Dec. 21, 1965 C. N. CHALLACOMBE ETAL 3,224,183

ELECTRICALLY ACTUATED TIME INTEGRATING DEVICE

Filed Oct. 14, 1963 3 Sheets-Sheet 1

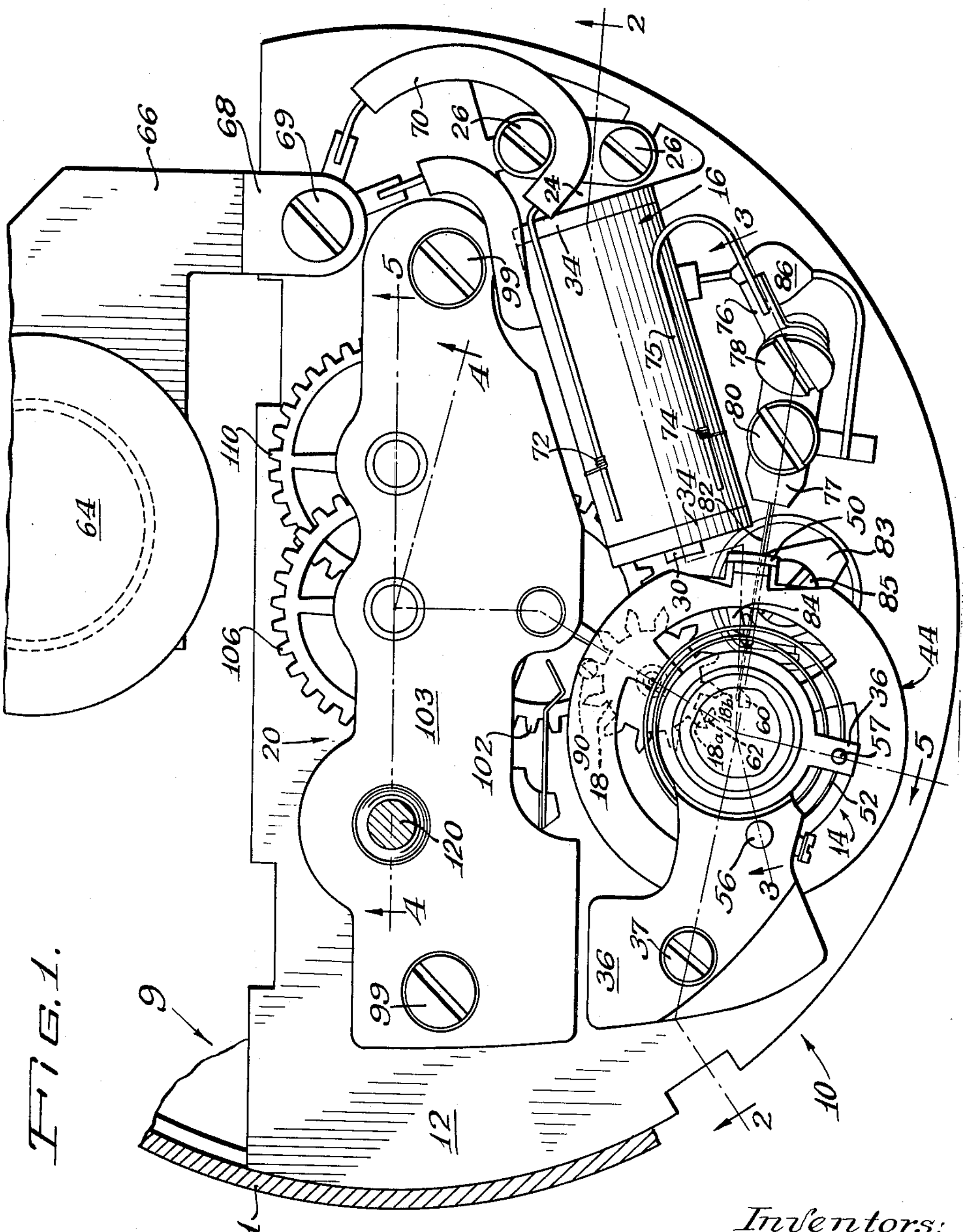

FIG. 1.

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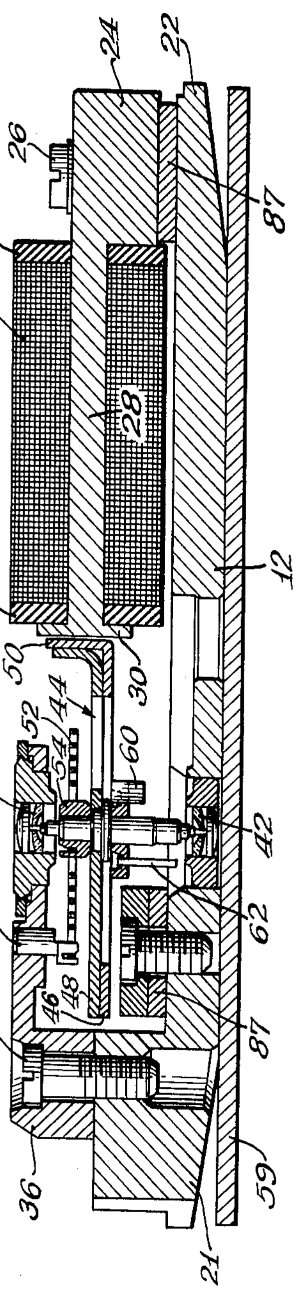

FIG. 2.

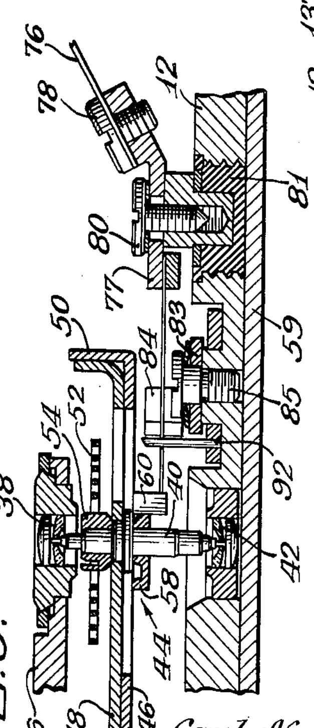

FIG. 3.

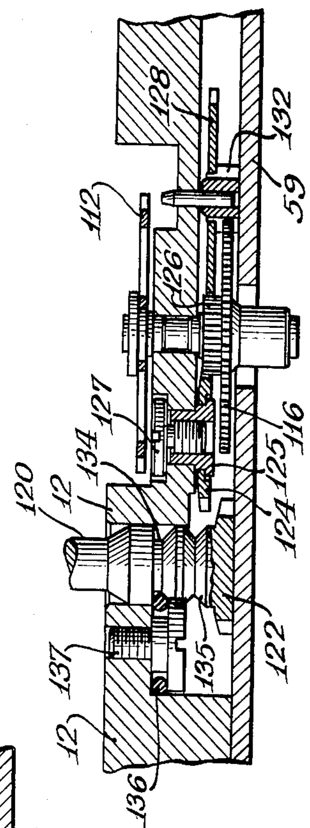

FIG. 4.

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ELECTRICALLY ACTUATED TIME INTEGRATING DEVICE

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FIG. 5.

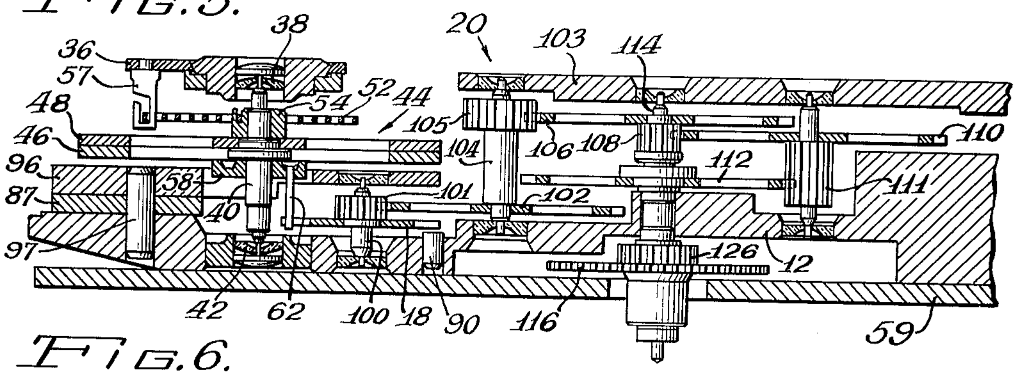


FIG. 6.

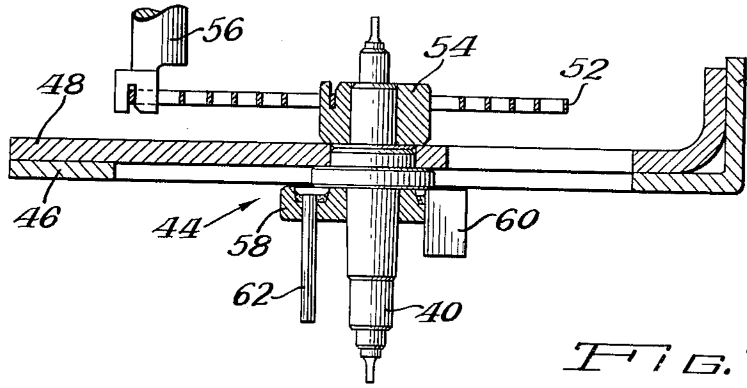


FIG. 7.

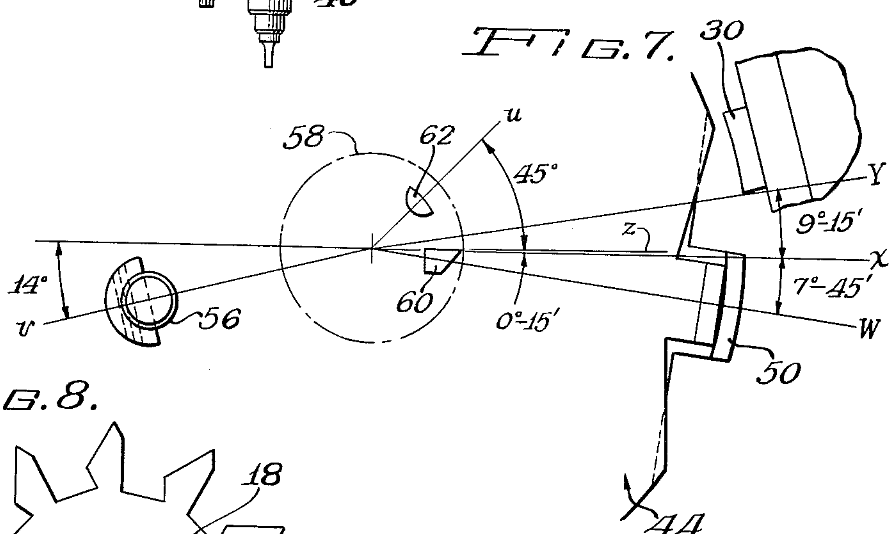
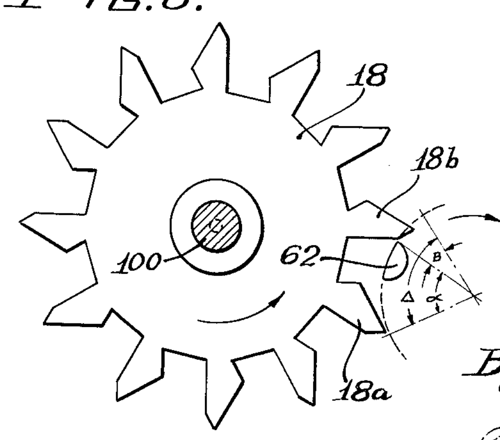


FIG. 8.



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ELECTRICALLY ACTUATED TIME INTEGRATING DEVICE

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Filed Oct. 14, 1963, Ser. No. 315,804

4 Claims. (Cl. 58—28)

The present invention relates to electrically-actuated time measuring devices and, more particularly, to an electrically-actuated time integrating mechanism for use in a self-contained watch structure of small size such as a wrist watch or lapel watch, which watch is operable over a long period of time without replacement or any manual adjustment of parts.

In commercial time measure devices utilizing an electric battery to maintain a balance or like system in oscillation for operating a time indicating train, there are generally no limitations as to the size of the components or power requirements. In smaller clocks of the type used, for example, in automobiles, wherein current is supplied from the automobile battery and may amount to several watts, there are but few restrictions.

When designing a wrist watch or lapel watch or like-sized watch having the size and weight restrictions acceptable in the commercial market, severe restrictions are imposed in terms of portability, freedom from replacement and adjustment of any parts by the user, and utilization of components which will fit within the restricted space and yet provide satisfactory time indicating operation over a period of a year or more.

An example of a watch having some of the characteristics desired for a commercially acceptable electrically-actuated timepiece is disclosed in Ensign, et al, Patent No. 2,865,163 granted December 23, 1958, and assigned to the assignee of the present application. The disclosure of the Ensign, et al. patent may be referred to for exemplifications of the watch configuration to which the present invention relates. Essentially the electrically-actuated timepiece comprises a casing which contains a time integrating mechanism or movement. Such movement includes a balance and hairspring assembly actuated by an electromagnetic power means including an electrical battery, time indicating means, as for example, hours, minutes and seconds hands, star wheel means incrementally actuated by the balance and hairspring assembly and a power train operatively connected to the star wheel means for actuating the time indicating means. The watch disclosed by Ensign, et al. was adapted to operate at a frequency of 2½ cycles or five one-half oscillations or "beats" per second. In a conventional watch, a "tick" is produced each one-half oscillation and a watch producing 5 ticks per second is designated as a 5 beat watch.

One of the most important factors in producing stability in the balance and hairspring assembly of the time integrating mechanism in a watch or timepiece is the alignment of the center of gravity of the balance with respect to its axis of rotation or axis of oscillation. In the watchmaking industry, the term "poise" is used to describe this factor. Thus, if a balance is out of center or has a defect thereon, then the oscillation will not be uniform and the watch will be "out of poise."

The effect of "out of poise" is governed by the following equation:

$$T=\pi\sqrt{\frac{I}{C}}\left\{2-\frac{mr\cos a}{C}[Fn(A)]\right\}$$

where

T is the period of half oscillation;

I is the moment of inertia of the balance;

2

C is a hairspring factor;

m is the mass of the defect;

r is the radius from the center of oscillation to the poise defect;

a is the angle between a vertical axis when the balance is at rest and the position of the poise defect; and

Fn(A) is a function of the amplitude of oscillation.

The product mr in the above equation represents the amount of "out of poise" producing the error in the time integrating mechanism.

It is seen that if balance system is in poise, the product of m times r is zero and Fn(A) cancels out and is of no effect. Then the period of oscillation becomes independent of amplitude and "isochronism" is obtained. Isochronism is a term used in the watch trade to indicate independence of rate on amplitude of oscillation.

Errors produced by the poise defect are due to gravity. Therefore the position of the poise defect relative to a vertical line passing through the axis of oscillation of the balance enters into the equation. Again considering the above equation, it will be noted that when the angle a equals 90 degrees, cos a equals zero, and although a poise defect may exist, it produces no effect.

The factor Fn(A) is an important one as is well known to watch designers. This factor becomes zero at 1.22 turns, which is equivalent to an amplitude of 220 degrees. Therefore, if the amplitude of oscillation of the balance can be maintained at 1.22 turns, there will be no adverse effect even though a poise defect exists.

Essentially there are two ways to eliminate a poise defect at a given frequency: (1) remove the defect and (2) maintain the amplitude of oscillation or motion at 1.22 turns or approximately 1¼ turns. Manufacturing techniques and cost practically limit the extent to which a defect can be removed. The poise defect remaining can be minimized by maintaining motion at about 220 degrees.

Considering again the above equation, it is seen that if the hairspring factor C is increased, the poise defect will be reduced. The constants C and I determine beat frequency. If a beat frequency of 5 beats per second is maintained, as is typical in electrically-actuated timepieces, and C is increased, I must be increased. However, to increase I effectively, the diameter of the balance must be increased. However, in a wrist watch, space is critical and increasing the diameter of the balance is undesirable. Therefore, to reduce poise defect by increasing C while reducing I, the frequency must be increased. Generally, increasing the frequency will increase stability of the balance system by reducing the effect of a poise defect. As seen from the above equation, C will increase as the square of the frequency, therefore, doubling the frequency will reduce the poise defect by a factor of four.

It is recognized as desirable in watch design to increase the frequency of oscillation of the balance and hairspring assembly. However, problems arise in increasing the frequency of oscillation. In ordinary mechanical watches there is a practical limit imposed by the increase of energy required. The additional energy is not available unless the size of the mainspring is increased. However, it is impractical and undesirable to significantly increase the size of the mainspring in a mechanical watch much beyond present size. In watches in which the balance is actuated by electric or electronic means, the balance drive system is essentially a form of electric motor. It was a desideratum of this invention to improve the efficiency of the motor utilized in a timepiece by designing a structure operable at increased speeds, thereby making it possible to operate the balance at a higher frequency. At present, electric wrist watches of the balance system type conventionally operate at 5 beats per second, whereas the watch of the present invention is adapted to operate at between 9 and 12 beats per second and preferably, at 10 beats per second.

At increased frequency of operation, further mechanical difficulties arise in indexing the star wheel. The momentum of the star wheel will increase in proportion to the frequency and difficulty will be encountered in locking the star wheel after indexing. A further problem was maintaining the motion at about a turn and one quarter as the frequency was increased. Damping increases as the square of the velocity and a point is reached where the energy input increases above acceptable values. By the present invention, there is provided a watch operable at about 10 beats per second, while requiring essentially the same power consumption as in a 5 beats per second watch. It was recognized that in doubling the frequency, there were twice as many pulses per second, but each pulse was only half as long. Further, it is known from basic motor theory that the efficiency of a motor depends upon the rate of change of flux in the torque generating air gap. In the present invention, this rate of change is about twice as fast as previously. To operate a mechanical watch at 10 beats per second would require twice as much energy input as opposed to a 5 beats per second mechanical watch. In the present improved electrical watch, the electrical conversion efficiency increases and little more power is required than for operating a 5 beats per second watch.

Another problem heretofore encountered in design of an electrically-actuated timepiece having a balance and hairspring assembly is termed "overbank." Overbank occurs in a watch when the amplitude of the balance reaches one turn or 360 degrees. In the electric watch, the motion of the balance triggers an impulse, delivering energy to the balance and hairspring assembly. If the one half amplitude reaches 360 degrees, the balance will receive additional and undesired pulses, which may be sufficient to maintain the balance in a state of superfluous motion. In conventional constructions, using a star wheel indexing system, this results in double indexing and the hands move at twice the desired speed. Therefore, to date, all electric watches having time integrating mechanisms including balance systems have been provided with some means to prevent overbanking. Such overbank control devices require adjustment, waste energy, and increase cost. Unexpectedly, it was found that by using a higher frequency and improving the construction of the time integrating mechanism in the electric watch, elimination of the overbank control became feasible.

Another deficiency in previous electric timepieces was that conventional means of shock proofing balance pivots against breakage were often inadequate. The two most prevalent devices were flexible balances or spring-loaded bearings. Both arrangements provide some degree of shock resistance, however at the risk of operating stability. It was found that if the ratio of the mass of the balance to the square of the pivot diameter were sufficiently reduced, as compared to conventional design, essentially the same degree of shock protection could be achieved as provided by the devices presently used. Practical structures necessary to achieve this objective must operate at frequencies of 9 beats per second and above, in watches of reduced diameter.

An object of the present invention is to provide an electric watch having an improved time integrating mechanism.

A further object of the present invention is to provide an electrically-actuated timepiece having a time integrating mechanism including a balance system adapted to operate at about twice the frequency of previous electrically-actuated timepieces, with improved stability and time-keeping ability.

Another object of the present invention is to provide a novel 10 beats per second electric watch which requires essentially the same power input as a conventional 5 beats per second electric watch.

Another object of this invention is to provide a novel electrically-actuated timepiece having a time integrating mechanism including a balance construction.

Yet another object of the present invention is to provide a time integrating mechanism for an electric watch which mechanism is constructed and arranged to obviate the need for an overbank control.

It is a further object of the present invention to provide a novel time integrating mechanism having improved stability and reliability as compared to conventional time integrating mechanisms, yet occupying no more space or volume than heretofore.

These and other objects of the present invention will be obvious from the foregoing description of a preferred embodiment of the invention. The invention will be described by reference to the attached drawings, wherein like numerals refer to like elements and in which

FIGURE 1 is a plan view of an electric timepiece embodying the time integrating mechanism of the present invention;

FIGURE 2 is a longitudinal cross-sectional view of the time integrating mechanism taken generally along line **2—2** of FIGURE 1;

FIGURE 3 is a detail cross-sectional view of the time integrating mechanism taken generally along line **3—3** of FIGURE 1, and more clearly illustrating the balance and hairspring assembly and its operative relationship with the contact means of the electromagnetic power means;

FIGURE 4 is a detail cross-sectional view taken generally along line **4—4** of FIGURE 1 and illustrating the setting stem and a portion of the power train selectively operated thereby;

FIGURE 5 is a detail cross-sectional view taken generally along line **5—5** of FIGURE 1, more clearly illustrating the operative association of the balance and hairspring assembly, the star wheel and the power train;

FIGURE 6 is an enlarged cross-sectional view of the balance and hairspring assembly;

FIGURE 7 is a schematic drawing of the relationship between the balance and the pole piece of the solenoid of the electromagnetic power means, and illustrating the specific angular relationships about the axis of oscillation of the balance considered from a radial line passing through the forward edge of the tab of the actuating means on the balance, the tab on the balance, the hairspring stud and the pole piece; and

FIGURE 8 is a bottom view illustrating the driving engagement between a lug on the balance wheel and a tooth of the star wheel.

It will be understood that for simplicity and clarity certain structures and parts normal to conventional watches, such as details of plates, pinion and wheel assemblies, and jewel bearings have been omitted from the drawings and that the inclusion of such if desired is within the purview of the illustrated preferred embodiment of the present invention.

Referring now to FIGURE 1, it is seen that the time integrating mechanism **10** of the present invention is supported in the casing **11** of an electrically-actuated timepiece **9** in a conventional manner. Such mechanism **10** comprises a base plate **12** upon which is mounted a balance and hairspring assembly **14**, electromagnetic power means **16** for suitably actuating and oscillating the balance of the balance and hairspring assembly **14**, a star wheel **18** positioned adjacent the balance and hairspring assembly and adapted to be moved incrementally thereby, and a power train **20** operatively connected to the star wheel and actuated thereby for suitably moving the sweep-seconds, minutes, and hours hands, typically utilized in a wrist watch. For details of the electrically-actuated timepiece or watch not shown herein as for example, the specific manner of supporting the base plate **12** in case **11** of timepiece **9**, reference may be made to the abovenoted Ensign et al. Patent No. 2,865,163.

The base plate or frame **12** (FIGURES 1 and 2) may be made of a magnetizable material of low permanent magnetism, i.e. remanence. The base plate **12** includes upwardly extending portions **21** and **22**. On the portion **22**, there is fixedly mounted a mounting block **24**, which is held in position by means of screws **26** passing through suitable holes provided in the block which are larger than the screw stems. The block **24** supports a core piece **28** at whose free end is a stator block **30** providing a pole face at the outer end thereof. The block **24**, core piece **28**, and stator block **30** are preferably formed integrally of a magnetizable material of low permanent magnetism.

A coil **32** is wound on the core piece **28** between the insulating end washers **34**, thus forming solenoid **33**.

A balance cock **36** is secured to the face of the projection **21** by fastening means or screw **37** and carries the bearing **38** for one end of the balance staff **40** of balance **44**. The balance staff **40** is supported at its other end by a bearing **42** in the frame structure **12**. The balance **44** must be very light to achieve the desired frequency in a small restricted space. The balance comprises a soft iron ring **46** supported on the balance staff **40** by means of a ring **48** having arm means **49** affixed to the balance staff. Formed on the soft iron ring **46** is an upstanding tab **50** which is adapted to be attracted by the stator block or pole **30** of the solenoid **33**. The ring **46** is preferably formed of a beryllium copper base to insure that the tab will be retained upright. Ring **48**, which may also be made from beryllium copper, functions to strengthen the balance ring **46**. The attraction of the tab **50** to pole **30** will cause movement of the balance and hairspring assembly counterclockwise about the axis of the balance staff as viewed in FIGURE 1. During counterclockwise movement of the balance and hairspring assembly **14**, the hairspring **52** which is affixed at one end to the collet **54** carried on the balance staff **40** and at the other end to a stud **56** extending from the balance cock **36**, is tensioned or wound upon itself and thus stores energy. This energy will later be utilized to rotate the balance in an opposite direction—clockwise as seen in FIGURE 1. A conventional hairspring regulator **57** is provided.

Supported on the balance staff **40** below the wheel **48** is a collet member **58** having a radially projecting fin **60** for actuating an electrical contact means in the electromagnetic power means **16** to provide a suitable impulse to the solenoid **33** for actuating and oscillating the balance and hairspring assembly **14**.

The fin **60** may be made of sapphire or a similar abrasion-resistant material. The collet **58** also carries actuator means defined by an axially projecting jewel pin or roller **62** for moving the power take-off star wheel **18** as described hereinafter.

The frame **12** is adapted to abut the dial **59** of the watch, which dial is provided on its lower or exposed face with the usual time indicating indicia.

As seen in FIGURES 1 and 3, electromagnetic power means **16** of the present invention is powered from a battery **64**, which has one side grounded to frame **12** and which is affixed at its other side to an electrically conductive arm or terminal member **66**. The arm **66** is, in turn, affixed to a terminal post **68** by means of a screw **69**. The terminal post **68** is affixed to and insulated from base plate **12**. Insulated conducting wire **70** extends from the terminal post **68** and is affixed to a contact **72**, such contact being defined as one end of the wire forming the coil **32** of the solenoid **33**. A contact **74** is provided on the other end of the wire forming the coil **32** of solenoid **33**. Contact **74** connects to conducting wire **75**, which is affixed to terminal **76**. Terminal **76** is connected to support **77** by a screw **78**. The support **77** is in turn affixed to a block **79** by screw **80**. Block **79** is carried in frame **12** by insulated washer member **81**.

Extending outwardly from the support **77** toward the

balance and hairspring assembly are electrical contact means defined by a contact wire **82**. The contact wire, which is on the order of 0.001 inch in diameter, is adapted to be periodically engaged by the fin **60** on the balance **44** and moved into contact with the electrical contact means defined by the knife edge **84** carried on plate-like member **83**, which is electrically connected to the frame **12** by screw **85**, to close an electrical circuit and energize the solenoid **33**. The member **83** is adjustably retained by screw **85**. Movement of member **83** will also move knife edge **84**, thereby varying the position of the knife edge with respect to contact wire **82**. Such adjustment will vary the length of the electrical impulse and therewith the amount of energy delivered for magnetically impulsing the balance system.

A diode **86** is electrically connected in shunt or parallel with the coil **32** of solenoid **33**. In this manner, coil **32** is shunted when current flows in an opposite direction to that required to produce the impulse on the balance of the balance and hairspring assembly. The diode **86** functions to prolong contact life by reducing the spark when the contact wire **82** separates from the knife edge **84**.

Thus, it is seen that when the contact wire **82** is away from the stationary contact or knife edge **84**, essentially no current flows through the electrical system from the battery.

When the contact fin **60** in its counterclockwise stroke (FIGURE 1) engages the contact wire **82** and moves it into engagement with the end of the stationary contact **84**, a circuit is closed, which may be traced from the battery **64** by terminal clip **66**, terminal **68**, conducting wire **70**, contact **72** and through the coil **32** to the contact **74**, thence by conducting wire **75** and terminal **76** to the block **77**, contact wire **82** and knife edge **84** to the frame **12** as at common ground, with return to the battery which is similarly grounded to the frame **12**. This current flow is in the same direction as that which has been imposing a static potential on the diode or rectifier member **86**, and hence the diode conducts no more current than before.

Upon energization of solenoid, the tab **50** which is an extension of the soft iron magnetic piece **46**, is attracted by pole **30**. The magnetic flux flows through tab **50**, ring **46**, and member **87** back to the end of solenoid **33** opposite pole **30**. The return path is not completely shown but the ends of member **87**, made from soft magnetic material, are indicated in FIGURE 2. An impulse is thereby delivered to rotate the balance **44** of the balance system.

The electrical circuit is completed for only a few milliseconds and then the fin **60** in its counterclockwise movement frees the end of contact wire **82** so that the circuit is again interrupted between the contact wire **82** and the stationary contact or knife edge **84**. Bouncing or excessive movement of the wire **82** is minimized by deflector jewel or pin **92**. At this time, the coil of solenoid **33** has maximum magnetic affect, and its induction tends to cause the current to continue to flow in the same direction as the stated impulsing current, that is, from the contact **72** to the contact **74**. This would normally cause a sparking between the contact blade **82** and the stationary contact **84** at the moment of breaking, but in this system, the current derived from the collapsing magnetic field can flow through the diode **86** so that the coil is essentially short-circuited and rapidly loses its induced voltage.

Considering now FIGURES 1 and 5, there is more clearly illustrated the cooperative relationship between the balance and hairspring assembly **14**, the star wheel **18** and the power train **20**.

The balance system oscillates in the usual manner. It receives an impulse magnetically at each cycle of oscillation. The collet **58** carries its jewel pin or roller **62** in a path which intersects the points or teeth of the star wheel 18.

In FIGURE 1, the parts are shown at neutral axis, that is, in the position at the start of the retrogate movement of the star wheel 18. In actual operation, pin 62 moves past point 18a in its counterclockwise stroke. The balance then moves clockwise. At the start of the retrograde movement, the jewel pin 62 encounters point 18a of the star wheel and produces a relative counterclockwise movement of the star wheel 18. The pin 62 in its circular rotational path leaves the tip of the star wheel point 18a and the balance system continues in its clockwise stroke without further action upon the star wheel.

FIGURE 7 shows the specific relationships between jewel pin actuating means 60 and 62 on the collet 58 movable with balance 44, the tab 50 on balance 44, the pole piece on solenoid 33 and the hairspring stud 56 in one presently preferred embodiment of this invention. The angle defined between the centerline w of the tab 50 and a line x extending from the axis of oscillation of the balance through the forward tip of the tab 50 is 7 degrees 45 minutes. The angle defined between line x and the line y extending from the axis of oscillation of balance 44 through the leading tip of pole 30 is 9 degrees 15 minutes. The leading edge of the fin or contact jewel pin 60 lies in a line z passing through the axis of oscillation at an angle of 15 minutes with respect to line x. The centerline u of indexing pin 62 lies at an angle of 45 degrees with respect to line z. The centerline v of hairspring stud 56 lies at an angle of 14 degrees with respect to line x.

Considering specifically FIGURE 8, there is illustrated a bottom view of the interaction between the driving pin or jewel pin 62 on the collet 58 affixed to the balance staff 40 and the teeth of the star wheel 18. The angle of interaction between the indexing jewel pin 62 and a tooth 18a of the star wheel or the "arc action angle," is indicated by the Greek letter delta. The angle indicated by the Greek letter alpha and lying between radii drawn from the axis of oscillation of the balance and hairspring assembly to the apices of adjacent teeth of star wheel 18 is the driving angle, and reflects the arcuate movement required for the indexing pin 62 to clear the apex of a tooth, for example 18b, and engage a tooth 18a to be driven. The angle denoted by the Greek letter beta is the passing angle. It is seen that the angle delta is the sum of the angles alpha and beta.

The teeth of the star wheel 18 have an asymmetrical configuration and include a pair of intersecting surfaces defining a relatively long passing face 88 and a relatively short driving face 89. The star wheel 18 is retained in the selected indexed position by means of the permanent magnet 90 (FIGURE 1) which is magnetically attracted to a tooth of the star wheel.

In operation, as the balance 44 and pin 62 carried therewith move clockwise as viewed in FIGURE 8, the pin 62 drives tooth 18b counterclockwise. Pin 62 moves past tooth 18b. The atraction of the magnet 90 (FIGURE 1) to an adjacent tooth causes continued movement of the star wheel 18 to its indexing position. On the return stroke of pin 62, the pin 62 strikes the next tooth 18a and causes a slight retrograde motion of the star wheel 18. The star wheel is retained in its indexed position, however, by magnet 90. The pin then moves past tooth or point 18a to a position to start the next driving action. From the foregoing, it is seen that the star wheel is driven in a step-by-step or incremental manner by the indexing pin 62 carried on the balance staff 40 of balance 44.

Referring to FIGURE 5, there is best illustrated the power train 20 untilized in the time integrating mechanism of the present invention. The power train is of generally conventional design and therefore it will not be described in detail. For a more complete understanding of the power train, reference may be made to Ensign et al. Patent No. 2,865,163. The star wheel 18, which is supported between star wheel cock 96 and pillar plate or base plate 12 in conventional jeweled bearings, carries on the shaft 100 thereof a pinion 101 for driving the power gear train 20. Steady pin 97 is utilized to align the frame 12, member 87, and star wheel cock 96. The power train is carried between the frame 12 and a bridge 103 spaced therefrom and suitably secured thereto, as for example, by screws 99. Bearings in the base plate or frame 12 and the bridge 100 support a shaft 104, which carries a wheel 102 at the lower end thereof operatively engaging the pinion 101 and a pinion 105 at the upper end thereof. The pinion 105 engages a sweep second wheel 106. Pinion 108, movable with the sweep second wheel 106, engages and drives wheel 110. Formed on wheel 110 and movable therewith is a pinion 11. The pinion 111 meshes with center wheel 112 mounted on the hollow minutes shaft 114. Also carried on the hollow minutes shaft is an hour wheel 116, which is adapted to be engaged by a minute pinion (not shown). It will be understood that the gears are a suitable ratio so that the hour hand turns once in 12 hours, the minute hand turns at one revolution per hour, and the sweep or center seconds hand operates at one revolution per minute.

Referring to FIGURE 4, there is illustrated the mechanism for manually setting the time integrating mechanism. The setting stem 120 extends through an aperture in the base plate 12 and is movable outwardly from the time integrating mechanism or upwardly as viewed in FIGURE 4 to move the gear 122 affixed on the end thereof into engagement with the cooperating gear 124, rotatably supported on the frame 12 by sleeve 125 and screw 127. The gear 124 is adapted to engage pinion 126 carried on the hollow minutes shaft, which pinion in turn meshes with the minutes wheel 128. Carried on the journal pin 130 for movement with the minutes wheel 128 is a pinion 132. Pinion 132 meshes with the hour wheel 116. Thus, it is seen that when the end of the setting stem 120 is pulled upwardly as viewed in FIGURE 4, so as to engage gears 122 and 124 and then rotated, the hours and minutes hands carried on the center shaft may be suitably adjusted.

It is noted that the setting stem 120 is provided with a pair of recesses 134 and 135, which recesses are adapted to receive a resilient annular ring or spring 136 held in position on frame 12 by suitable fastening means, as for example, screw 137. When the setting stem is pushed inwardly, the ring 136 will engage in recess 134 and hold the gears 122 and 124 disengaged. When the setting stem 120 is pulled upwardly as viewed in FIGURE 4, the ring 136 will engage recess 135 and maintain gears 122 and 124 in engagement.

In considering the design criteria for a commercially acceptable electrically-actuated time device of small size, as for example, a wrist watch, it has been found desirable that the time integrating mechanism or movement be not greater than about one inch. In watch industry terminology, the size of a movement is denoted by the shortest distance across the movement taken through the axis of the indicating means. Another desideratum of the present invention is to increase the stability of the balance system in the time integrating mechanism of such small watch and minimize poise defects by increasing the frequency to above 10 beats per second, or approximately twice the frequency conventionally utilized for electrically-actuated wrist watches utilizing balance and hairspring-type oscillator systems.

The diameter of the balance has been found to be a critical feature. Where size and space are at a premium, as is the case with the present invention, the balance must be of such mass as to provide a satisfactory ratio between the balance moment of inertia and the star wheel moment of inertia. Also, it must be of adequate size to provide a satisfactory linear distance between the tab 50 on the balance 44 and the pole 30 when current is applied to the solenoid **33**, which linear distance is a function of lead time required for the coil. The electro-magnetic drive places limitations on the usable contact time. As tab **50** approaches pole **30**, the current must be applied with sufficient lead time to allow the flux in coil **32** to approach its maximum value as the corner of the tab approaches the corner of the pole. The electrical contact lead time is somewhat greater than the time constant of the coil where the time constant of the coil is defined as the ratio of the coil inductance (measured when the tab **50** is held directly opposite pole **30**) and the coil resistance. It has been determined that optimum operating results are obtained when the coil has a time constant of from one to three milliseconds and a volume on the order of 30 to 50 cubic millimeters.

In the present design, the moment of inertia of the star wheel restricts the minimum diameter of the balance. A star wheel having a moment of inertia less than about 0.15×10^{-3} gram centimeters squared has been found impractical to manufacture. The upper limit of diameter of the balance is limited by the frequency range of operation selected for the timing device. The time constant of the electrical circuit determines the required lead time of the contact means. Since the balance is operated at twice the angular speed of previous designs, it will rotate through twice the angle during the current build-up time required by the coil structure. If the balance diameter is too large, the tab **50** will be too far from pole **30** at the instance contact wire **82** engages the knife edge **84**. The efficiency of inducted drive is proportional to the rate of change of flux as the tab approaches the pole; which in turn is proportional to the peripheral velocity of the balance. Efficiency is therefore increased with increased balance diameter and with increased beat frequency for there is an increase in the rate of change of permeance in the air gap between tab **50** and pole **30**. However, it becomes increasingly difficult to operate satisfactorily with larger diameter balances as the frequency increases. It has been ascertained that in a 10 beats per second electrically-actuated watch, the optimum balance diameter is between 6 and 8 millimeters.

Having ascertained that the balance diameter should be limited to a range of 6 to 8 millimeters, it was found to be impractical to design a balance having a moment of inertia exceeding about 7×10^{-3} gram centimeters squared, for above this limit the mass becomes excessive and larger pivots are required than is customarily used. It has unexpectedly been found that restricting the balance mass provides a measure of shock protection of the balance pivots and obviates the use of supplementary shock protection devices, such as spring-mounted bearings. The minimum balance moment of inertia should not be less than about 300 times the moment of inertia of the star wheel, which is of the order of $.015 \times 10^{-3}$ to $.0225 \times 10^{-3}$ gram centimeters squared. The optimum ratio between the moment of inertia of the balance and the moment of inertia of the star wheel for operation of an amplitude in the neighborhood of 225 degrees is on the order of 300–450 to 1. It is preferred that the mass of the balance be minimized and, accordingly, a balance having a moment of inertia of about 4.5×10^{-3} gram centimeters squared is preferred.

The selection of the size of the balance moment of inertia places restrictions upon the optimum parameters of the hairspring. If by sudden jars or movements of the wrist, the balance attains an one half amplitude of 360 degrees or 2 turns, the electrical contact means are closed and the balance will receive an additional and undesirable pulse. At the time this pulse is received, the hairspring has been wound to a displacement of 360 degrees or 2π radians. The hairspring torque opposes the pull exerted by the excited electromagnet and of this torque exceeds the holding torque of the electromagnet, no additional energy is imparted to the balance during the undesired pulse. The balance will quickly drop back to its normal amplitude of 225 degrees or 1¼ turns. The holding torque for the electromagnet system, having design specifications as set forth, is of the order of 25 to 30 dyne centimeters. A hairspring of sufficient strength to furnish sufficient counteracting torque when wound through 2π radians must have a strength of the order of 5 dyne centimeters per radian. Therefore, a minimum hairspring strength of C equals 5 dyne centimeters per radian is required. A maximum hairspring strength of 7 dyne centimeters per radian is imposed by practical limitations of the design. Thus, the spring factor for the hairspring lies in a range of 5 to 7 dyne centimeters per radian.

By the present invention, there is provided a 10 beats per second timepiece having a stronger hairspring (one having a higher spring constant C) than heretofore, in combination, with a lighter balance (one having a lower moment of inertia). More stored energy is provided in the oscillating balance and hairspring assembly, thereby improving the timekeeping of the watch while still retaining the desirable small size of the timepiece.

It is impractical to reduce the moment of inertia of the star wheel. With increasing frequency, the indexing problems are amplified and the star wheel absorbs too much energy, making it difficult to maintain adequate balance amplitude within the parameters of the coil design.

The present invention provides an electrically-actuated timepiece or watch which requires no overbank control. As aforenoted, increasing the frequency from 5 beats per second to 10 beats per second results in the hairspring supplying four times as much counter torque to be overcome by the undesired pulse where the one half amplitude of the balance exceeds 360 degrees. In the present design, the frequency has been essentially doubled (from 5 to 10 beats per second) with little increase in power requirements, thereby permitting use of conventional watch batteries. There are, therefore, twice as many pulses and each pulse will supply one-half as much energy. The hairspring resistance is equal to or somewhat greater than the energy input to prevent the balance from locking in at a state of excess motion. The present invention provides a ten beats per second timepiece having no overbank control.

By the present invention, there has been provided an electric watch having an improved time integrating mechanism. The time integrating mechanism includes a balance system operable in the range of 1⅛ to 1¼ turns—a range where poise defects are minimized. The construction restricts the balance from moving in higher amplitudes and accordingly overbanking is obviated, except perhaps for sudden violent movements of the watch.

It will be apparent that the balance **44** of the present invention can be utilized in movements smaller than one inch, as for example, movements for ladies' watches, which are on the order of 0.6 inch.

While there has been shown and described a particular embodiment of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention and, therefore, it is intended in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What we claim as new, and desire to secure by Letters Patent of the United States, is:

1. In an electrically-actuated time integrating mechanism, the combination of: a frame, a balance and hairspring assembly supported on the frame for oscillatory movement, said assembly including a balance being no greater in diameter than **8** millimeters, electromagnetic power means cooperating with said balance for actuating said oscillatory balance and hairspring assembly, and star wheel means rotatably mounted on said frame and being adapted to drive a power train, said balance actuating said star wheel means during oscillation thereof for advancing the star wheel means incrementally, said balance having a moment of inertia in a range of

4.5×10^{-3} to 7×10^{-3} gram centimeters squared, and the moment of inertia of the balance being not less than 300 times the moment of inertia of the star wheel means, whereby said time integrating mechanism functions at a frequency of from 9 to 12 beats per second and the amplitude of the balance is sustained at a level of less than and limited to two turns of motion.

2. In an electrically-actuated time integrating mechanism, the combination of: a frame, a balance and hairspring assembly supported on the frame for oscillatory movement, said assembly including a balance having a diameter in the range of 6 to 8 millimeters and a hairspring having a spring factor in the range of 5 to 7 dyne centimeters per radian, electromagnetic power means cooperating with said balance for actuating said oscillatory balance and hairspring assembly, said electromagnetic power means including a magnetic circuit having a time constant in the range of 1 to 3 milliseconds, and star wheel means rotatably mounted on said frame and being adapted to drive a power train, said balance actuating said star wheel means during oscillation thereof for advancing the star wheel means incrementally, said balance having a moment of inertia in a range of 4.5×10^{-3} to 7×10^{-3} gram centimeters squared, and the moment of inertia of the balance being not less than 300 times the moment of inertia of the star wheel means, said time integrating mechanism operating at a frequency of from 9 to 12 beats per second and the amplitude of said assembly being restricted such that an overbank control is not required.

3. An electrically-actuated time integrating mechanism for use in a time device, said integrating mechanism being operable at eight to twelve beats per second, said time integrating mechanism comprising, in combination: a frame, a balance oscillatable on the frame, a hairspring affixed to the balance and to the frame, electromagnetic power means cooperating with said balance for maintaining oscillation of said balance, star wheel means rotatably mounted on said frame and adapted to drive a power train, said star wheel means being advanced incrementally in response to the oscillation of said balance, said balance having a diameter in the range of 6 to 8 millimeters and having a moment of inertia from about 4.5×10^{-3} to 7×10^{-3} gram centimeters squared and said hairspring having a spring factor in the range of 5 to 7 dyne centimeters per radian whereby the combination and cooperation of the elements of the integrating mechanism obviates the requirement of an overbank control.

4. An electrically-actuated time integrating mechanism for use in a time device, said integrating mechanism being operable at eight to twelve beats per second, said time integrating mechanism comprising, in combination: a frame, a balance oscillatable on the frame, a hairspring affixed to the balance and to the frame, electomagnetic power means cooperating with said balance for maintaining oscillation of said balance, star wheel means rotatably mounted on said frame and adapted to drive a power train, said star wheel means being advanced incrementally in response to the oscillation of said balance, said balance having a diameter in the range of 6 to 8 millimeters and having a moment of inertia from about 4.5×10^{-3} to 7×10^{-3} gram centimeters squared wherein the ratio of the moment of inertia of the star wheel to the moment of inertia of the balance is in the order of $\frac{1}{300}$ to $\frac{1}{450}$ and said hairspring having a spring factor in the range of 5 to 7 dyne centimeters per radian whereby the combination and cooperation of the elements of the integrating mechanism obviates the requirement of an overbank control.

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LEON SMILOW, *Primary Examiner.*