Oct. 11, 1966 YASUO NOMURA ET AL 3,277,644

TUNING FORK TIMEPIECE

Original Filed July 1, 1963 6 Sheets-Sheet 1

Fig. 1

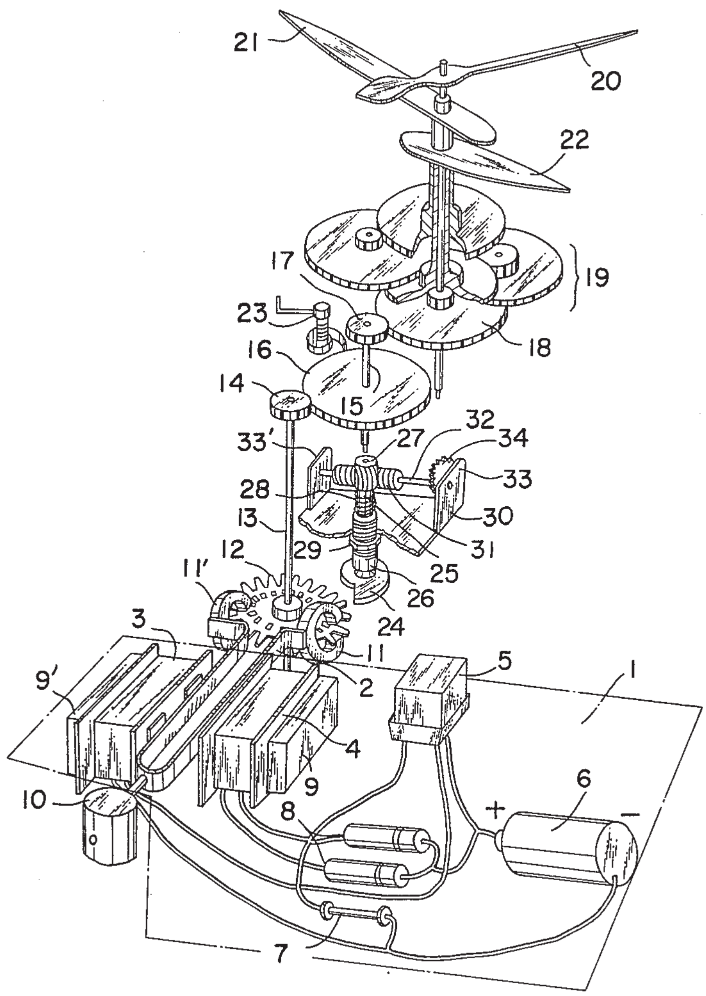

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Fig. 2

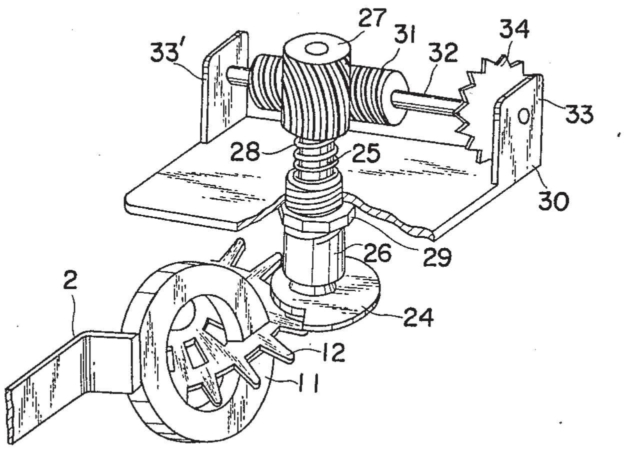

Fig. 3

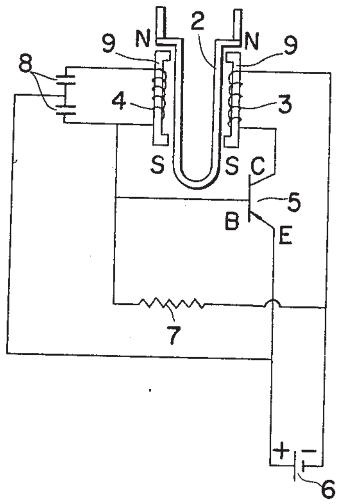

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Fig. 4

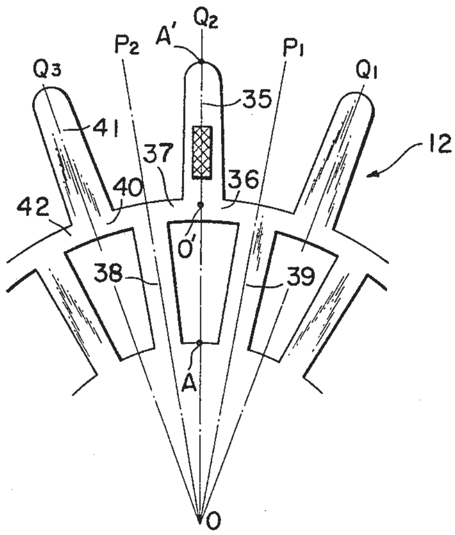

Fig. 5

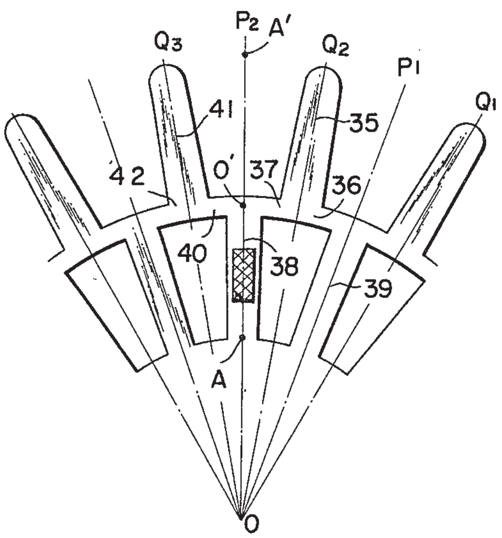

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Fig. 6

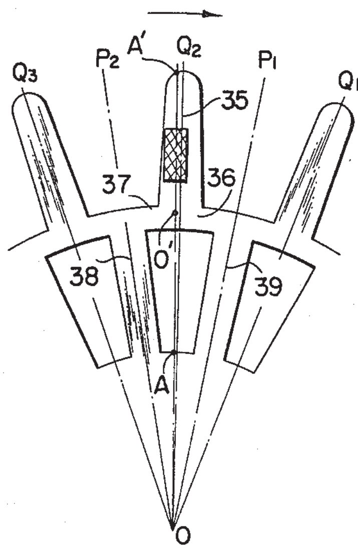

Fig. 7

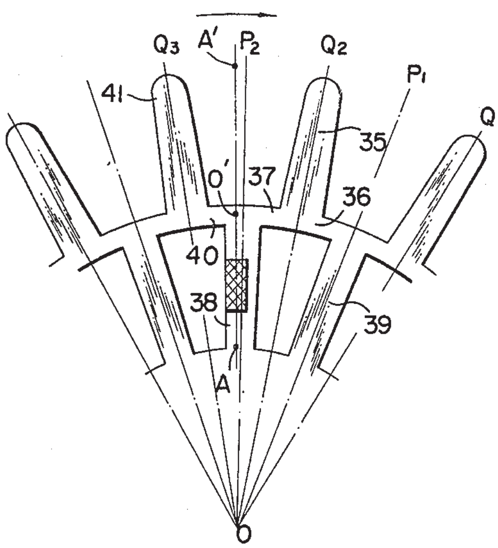

Fig. 8

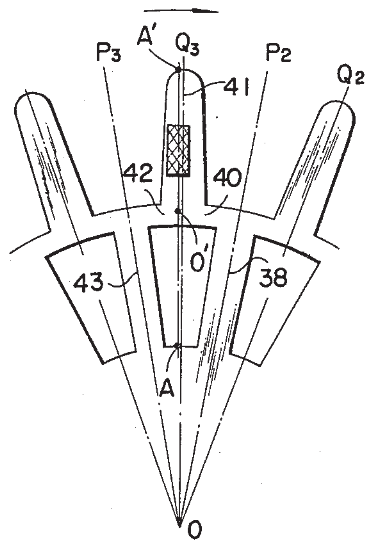

Fig. 9

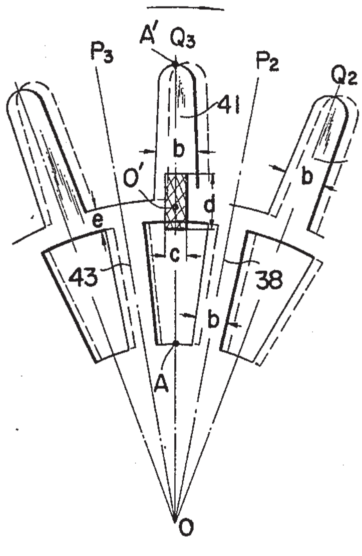

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Fig. 10

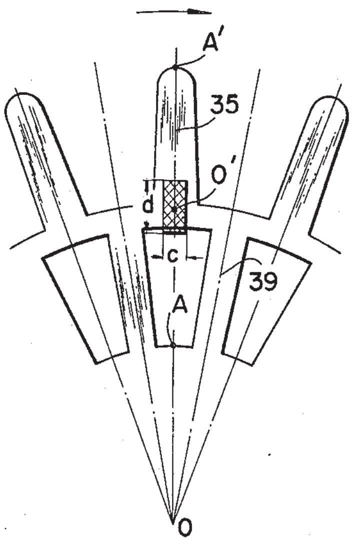


Fig. 11

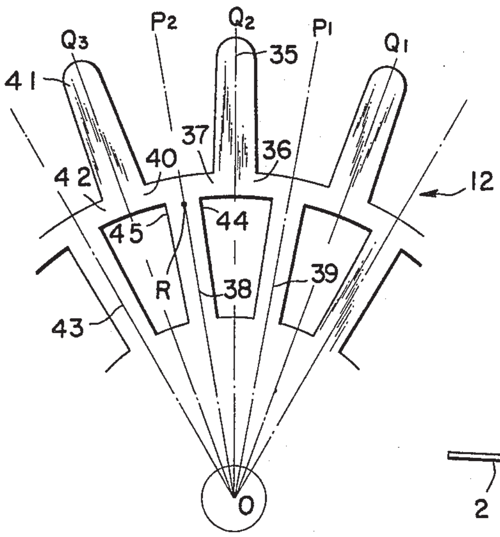
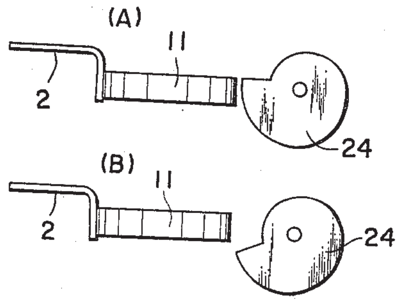


Fig. 12



3,277,644
TUNING FORK TIMEPIECE

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Continuation of application Ser. No. 291,763, July 1, 1963. This application June 8, 1965, Ser. No. 471,492
6 Claims. (Cl. 58—23)

This application is a continuation of application Serial No. 291,763, filed July 1, 1963 and now abandoned.

This invention relates to a tuning fork clock.

Heretofore there have been clocks and watches in which balance wheels or pendulums are used as oscillators. However, such oscillators are so low in mechanical Q and isochronism that they are not satisfactory for high precision clocks. Moreover, even if it were possible to make high precision clocks with such oscillators, the manufacture of such products would be very expensive.

Tuning fork clocks and watches in which tuning forks are used instead of balance wheels and pendulums are already known, as illustrated, for example in U.S. Patent No. 2,971,323. However, in such tuning fork clocks, the oscillatory motion of the tuning fork is converted to rotary motion by mechanical converters which are difficult to make and very costly.

Furthermore, a magnetic escapement mechanism has been proposed wherein a permanent magnet is attached to the forward end of an oscillator, and a rotary wheel (escapement wheel) made of a magnetic material and having magnetically nonsymmetrical undulating magnetic tracks is arranged between the magnetic poles of said permanent magnet so that said rotary wheel may be driven by the oscillatory motion of the oscillator. Such a mechanism is described, for example, in British Patent No. 660,584 but has not been practiced probably because the toque which is generated by the magnet of the oscillator attracting the nonsymmetrical part of the rotary wheel is so small that it is difficult to synchronize both magnet and wheel. Also, it is difficult to manufacture rotary wheels having magnetically nonsymmetrical undulated magnetic paths.

A main object of the present invention is to provide a low cost, high precision tuning fork clock wherein the oscillatory motion of the tuning fork is converted to a rotary motion by a very simple mechanism.

Another object of the present invention is to provide easy to manufacture rotary disks having magnetically symmetrical magnetic teeth for use with a tuning fork oscillator.

A further object of the present invention is to provide a tuning fork clock having a mechanism for simply adjusting the frequency of the mechanical oscillator.

The present invention shall now be explained with reference to the accompanying drawings of which:

FIGURE 1 is a perspective view of an illustrative embodiment of the tuning fork clock according to the present invention;

FIGURE 2 is an enlarged fragmentary perspective view showing the relative positions of the magnetic poles of a magnet and a rotary disk;

FIGURE 3 is a wiring diagram for an electric reciprocating motion generating device;

FIGURES 4 to 10 are plan views each showing the relative positions of magnetic poles and the magnetic teeth of a rotary disk;

FIGURE 11 is an explanatory plan view of the magnetic teeth of a rotary disk;

FIGURE 12 is a plan view of an oscillator frequency adjusting device.

In FIGURE 1, **1** is an electric reciprocating motion generating device for a tuning fork, **2** is a tuning fork having a predetermined natural frequency of vibration, **3** is a driving coil, **4** is a researching coil, **5** is a transistor, **6** is a dry cell, **7** is a resistance, **8** is a condenser and **9** and **9'** are magnets.

The operation of the electric reciprocating motion generating device is as follows:

When the dry cell **6** is connected to the circuit, due to a base current flowing to the resistance **7**, a collector current will flow through the driving coil **3**. Due to this collector current, the driving coil **3** will attract the tuning fork **2**. The researching coil **4** will research the motion of said tuning fork as a voltage signal, and will reversely apply the signal to the base emitter of the transistor **5**, thus interrupting the base current and the collector current. Therefore, a pulse energy accompanying the free oscillation of the tuning fork will be given to the tuning fork from the electric circuit and the oscillation of the tuning fork **2** will be sustained.

10 is a supporting stand for supporting the tuning fork **2**, **11** and **11'** are permanent magnets fixed to the free ends of said tuning fork **2**, rotary disk or whose teeth are connected only magnetically with the tuning fork **2** between the N and S poles of the magnets **11** and **11'**, is fixed to a shaft **13**. A pinion **14** also fixed to said shaft **13** meshes with a gear **16** fixed to a shaft **15**. **17** is a pinion fixed to said shaft **15**. A second hand **20** is rotated by a second hand gear **18** and an hour hand **22** and a minute hand **21** are rotated through gears **19**. A starting device **23** is provided for starting the clock.

An adjusting plate **24** which is so arranged that its side may be opposite the magnet **11** is fixed to one end of the shaft **25** carried in a sleeve **26**. A pinion **27** fixed to the other end of shaft **25**. **28** is a spring set between the sleeve **26** and pinion **27** to bring the tapered parts of the adjusting plate **24** and of sleeve **26** into perfectly close contact with each other. **29** is a nut to fix the sleeve **26** to a ground plate **30**. **31** is a worm gear meshed with the pinion **27**. **32** is a worm gear shaft mounted in flanges **33** and **33'** of plate **30**. **34** is an indicating wheel fixed to the shaft **32**.

In operation, when electric energy is fed to the electric reciprocating motion generating device from the electric cell **6**, the tuning fork **2** will begin to oscillate. Therefore, when the starting device **23** is operated to temporarily rotate the rotary disk **12** at a rotating speed higher than synchronized speed the oscillatory motion of the tuning fork **2** will be transmitted as a rotary motion to the rotary disk **12** and a normal operating state will set in. That is to say, the rotary disk **12** will be rotated by the tuning fork **2** always fed with an energy to keep its oscillation by the electric reciprocating motion generating device **1** and the oscillatory motion of the tuning fork **2** will make said rotary motion perfectly synchronize. How the oscillatory motion of the tuning fork **2** is transmitted as a rotary motion to the rotary disk **12** as described above shall be more freely discussed herein with reference to FIGURES 4 to 10.

The phrase "the motion of the N and S magnetic poles" is used in the ensuing discussion to simplify the explanation and includes the simple oscillatory motion of the tuning fork **2** having the magnets **11** and **11'** fixed to the forked ends.

In FIGURES 4 to 10, the double cross hatched member used to represent magnetic poles N and S represents the projection of the magnetic poles N and S shown in FIGURE 2 on the rotary disk **12**. Furthermore, though two magnets **11** and **11'** are combined with the rotary disk **12** in FIGURE 1, the operation of only one magnet is described herein but it should be apparent that the other magnet works in the same manner.

Consider the magnet **11** fixed to the forked end of the tuning fork **2** for example, with oscillating a maximum amplitude smaller than $\overline{AA'}$ on the track $\overline{AA'}$, making the point O′ an original point. As the rotary disk **12** is made of a magnetic material of a magnetic resistance much lower (that is, of a magnetic permeability higher) than of air, with the motion of the magnetic poles N and S on the track $\overline{AA'}$, any one of the magnetic material parts **35, 36, 37, 38** and **39** between the N and S magnetic poles will always be magnetically attracted and the rotary disk **12** will rotate either clockwise or anticlockwise by a slight angle around the center axis O of the rotary disk. The parts between the adjacent outside radial magnetic teeth **35** and **41** and between the adjacent inside radial magnetic teeth **38** and **39** are punched out and generally rectangular in shape, for example, as illustrated in FIGURE 4.

Therefore, when the magnetic poles N and S further continue the motion on the track $\overline{AA'}$ toward the axis O of the rotary disk from the position shown in FIGURE 4 (see FIGURE 5), the rotary disk will rotate either clockwise or anticlockwise by a very small angle around the axis O of the rotary disk so that either the magnetic tooth **39** connected with the connecting part **36** or the magnetic tooth **38** connected with the connecting part **37** may be between the magnetic poles N and S. However, as both connecting parts **36** and **37**, of the rotary disk **12** are made respectively symmetrical with respect to the radial centerline of tooth **35** OQ_2, when the center axis OQ_2 coincides perfectly with the track $\overline{AA'}$ of the magnetic poles N and S as shown in FIGURE 4, if the magnetic poles N and S move toward A on the track $\overline{AA'}$ from the magnetic tooth **35**, the rotary disk **12** will rotate so that either the connecting part **36** and the tooth **39** or the connecting part **37** and the tooth **38** may happen to be guided between the magnetic poles N and S. That is to say, the direction of rotation is not limited to only one direction but is always either clockwise or anticlockwise. This is the same also in the case as shown in FIGURE 5, the track $\overline{AA'}$ and the radial centerline $\overline{OP_2}$ of tooth **38** perfectly coincide with each other and the magnetic poles N and S move toward A′ on the track $\overline{AA'}$ from the magnetic tooth **38**. Therefore, the torques generated on the axis of shaft **13** of the rotary disk will be substantially equal to each other in both clockwise and anticlockwise rotations and the resultant torque will be substantially equal to zero.

However, it is necessary to generate a torque on shaft **13** which is sufficient to convert the oscillatory motion of the tuning fork **2** having the magnet **11** of the poles N and S fixed to the forked end to the rotary motion of said rotary disk **12**, to rotate the rotary disk **12** in any desired direction for driving the clock mechanism and other movable parts connected to the pinion **14**.

First of all, the tuning fork **2** is designed to maintain an oscillatory motion and a force to produce sufficient rotary motion above the fixed speed is applied to the rotary disk by the starting device **23**. Then, when the radial magnetic tooth of the rotary disk **12** is located between the magnetic poles N and S (see FIGURE 4 or 5) and the magnetic poles N and S move toward A on the track $\overline{AA'}$ from the position shown in FIGURE 4 due to the motion of the tuning fork **2**, if a clockwise torque, for example, is given to the rotary disk **12** with the starting device, as shown in FIGURE 6, the rotary disk **12** will be rotated clockwise and therefore a "displacement" will be produced between the track $\overline{AA'}$ of the magnetic poles N and S and the radial centerline $\overline{OQ_2}$ of the rotary disk **12**. Therefore, when the magnetic poles N and S move toward A on the track $\overline{AA'}$, the "attraction" received by the left magnetic tooth **38** will be so much larger than that received by the right magnetic tooth **39** that the magnetic tooth **38** will be strongly attracted by the magnetic poles N and S so as to be guided between the poles N and S and the rotary disk **12** will be rotated. Furthermore, when the magnetic tooth **38** is guided between the magnetic poles N and S and the magnetic poles N and S turn to move toward A′ instead of A, while the magnetic poles move from the magnetic tooth **38** to the next magnetic tooth such "displacement" as shown in FIGURE 7, will be produced between the radial centerline $\overline{OP_2}$ and the track $\overline{AA'}$, therefore, with the movement of the magnetic poles N and S toward A′ on the magnetic tooth **38**, the magnetic tooth **41** will be strongly attracted by the magnetic poles N and S and the rotary disk **12** will rotate further clockwise so that the magnetic tooth **41** may be guided between the magnetic poles N and S. Now, when the magnetic tooth **41** is between the magnetic poles N and S, as previously explained with reference to FIGURE 6, while the magnetic poles N and S turn again to move toward A on the track AA′, a "displacement" will be produced, the magnetic tooth **43** connected to the connecting part **42** will be attracted (see FIGURE 8) and therefore the rotary disk **12** will be rotated clockwise to guide said magnetic tooth **43** between the magnetic poles. Thus the same action will appear on all the radial centerline $\overline{OP_1}$, $\overline{OQ_1}$, $\overline{OP_2}$, $\overline{OQ_2}$, $\overline{OP_n}$, $\overline{OQ_n}$ etc. of the rotary disk teeth and clockwise rotation will continue. The above explanation is with regard to the case of starting the rotary disk from the position of the radial centerline of tooth **35** $\overline{OQ_2}$ as in FIGURE 4. Even by starting it from the position of such radial centerline $\overline{OP_2}$ of tooth **38** as in FIGURE 5, the same motion will be obtained with only the phase displaced by a half cycle. In the above explanation, the rotary disk is started clockwise, however, if it is started anticlockwise, it will rotate anticlockwise. It has been explained above that the "attraction" is produced by the "displacement" between the magnetic poles N and S and the magnetic teeth **35, 38, 41** (the radially extended parts) and **43** so that the rotary disk **12** may follow the movement of the magnetic poles N and S. However, in the strict sense, the "attraction" may be produced also between the magnetic poles and those parts connecting the radial magnetic teeth **35, 38, 41** and **43** viz. connecting parts **36, 37, 40** and **42**. Actually the attraction for connecting parts will be so much weaker that in fact, the rotary disk **12** will be practically rotated only by the "attraction" for the radial magnetic teeth **35, 38, 41** and **43**. Therefore, if the shapes of radial magnetic teeth **35, 38, 41** and **43** are made to meet such requirements as are described herein, the shapes of the connecting parts **36, 37, 40** and **42** which are connecting said radial magnetic teeth will not be too important. For example, even if such connecting parts are formed of a nonmagnetic material, there will be no trouble in rotating the rotary disk.

In order that the oscillatory motion of the tuning fork **2** may be efficiently and effectively converted to a rotary motion by the rotary disk **12**, the shape of each of the magnetic poles N and S and the width of each of the radial magnetic teeth **35, 38, 39, 41** and **43** must be considered so that, when the radial magnetic teeth **35, 38, 39** and **41** are guided between the magnetic poles N and S, the magnetic poles N and S may attract the radial magnetic teeth strongly enough to smoothly produce a "displacement" between the track $\overline{AA'}$ and the center axis $\overline{OP_n}$ or $\overline{OQ_n}$ and to make the rotary disk **12** follow the movement of the magnetic poles N and S.

According to the present invention, in order to make such "displacement" and "attraction" smoother, the width *c* of each of the magnetic poles is made smaller (or larger) than the width *b* of each of the magnetic teeth **35, 38, 39, 41** and **43** of the rotary disk so that the "displacement" may take place in a substantially unrestrained state, because, in case the width *c* of each of the magnetic poles N and S is made somewhat smaller than the width *b* of the magnetic tooth as shown in FIGURE 9, when the rotary disk **12** rotates from the position represented by the solid lines to the position represented by the dotted lines, the magnetic flux between the magnetic poles N and S will vary so little that the magnetic attraction acting on the rotary disk **12** will be able to be substantially neglected and the effect of damping such rotary motion (equal to the "displacement") of the rotary disk **12** as is produced by the "attraction" will not be able to be considered to exist at all. In the case where the width *c* is made larger than the width *b*, the magnetic attraction is also considered negligible. The last case, where *c* equals to *b* is most undesirable.

The thickness *d* of each of the magnetic poles N and S proper to make the attraction stronger is 1.2 to 4 times as large as the width *e* of the connecting part. Unless the amplitude of each of the magnetic poles N and S is large enough, increasing said thickness *d* will impair the "attraction" and will not be desirable, because, if, as shown in FIGURE 10, the amplitude of each of the magnetic poles N and S is not large enough for its thickness *d*, such force of the lower end part of each of the magnetic poles N and S as will impart the rotation of the escapement wheel **12** in any desired direction will act while the magnetic poles N and S move from the magnetic tooth **39** to the magnetic tooth **35** and will impair the "attraction." Therefore, said thickness *d* should be determined by considering not only the magnitude of the magnetic flux but also the maximum and minimum amplitudes which the forked ends of the tuning fork **2** can take.

It has been already explained that, when the tuning fork **2** is to be driven and the rotary disk **12** is to be rotated, if a torque in any desired direction is given to the rotary disk **12** by means of the starting device only at the time of starting and the escapement wheel **12** is rotated at a rotating speed higher than is fixed, the magnetic paths of the rotary disk **12** will follow the movement of the magnetic poles N and S and the rotary disk **12** will be rotated by the magnetic poles N and S.

The force to be given to the rotary disk **12** from the starting device **23** at the time of starting must be large enough to rotate said rotary disk at fixed speed.

As detailed in above, in the time keeping mechanism according to the present invention, when the oscillator (tuning fork) is oscillated by an electric or any other means, the permanent magnets fixed to the free ends will attract the inside and outside magnetic teeth which are the main component elements of the rotary disk and the oscillatory motion of said tuning fork will be converted to the rotary motion of the rotary disk. In order that such action may take place efficiently, the width *c* of the magnetic pole is made smaller or larger than the width *b* of the magnetic tooth (FIGURE 9) and the thickness *d* of the magnetic pole is selected to be 1.2 to 4 times as large as the width *e* of the magnetic connecting part (FIGURE 9).

On the other hand, in the conventional mechanism of this kind or the mechanism mentioned in British Patent No. 660,584, said permanent magnets attract the undulated magnetic paths which are the main component elements of the rotary disk or escapement wheel to attain the above mentioned action. In order to make this action safe in the case that the amplitude of the oscillator is so large as to deviate from said undulated magnetic path, inside and outside magnetic paths are provided to be concave and convex so as to guide and magnet with the concave and convex parts of said undulation. Further, it is considered therein to be most desirable that the thickness of the magnetic pole (corresponding to the thickness *d* of the magnetic pole in the present invention) is formed to be the same as the width of the undulated magnetic path (substantially corresponding to the width *b* or *e* of the magnetic teeth in the present invention). Therefore, the magnetic parts to be attracted by the permanent magnets are the inside and the outside radial magnetic teeth of the rotary disk in the present invention but are the undulated magnetic paths in said British patent.

The pole form described in the present invention is not symmetrical or nonsymmetrical with respect to the radial magnetic teeth **38, 39, 35** and **41** (FIGURE 11).

It shall be explained with reference to FIGURE 11. For example, whether an escape wheel is symmetrical or not in a plane or in three dimensions by taking its thickness into consideration is judged with having symmetrical connecting parts to the radial axis ($\overline{OP_2}$ in FIGURE 11) passing through the middle point R of the two right and left sides **44** and **45** in contact with the respective adjacent connecting parts **37** and **40** from the center O, or not.

In the present invention, a tuning fork is used as a time keeping oscillator instead of such conventional oscillator as a balance wheel or a pendulum. As the rate variation Δf of the time keeping mechanism of this kind is represented by the formula

$$\Delta f = f/Q$$

wherein f is the natural frequency of the oscillator, in case a tuning fork having a value of Q of 3,000 to 5,000 much larger than of such conventional oscillators as are mentioned above is used, the rate variation Δf will be so small that a clock of a high precision will be obtained.

The precision of the tuning fork clock of the present invention is very high as described above. However, the precision can be further improved by providing an adjusting plate near the permanent magnet and fixed to the free end of the tuning fork.

In operation the adjusting device in the present invention varies the magnetic coupling force between the leakage flux at the forward end of a permanent magnet **11** and the adjusting plate **24**.

In FIGURE 12, (A) indicating the position when the coupling force between the magnet **11** and the adjusting plate **24** is the largest and (B) indicates the case when the coupling force is the smallest. That is to say, in the present invention, the contour of the adjusting plate **24** is so determined that, when the adjusting plate **24** opposite the magnet **11** is moved from the position shown in (A) to that shown in (B) or vice versa in FIGURE 12, the relative distance between both magnetic bodies may be varied and the magnetic coupling force acting between both magnetic bodies may be controlled so that the frequency of the oscillator **2** may vary linearly with the angle of rotation of the adjusting plate **24**. In order to make the movement of the adjusting plate **24** finer and to improve the precision of the adjustment, the pinion **27** and worm gear **31** are provided so that the rotation of an indicating wheel **34** may be greatly reduced and may be transmitted to the adjusting plate **24**.

As the contour of the adjusting plate **24** is so determined that the frequency of the oscillator **2** may be varied linearly with the angle of rotation of the adjusting plate **24** as described above, it is possible to equivalently vary the frequency by rotating the indicating wheel by the equivalent rotation over the entire range (that is, while the relative position between the magnet **11** and the adjusting plate **24** varies from the position shown in (A) to that shown in (B) or vice versa in FIGURE 12).

According to our experience of actually using it as an adjusting device for a tuning fork clock, when the total adjusting capacity (the amount of variation of the frequency when the adjusting plate is rotated from the position shown in (A) to that shown in (B) in FIGURE 12) is 20 seconds per day and the number of teeth of the pinion **4** is 20, 20 seconds per day can be adjusted by rotating the indicating wheel **34** by 20 revolutions, that is to say, 20 seconds per day can be correctly adjusted at a rate of one second per day per revolution.

Therefore, in the clock provided with such adjusting device, if an error of 5 seconds a day is to be corrected, the step of the clock can be adjusted to be substantially zero by rotating the indicating wheel **34** by 5 revolutions in the direction in which the relative position between the adjusting plate **24** and the magnet **11** approaches the position shown in (B) in FIGURE 12 without requiring any measuring instrument.

As described above, when the frequency adjusting device according to the present invention is used, it will be possible to linearly adjust the frequency against the angle of rotation of the indicating wheel. Therefore, the present invention has a feature that the frequency of the oscillator can be simply and accurately adjusted to any desired value by rotating the indicating wheel an angle determined by the amount of adjustment for the unit angle of rotation of the indicating wheel and the amount of adjustment required of the oscillator without requiring any measuring instrument.

In accordance with the present invention, by effectively utilizing the "attraction" between the magnetic poles N and S of the magnet **11** fixed to the free end of the tuning fork **2** and the radial magnetic teeth of the rotary disk **12** combined with such loading device as the clock mechanism and the "displacement" between the track of the movement of the magnetic poles N and S and the center axis of the radial magnetic tooth, said rotary disk once started will be continuously rotated by the oscillatory motion of the tuning fork **2**.

Therefore, the present invention is simple and does not include a mechanism of mechanically converting an oscillatory motion to a rotary motion as in the conventional tuning fork clock. It has therefore an effect of obtaining a tuning fork clock which is stable and trouble-free in operation and high in performance.

Furthermore, the rotary disk used in the present invention is simple in construction as well as easy to produce. The connecting magnetic parts in said rotary disk are made so narrow that, even in case the amplitude of the tuning fork is small, the oscillation of the oscillating element can be accurately caught.

We claim as our invention:

1. In a timepiece including a rotary indicating mechanism, a support member, a tuning fork having a natural frequency of vibration with the base portion of the tuning fork being rigidly secured to said support member, a transducer operatively associated with said tuning fork for vibrating the tines of said tuning fork at a predetermined frequency and an electronic control circuit responsive to the vibratory motion of said tuning fork for periodically energizing said transducer to sustain the vibratory motion of said tuning fork at said predetermined frequency, the improvement comprising:

(a) a rotary member coupled to said indicating mechanism for driving hte same;

(b) said rotary member being formed of at least two concentric circular arrays of radially extending, circumferentially spaced elements of magnetic flux conducting material with the elements in one circle being circumferentially offset from the elements in the next adjacent circle;

(c) a permanent magnet mounted on at least one of the tines of said tuning fork including a pair of opposed pole faces of opposite polarity; and

(d) said pole faces being disposed on opposite sides of said rotary member and extending substantially parallel to the plane of said member for movement in the same direction as the vibratory motion of said tines along a radial path with respect to said rotary member so that when said tines vibrate, adjacent ones of said offset magnetic members are magnetically attracted thereby rotating said rotary members at a speed directly proportional to the frequency of vibration and independently of the amplitude of vibration of said tuning fork.

2. A timepiece in accordance with claim **1** characterized by a plurality of circumferential connecting sections interconnecting said magnetic elements and the radial width of said pole faces being substantially greater than the radial width of the circumferential connecting sections.

3. A timepiece in accordance with claim **2** wherein the radial width of the pole faces is approximately 1.2 to 4 times greater than the radial width of the connecting sections.

4. A timepiece in accordance with claim **2** wherein the circumferential width of the magnetic members is substantially less than the width of the pole faces.

5. A timepiece in accordance with claim **2** wherein the width of the magnetic members is substantially greater than the width of the pole faces.

6. A timepiece in accordance with claim **1** including rotatable adjusting means mounted adjacent the free end of said tuning fork and said adjusting means having a surface contour so that the relative distance between said surface and said tuning fork may be varied with the magnetic coupling force acting therebetween controllably varying the frequency of the tuning fork linearly with the angle of rotation of the adjusting means.

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