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Hetzel [45] Dec. 18, 1973

[54] **MOTION TRANSFORMER**

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[57] **ABSTRACT**

In a motion transformer for converting oscillatory to rotary motion, comprising (a) an enclosure including a base plate, a cover plate, and side members, all of which are substantially rigid, (b) a ratchet wheel within the enclosure mounted for both oscillatory and rotary motion, (c) a pair of stops limiting the amplitude of such oscillatory motion, (d) a ratchet pawl coacting with the ratchet wheel and a restraining member preventing retorgrade rotation thereof to convert oscillatory motion thereof to unidirectional rotary motion, and (e) a liquid filling the space in said enclosure, an expansion chamber is provided adjacent the enclosure in communication therewith through a capillary channel and is partially gas-filled to accommodate thermal expansion and contraction of the liquid. Such apparatus is made by immersing it in the liquid, subjecting the liquid to high vacuum to withdraw air, then restoring atmospheric pressure to drive the liquid into the apparatus, then heating the apparatus to above its maximum expected operating temperature followed by cooling to allow the liquid to contract and cause some air to enter the expansion chamber, and then hermetically sealing the apparatus.

17 Claims, 2 Drawing Figures

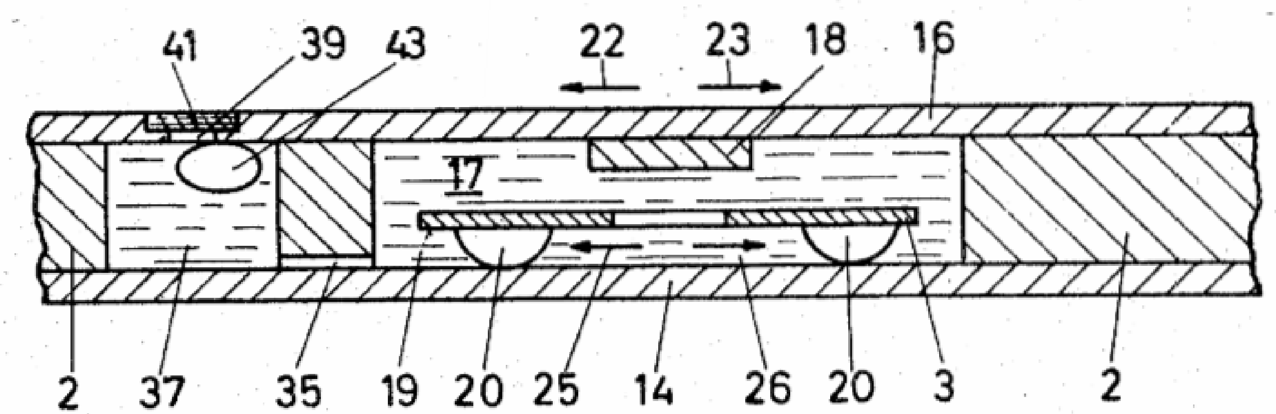

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FIG.1

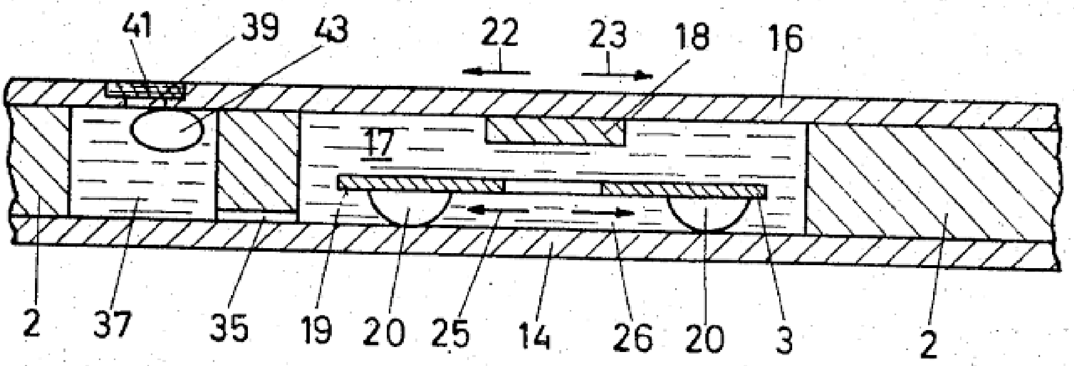
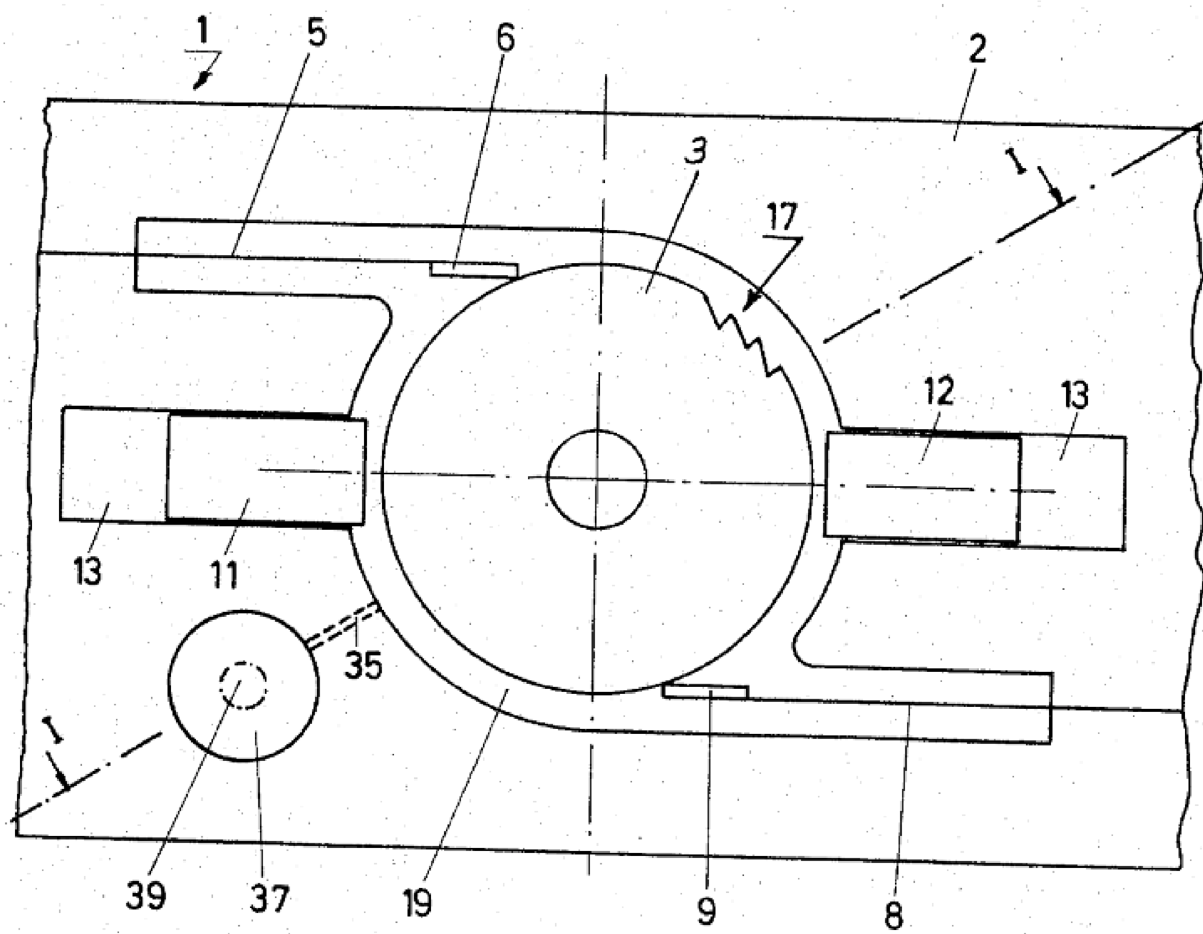


FIG.2



MOTION TRANSFORMER

RELATED APPLICATION

This application describes an improvement of the motion transformer mechanism disclosed in United States application Ser. No. 88,715, now U.S. Pat No. 3,691,954.

SUBJECT OF THE INVENTION

This invention relates to motion transformers, especially for use in timepieces such as wrist watches, for converting oscillatory or reciprocating motion to rotary motion. The invention pertains particularly to motion transformers comprising a ratchet wheel mounted in an enclosure so that it can oscillate back-and-forth through a limited path of travel and also rotate substantially about its center axis, and further comprising stops to limit the amplitude of the back-and-forth oscillatory motion, and a pawl coacting with the ratchet wheel teeth and a restraining member to prevent retrograde rotation thereof to cause the ratchet wheel to rotate unidirectionally at a velocity determined by the frequency of the oscillations. The rotating ratchet wheel is coupled magnetically to the drive gear in a watch or other timepiece gear train, and is attracted by such magnetic coupling toward the base plate of the enclosure. The enclosure is filled with a liquid such as a low viscosity, e.g., one centistoke, lubricating oil; and the invention particularly relates to means for accommodating thermal expansion and contraction of such liquid. The invention further provides a method of making the liquid-filled motion transformer.

BACKGROUND OF THE INVENTION

A common type of electric (battery-energized) wrist watch utilizes a vibratory element which is electrically driven at a predetermined accurate (usually resonant) frequency. The vibratory back-and-forth motion of this element must be converted by a motion transformer to rotary motion by which the gear train of the timepiece can be actuated. Heretofore it has been common practice to effect such motion transformation by means of a driving pawl attached to the vibrator and aligned in the vibration direction, which pawl engages the teeth of a ratchet wheel. The pivot axis of the latter is stationary relative to the vibrator. A restraining pawl likewise en•gages the teeth of the ratchet wheel to prevent reverse motion, the fixed end of this restraining pawl likewise being stationary relative to the vibrator.

The operating frequency of vibrators of the described type is usually in the range from 200 to 700 oscillations per second. The diameter of the ratchet wheel generally is about I to 3 mm. (0.040 to 0.120 inch). These figures alone make it apparent that the design of a reliable motion transformer for a wrist watch presents a difficult technological problem. Moreover, the effectiveness of the motion conversion must be very high, for two reasons. The first reason is that the energy consumption of a vibrator and motion transformer for small watches, must be low to be within the energy content of a battery of a size which meets the demands of the market. The second reason is that loss of energy leads to destruction of the motion transformation should the power loss exceed a certain value. In order to achieve a high efficiency of motion transformation, as well as reliability and accuracy of time keeping, very accurate adjustment of the pawls relative to the ratchet wheel, and especially strong materials of construction, are required. The adjustment of the pawls and the mounting of the ratchet wheel, in the case of motion transformers heretofore commonly used, are unfortunately subject to undesirable changes during operation, since the fastening points of vibrator, ratchet wheel rotation axis and restraining pawl are located in general relatively far apart on the watch base plate and are subject to relative displacement by both thermal and mechanical effects in order for the reciprocating movement of the vibrator to serve as a synchronous motor for working control for clocks and watches it is necessary that the accurate frequency of oscillation of the vibrator be converted into equally accurate speed of rotation of the ratchet wheel. From this it follows that in a motion transformer utilizing a driving pawl attached to the vibrator and a fixedly pivoted ratchet wheel, the amplitude of the movement of the vibrator must be held constant within very narrow limits and that the positions of the pawls and the ratchet wheel relative to each other must remain unchanged within narrow limits. Such conditions can be met only with great difficulties.

Many of the difficulties in the manufacture and adjustment of motion transformers as described above have been to a considerable extent overcome by the recent development of an improved motion transformer in which the ratchet wheel, instead of being fixedly pivoted, is free to oscillate diametrically through a limited path of travel as well as to rotate. Stops at opposite ends of the path of oscillatory travel of the ratchet wheel limit such travel, and pawls engaging the ratchet wheel teeth (or at least one such pawl plus a restraining member to prevent retrograde motion of the ratchet wheel) cause the ratchet wheel to rotate uni-directionally at a rate determined by its frequency of oscillation. This entire ratchet wheel assembly in a suitable enclosure is mounted directly on or otherwise is directly connected to the vibrator so that it vibrates therewith. Since pawls and stops are mounted in close proximity on the assembly enclosure, this motion transformer is relatively insensitive to loss of adjustment due to thermal effects or mechanical shock, and its design is such that the speed of rotation of the ratchet wheel is dependent only on the frequency of oscillation of the vibrator and is essentially independent of the amplitude of such oscillation. The basic design and mode of operation of this improved motion transformer is described in greater detail in the aforesaid U.S. application Ser. No. 88,715.

It is essential, for efficient operation of this improved motion transformer, that the ratchet wheel be free to oscillate and rotate with minimum frictional losses and with minimum interferences from dust or other foreign body particles that may inadvertently be present in the ratchet wheel enclosure. For this reason it is desirable to fill the ratchet wheel enclosure with a suitable low-viscosity liquid, such as light oil of, say, one centistoke viscosity. Experience with this improved motion transformer has shown, however, that special provision must be made to compensate for the effects of temperature.

Since the coefficient of expansion of the materials forming the enclosure is in general many times smaller than that of the liquid filling it, provision must be made to accommodate the differential in thermal expansion.

STATEMENT OF THE INVENTION

The invention, accordingly, relates to a motion transformer for converting oscillatory motion to rotary motion comprising an enclosure including a base plate, a cover plate, and side members, all of which are substantially rigid, a ratchet wheel within such enclosure mounted for both oscillatory back-and-forth motion substantially on a diameter thereof and for rotary motion substantially about its center, a pair of stops fixedly mounted for limiting the amplitude of the oscillatory motion of the ratchet wheel within the enclosure, a ratchet pawl coacting with said ratchet wheel and a restraining member preventing retrograde rotation thereof to convert oscillatory motion of the ratchet wheel to unidirectional rotary motion, and a liquid filling the space in said enclosure about said ratchet wheel, stops, pawl and restraining member. The invention provides, in such a motion transformer, an expansion chamber adjacent the enclosure and communicating with the interior thereof through a capillary channel. The capillary channel and a portion of the expansion chamber also are filled with the liquid, and a gas, generally air, fills the remainder of the expansion chamber. Both the enclosure containing the ratchet wheel mechanism and the expansion chamber are hermetically sealed. Hence thermal expansion or contraction of the liquid in the enclosure is accommodated by flow of liquid through the capillary channel and corresponding compression or expansion of the gas in the expansion chamber.

The expansion chamber preferably is formed with an opening to the exterior of the apparatus, to permit filling the apparatus with the liquid. In the completed liquid-filled apparatus, their opening is hermetically sealed by a closure member, which preferably is a jewel (e.g., ruby or sapphire) lamina adhesively bonded over the opening by means of a suitable adhesive, preferably a two-component catalyzed thermosetting resin adhesive such as an epoxy adhesive. Advantageously the expansion chamber and the capillary channel are formed in one of the side members of the enclosure, preferably in the form of an opening extending through such side member and closed top and bottom by the cover and base plates. The opening of the expansion chamber to the exterior then is formed in one of said plates, and the closure lamina is cemented to such plate over the opening.

Preferably the volume of the ratchet wheel enclosure, and hence the volume of liquid which it contains, is made as small as possible by configuring the side members of the enclosure to fit in closely spaced relation about the ratchet wheel. Thus the side members may be configured to form a substantially cylindrical enclosure chamber only slightly larger in diameter than required to accommodate oscillatory motion of the ratchet wheel. Such side members may further define a substantially tangential channel to receive the ratchet pawl; and when the restraining member is itself a second pawl, they may define a second tangential channel to receive it also. The side members further may be formed with additional channels in which the stops are received and fixed in proper spaced relation relative to the ratchet wheel. Such design makes it possible to use two substantially identically configured side members (except for the preferable provision in one of the side members of the expansion chamber and capillary channel) which can be bonded together and to the base and cover plates to form a hermetically sealed enclosure, and at the same time to facilitate accurate alignment of stops, pawls and ratchet wheel.

The invention further provides an improved method for making a liquid-filled motion transformer comprising essentially an enclosure formed by a base plate, a cover plate, and side members all of which are substantially rigid and hermetically sealed together, a ratchet wheel mounted for oscillatory back-and-forth motion and for rotation in such enclosure, and an expansion chamber adjacent the enclosure and communicating therewith through a capillary channel, said expansion chamber being formed with an opening communicating with the exterior of the apparatus. The method of the invention comprises a liquid-filling said motion transformer by immersing it in a body of liquid contained in a closed vessel, and evacuating said vessel to withdraw substantially all air from the enclosure and expansion chamber of the motion transformer. Then the vessel is opened substantially to atmospheric pressure to enable liquid to flow into and fill the enclosure, the capillary channel and the expansion chamber. The liquid-filled motion transformer is then taken from the vessel and is heated to a temperature somewhat above its maximum expected operating temperature, and then is cooled to substantially below such temperature. Thereby a quantity of air (or other gas if the operation is carried out in a controlled atmosphere) enters the expansion chamber as the liquid contract in consequence of such cooling. Finally the opening from the exterior into the expansion chamber is hermitically closed. As a result of these operations the enclosure is fully filled with liquid, as is the capillary channel, and the expansion chamber is filled in part with liquid and in part with air or other gas.

In carrying out the method of the invention, the vessel preferably is evacuated to a pressure below 10^{-2} torr. A high degree of evacuation is necessary to ensure substantially complete filling of the ratchet wheel enclosure with the liquid.

After filling with liquid, the motion transformer is preferably heated to at least 40°C., and even to 70°C. or higher. It is then cooled by at least 10°C., and desirably to near atmospheric temperature, to ensure that a sufficient amount of air or other gas will enter the expansion chamber.

Finally, the apparatus is hermetically closed by adhesively sealing a jewel lamina or other closure member over the opening from the exterior into the expansion chamber.

The capillary channel should of course be small enough so that surface tension forces prevent the air or other gas in the expansion chamber from flowing into the ratchet wheel enclosure simply as a result of tilting of the motion transformer. Entry of such gas into the ratchet wheel enclosure would impair efficient operation of the ratchet wheel. For the same reason, the volume of liquid in the expansion chamber should be great enough so that the air or other gas therein will not be drawn into the ratchet wheel enclosure by thermal contraction of the liquid at the lowest intended operating temperature of the motion transformer.

The liquid with which the apparatus is filled is preferably a light lubricating oil of, say, 1 to 5 centistokes viscosity.

DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 is a sectional view through a motion transformer according to the invention, taken substantially along the line I — I of FIG. 2, showing a preferred arrangement of the capillary channel and expansion chamber and

FIG. 2 is a schematic top view of the motion transformer of FIG. I with cover plate removed.

DETAILED DESCRIPTION OF ILLUSTRATED EMIODIMENTS OF THE INVENTION

The motion transformer I shown in FIGS. 1 and 2 constitutes a unitary assembly mounted in an enclosure 19 formed by base plate 14 and cover plate 16 joined by side members 2 all hermetically sealed together after assembly and adjustment of the mechanism within the enclosure. In use the assembly is mounted on a vibratory member which is caused to vibrate at a predetermined frequency by a battery-energized electronic circuit, as is well understood in the electric timepiece art. The mounting of the motion transformer of FIG. I on such vibratory member is such as to cause the assembly to oscillate back-and-forth in the direction indicated by the arrows 22 and 23.

The motion transformer mechanism comprises a ratchet wheel 3 provided with ratchet teeth (fragmentarily indicated in FIG. 2). The ratchet wheel is not secured in place by a fixed pivot or shaft, but instead is free to oscillate within the enclosure through a limited path of back-and-forth travel in the directions indicated by the arrows 25, 26, and also to rotate substantially about its center. Oscillation of the entire motion transformer assembly by the vibratory member on which it is mounted causes the ratchet wheel, because of its inertia, to oscillate correspondingly within and relative to the enclosure. A first pawl arm 5 terminates at one end in a pawl jewel 6 which engages the ratchet wheel teeth and is fastened at its other end to the enclosure base plate. Similarly, a restraining member in the form of a second pawl arm 8 is provided at one end with a pawl jewel 9 which engages the ratchet wheel and is attached at its other end to the enclosure base plate. The pawl jewels 6 and 9 engage the ratchet wheel at substantially diametrically opposite positions, approximately perpendicularly to the direction of oscillation of the ratchet wheel.

A pair of stop members, 11, and 12, secured in channels 13 in the side members 2 limit the maximum path of travel of the ratchet wheel in its hack-and-forth oscillation. As the ratchet wheel oscillates the pawls compel rotation of the ratchet wheel (in a clockwise direction in the apparatus of FIG. 2), as is described in detail in the above-mentioned U.S. application Ser, No. 88,715.

As is apparent from FIG. 2, the side members 2 are configured so as to provide a generally cylindrical enclosure 19 the walls of which are closely spaced relative to the ratchet wheel 3 and allow only slightly more than enough space for the latter to execute its oscillatory motion between the stops 11 and 12. Thus the volume of the enclosure 19 is minimized. Further to minimize this volume, the pawl arms 5 and 8 are received in narrow channels formed in the side members 2 and extending tangentially from the main cylindrical portion of the enclosure 19. In the apparatus of FIG. 2 the two side members 2 are of almost identical configuration and abut along projections of the center lines of the tangential channels in which the pawl arms 5 and 8 are received. When these side members are bonded together (by an adhesive, for example) where they abut, and are bonded to the base plate 14 and cover plate 16 they form a hermetically sealed chamber 19 (except for the provision of a capillary channel 35 communicating with an expansion 37).

As can be seen in FIGS. 1 and 2 the chamber 19 is of minimum dimensions to adapt it to the dimensions of the ratchet wheel 3 and the pawls 5 and S. In order to ensure low constant resistance to motion of the ratchet wheel, the enclosure 19 is entirely filled with a liquid 17 such as a low viscosity lubricating oil, This minimum volume of the enclosure 19 is important in order to reduce to a minimum the effect of volume changes of the liquid which are caused by temperature changes and which may exceed by a power of 10 those of the solid parts forming the enclosure 19 (i.e., the side members 2 and the base and cover plates 14 and 16).

The ratchet wheel 3 is made of magnetic material of high coercivity, such as platinum-cobalt alloy, and is permanently magnetized. Thereby it is magnetically attracted to and coupled with a fixedly pivoted magnetic wheel (not shown) which may be the drive gear of a timepiece gear train and which is mounted externally of the enclosure in parallel relation with and directly below the base plate 14. Not only does the magnetic coupling of the ratchet wheel to the external fixed pivot wheel provide for driving the latter by rotation of the former, but it also causes the ratchet wheel to be attracted toward the base plate 14 and away from the cover plate 16. Although the cover plate 16 normally is not touched by the freely moving ratchet wheel 3, the cover plate is provided with means to limit axial deflection of the ratchet wheel away from the base plate. Such means is in the form of a disc 18 which preferably, like the base plate 14 and the cover plate 16, is made of a hard non-magnetic material such as jewel stone, e.g., ruby, and which, since it is ground to a lamina, is transparent.

The ratchet wheel 3 is provided advantageously with four supports 20, mounted at equi-angular positions, which may be glued or cemented to the wheel 3. These supports 20, preferably of spherical hemispherical shape, likewise are made of jewel stone, in particular ruby, or alternatively, of hard metal, e.g., tungsten carbide.

FIG. 1 also shows by way of the arrows 22 and 23 the directions in which the vibrator imparts back-and-forth oscillation to the entire motion transformer 1. Arrows 25 and 26 show the direction of' the oscillatory movement of the ratchet wheel 3 relative to its enclosure, a movement which depends on the inertia of the ratchet wheel 3 and which is controlled by the pawls 5 and 8 with pawl stones 6 and 9, and by the stop members 11 and 12, in such a way that the ratchet wheel is made to rotate in one direction (clockwise, as viewed in FIG. 2).

In order to reduce to a minimum the undesirable effects of volume changes in the liquid 17 due to temperature changes, the expansion chamber 37 is provided. This chamber is defined by an opening extending through one of the side members 2; and the small capillary channel 35 is formed by cutting into this side members between the enclosure 19 and the expansion chamber 37, to provide communication therebetween. The capillary channel 35 and a considerable volume of the expansion chamber 37 also is filled with the liquid 17. However, a bubble of gas 43 entrapped in the expansion chamber 37 fills the remainder of this chamber.

The expansion chamber 37 is closed at one end by the base plate 14 and is overlain at the other end by the cover plate 16. However, the chamber 37 is provided with an opening 39 to the exterior of the apparatus, which opening is formed in the cover plate 16. In the completed liquid-filled apparatus, this opening is hermetically closed by a lamina 41 of ruby or other suitable material which is adhesively bonded to the cover plate over the opening 39.

Due to the small dimension of the capillary channel 35, the gas bubble 43 cannot pass into the enclosure 19 merely as a result of tilting the motion transformer to a position in which the entrance to the channel from the expansion chamber is uppermost. However, within the temperature range over which the apparatus is intended to operate, e.g., from —10°C to 60°C., the size of the bubble will vary. The size of the expansion chamber is large enough so that over this range the bubble is always of less volume than the chamber, and always large enough not to flow spontaneously through the capillary channel 35.

The method of the invention for making the above-described motion transformer is as follows: The assembly comprising the enclosure 19 with the ratchet wheel and associated pawl mechanism, and including the expansion chamber 37 connected to the enclosure 19 through the capillary channel 35, but without the closure member 41 in place, is introduced to below the surface of the liquid (e.g., a light lubricating oil) in a vacuum vessel, and the vessel is evacuated to a very low pressure, preferably 10—2 torr or below. Air contained in the enclosure 19 thereby will be withdrawn through the channel 35 and the expansion chamber 37. Thereafter the vacuum is broken and the liquid pressure in the vessel is brought to about atmospheric pressure. As a result liquid will flow into and fill the expansion chamber 37, the capillary channel 35, and the enclosure 19.

The apparatus is then removed from the liquid and cleaned with absorbing material such as filter paper to remove excess liquid. Then the apparatus is heated to a temperature slightly higher than the maximum temperature at which it is expected to operate, say to at least 40°C. and preferably to at least 70°C. The liquid in the apparatus will thereby be expanded and excess will flow out of the expansion chamber 37 through the opening 39. Such outflow is absorbed by some suitable material such as filter paper.

Next the apparatus is allowed to cool somewhat, by at least 10°C. (say from 70°C. to 60°C. or even to near room temperature). Due to the resulting thermal contraction of the liquid, air enters through the opening 41 and forms the gas bubble 43 in the expansion chamber. Thereupon the opening 39 is hermetically sealed by means of the lamina closure 41, which is adhesively bonded over the opening 39. Any suitable thermosetting adhesive, such as a two-component epoxy cement, may be used for this purpose.

As previously noted, the dimensions of the channel 35 and the expansion chamber 37 are such that at the lowest temperature at which the motion transformer is intended to operate, e.g. —10°C., the bubble 43 will have a smaller volume than that of the expansion chamber 37. On the other hand, at the maximum temperature at which the motion transformer is intended to operate, e.g., 60°C., the expansion of the liquid will compress the bubble, but without building up a pressure too high to cause damage to the apparatus or to prevent the bubble from expanding again as the temperature of the apparatus falls. Neither will the bubble even at maximum intended temperature of operation be compressed so much as to be able to flow spontaneously through the capillary channel into the enclosure 19,

As described in detail in the above-mentioned application Ser. No. 88715, the entire motion transformer 1 is, for example connected to a tuning fork, which imparts to it a translatory motion alternately in the direction of the arrows 22 and 23. The ratchet wheel 3, due to its inertia, will lag behind when the enclosure moves in the direction of the arrow 22, with the result that it will move relative to the enclosure in the direction of the arrow 26 until its corresponding tooth or teeth run up against the stop 12. Meanwhile, the enclosure has started to move in the direction of the arrow 23, so that the ratchet wheel 3 due to its inertia now moves relative to the enclosure in the direction of the arrow 25, until the stop 11 acts to brake its motion. This to-and-fro oscillation of the ratchet wheel 3 in its enclosure occurs at the frequency with which the tuning fork or other vibrator oscillates. During this to-and-fro motion of the ratchet wheel 3 the pawl stones 6 and 9 of the pawls 5 and 8 engage the teeth of the ratchet wheel 3, whereby during movement of the ratchet wheel 3 in one direction it is pivoted on one of the pawl stones as fixed point, and during movement in the other direction the corresponding edge of the other pawl stone serves as the fixed point for the pivoting of the ratchet wheel 3, so that the ratchet wheel 3 is caused to execute a unidirectional rotary motion; that is, the back40 and-forth oscillatory motion of the motion transformer assembly is converted by the action of the ratchet and pawls into rotary motion of the ratchet wheel.

It is quite obvious that this rotary motion must take place with as little frictional and other losses as possible. Accordingly, the contact surface between ratchet wheel and base plate is designed as small as possible, approaching point contacts. Because the weights here involved are so small, this can be done without difficulty, for even with nearly point contacts the contact pressures will remain exceedingly small.

In a liquid-filled motion transformer constructed in accordance with the invention, expansion of this liquid, due to temperature changes, will have little effect on the walls of the chamber 19. Without the expansion chamber provided by the invention, and depending on the temperature at which the chamber 19 is entirely filled with liquid, an internal pressure could develop in the chamber, with increasing temperature, of sufficient magnitude to burst the enclosing walls of the chamber. On the other hand, a decreasing temperature could lead to such a Contraction of the liquid as to create a bubble which, if sufficiently large, might cause the mass of liquid in the chamber 19 to at least partially oscillate along with the ratchet wheel, resulting in increased friction loss and higher current consumption by the timepiece; and it might even impair proper functioning of the motion transformer in converting reciprocating movement to rotary motion of controlled velocity. For these reasons the provision of the expansion chamber in connection with the design of the ratchet wheel enclosure, and the shape of the enclosure chamber, are of substantial importance.

I claim:

1. In a motion transformer for converting oscillatory motion to rotary motion comprising an enclosure defined by a base plate, a cover plate, and side members, all of which are substantially rigid, a ratchet wheel within said enclosure mounted both for oscillatory back-and-forth motion substantially on a diameter thereof and for rotary motion substantially about its center, a pair of stops fixedly mounted for limiting the amplitude of the oscillatory motion of the ratchet wheel within the enclosure, a ratchet pawl co-acting with said ratchet wheel and a restraining member preventing retrograde rotation thereof to convert oscillatory motion of said ratchet wheel to unidirectional rotary motion, and a liquid entirely filling the interior of said enclosure about said ratchet wheel, stops, pawl and restraining member, the improvement comprising an expansion chamber adjacent said enclosure and communicating with the interior thereof through a capillary channel, said capillary channel and a portion of said expansion chamber also being filled with said liquid, and a gas filling the remainder of said expansion chamber, said enclosure and chamber being hermetically sealed, whereby thermal expansion or contraction of the liquid in the enclosure is accommodated by flow of liquid through the capillary channel and corresponding compression or expansion of the gas in the expansion chamber.

2. Apparatus according to claim 1 wherein the expansion chamber is formed with an opening to the exte- nor and said opening is hermetically sealed by a closure member.

3. Apparatus according to claim 2 wherein the closure member is adhesively bonded in place over said opening.

4. A motion transformer according to claim I wherein the side members of the enclosure are configured to fit in closely spaced relation about the ratchet wheel and thereby to minimize the volume of the enclosure interior.

5. A motion transformer according to claim 6 wherein the side members are configured to form a substantially cylindrical enclosure chamber only slightly larger in diameter than required to accommodate oscillatory motion of the ratchet wheel and to define at least one substantially tangential channel to receive the ratchet pawl.

6. A motion transformer according to claim 7 wherein the restraining member is a second pawl and the side members define a second substantially tangential channel to receive said second pawl.

7. A motion transformer according to claim 6 wherein the side members are formed with channels in which the stops are received and fixed in proper spaced relation relative to the ratchet wheel. 8. A motion transformer according to claim 6 wherein two substantially identically configured side members are bonded together and to the base and cover plates to form the enclosure.

9. A motion transformer according to claim 1 wherein the expansion chamber and the capillary channel by which it communicates with the interior of the enclosure are formed in one of the enclosure side members.

10. A motion transformer according to claim 9 wherein the expansion chamber extends through the side member and is closed by the base and cover plates, one of said plates being formed witn an opening to the interior of the expansion chamber, and a closure member adhesively bonded in place over said opening.

Il. The method of making a motion transformer comprising an enclosure defined by a base plate, a cover plate, and side members, all of which are substantially rigid and hermetically sealed together, a ratchet wheel mounted for oscillatory back-and forth motion and for rotation in said enclosure, and an expansion chamber adjacent said enclosure and communicating therewith through a capillary channel, said expansion chamber being formed with an opening communicating with the exterior of the apparatus, which comprises immersing said motion transformer in a body of liquid contained in a closed vessel, evacuating said vessel to withdraw substantially all air from said enclosure and expansion chamber, then opening said vessel substantially to atmospheric pressure to enable the liquid to flow into and fill the enclosure, the capillary channel and the expansion chamber, then heating the liquid-filled motion transformer to a temperature somewhat above its maximum expected operating temperature, and then cooling said liquid substantially, whereby a quantity of atmospheric gas enters the expansion chamber as the liquid contracts in consequence of such cooling, and then hermetically closing the opening into the expansion chamber.

12. The method according to claim 11 wherein the vessel with the motion transformer immersed in the liquid therein is evacuated to below 10—2 torr.

13. The method according to claim 11 wherein the motion transformer after being filled with liquid is heated to at least 40CC. and is then cooled.

14. The method according to claim 11 wherein the motion transformer after being filled with liquid is heated to at least 70°C. and is then cooled.

15. The method according to claim 11 wherein the motion transformer is cooled at least 10°C. below the temperature to which it is heated after being liquid- filled.

16. The method according to claim 11 wherein the motion transformer is cooled substantially to room temperature after being heated.

17. The method according to claim 11 wherein the opening into the expansion chamber is closed by adhesively sealing a jewel lamina thereover.

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