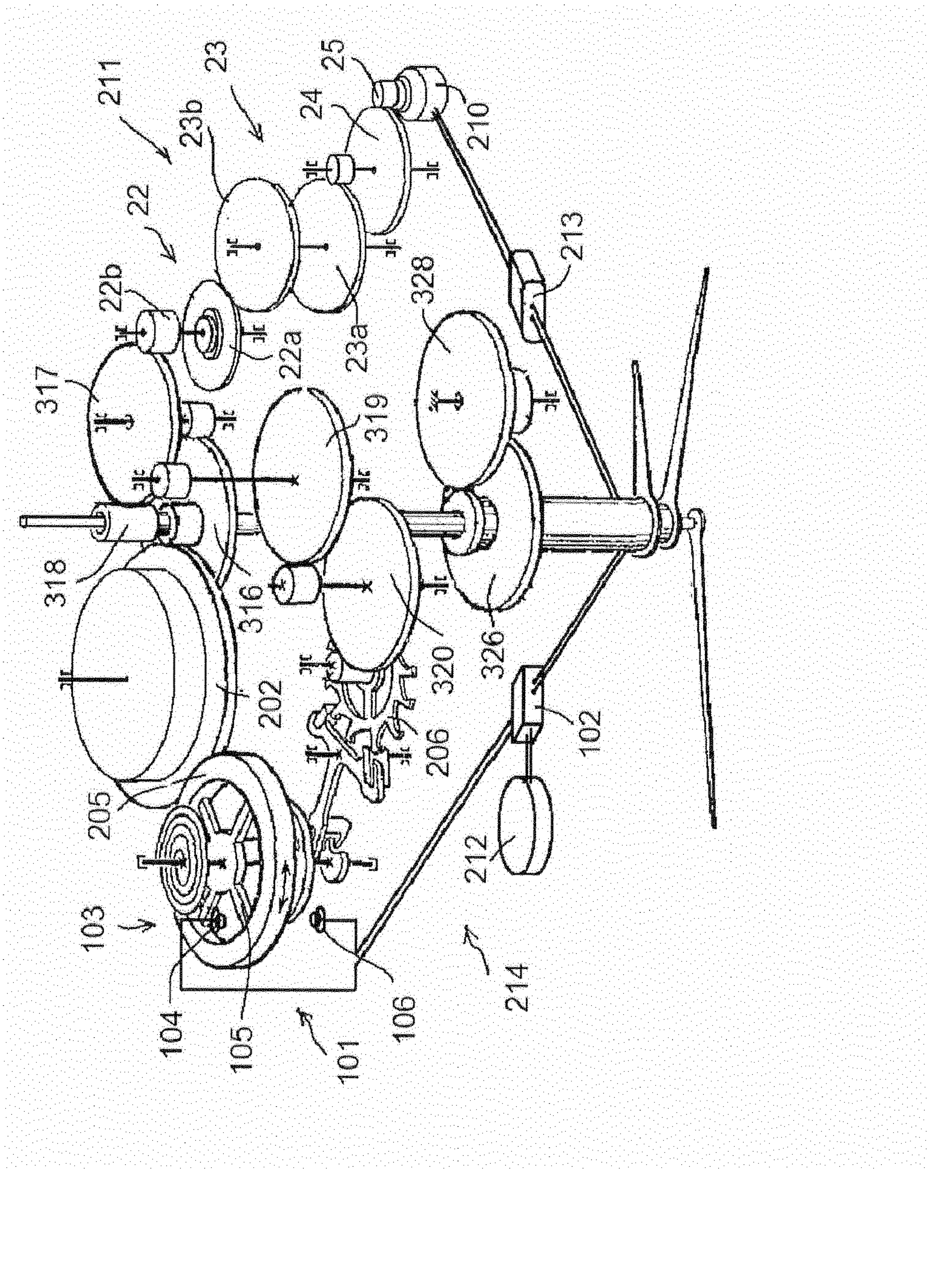


FIG. 9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22a
23a
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202
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102
205
212
103
104
105
101
106
214

FIG. 10

Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 14 17 3474

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	EP 1 975 746 A2 (SEIKO EPSON CORP [JP]) 1 October 2008 (2008-10-01) * paragraphs [0016], [0017], [0050], [0051]; figure 1 * -----	1-15	INV. G04C3/04 G04B1/22
A,D	EP 1 988 434 A1 (YANG TAI-HER [TW]) 5 November 2008 (2008-11-05) * paragraph [0006]; figure 1 * -----	1-15	
A	FR 404 908 A (ERIEL D'USINES A GAZ [FR]) 15 December 1909 (1909-12-15) * page 2, line 45 - line 87; figure 1 * -----	1-15	
A	EP 1 914 604 A1 (GIRARD PERREGAUX SA [CH]) 23 April 2008 (2008-04-23) * paragraphs [0004], [0020] - [0037]; figure 1 * -----	1-15	

TECHNICAL FIELDS SEARCHED (IPC)

G04C
G04B

The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
The Hague	15 January 2015	Mérimèche, Habib

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