Clocks and Watches

TIMEWORX

Any periodically repeated phenomenon can be utilised for time measurement, so long as the duration of the period remains accurately constant. In early timepieces the periodic movement was performed by a pendulum (Fig. 1).

The weight which drives the watch is applied to the circumference of the spindle, causing it to rotate. This rotation is, however, arrested by the anchor, which is linked to the pendulum and which periodically engages with, and releases, a toothed wheel called the escape wheel (the combination of escape wheel and anchor is called the escapement). Each time the pendulum reaches its maximum amplitude, one of the projections (called pallets) of the anchor releases a tooth of the escape wheel, allowing this wheel to rotate a corresponding amount. Its rotation is therefore performed in a series of jerks, controlled by the anchor and pendulum, and this rotation is transmitted to the hands of the clock through a train of gear wheels.

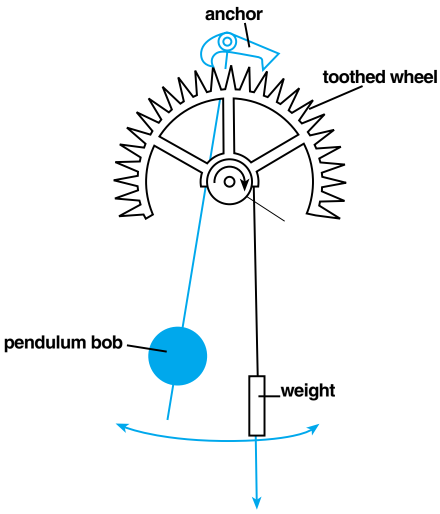

Fig. 1 PENDULUM DRIVE


Fig. 2 PENDULUM MOTION IS MAINTAINED BY IMPULSES DELIVERED AT REGULAR INTERVALS

Friction would soon cause the pendulum to stop swinging if it were not given an impulse at regular intervals to keep it in motion, just as a child's swing has to be pushed each time it reaches it's full amplitude (Fig. 2).

In the pendulum clock an impulse is imparted to the pendulum by the escape wheel (which is driven by the weight) through the pallets. The frequency (number of swings per second) of the pendulum can be varied by sliding the bob of the pendulum up or down on its rod. Lowering the bob makes the pendulum swing more slowly, and vice versa. In this way the period (time of oscillation) of the pendulum can be adjusted and, the clock itself thus be regulated.

In watches the controlling action of the pendulum is performed by a device called the balance (Fig. 3). Attached to the spindle of the balance is a spiral spring, named the balance spring or hairspring, which controls the oscillations of the balance. Attached to the balance is a pin which engages with the lever. With each oscillation of the lever the pallets release the escape wheel, allowing it to rotate a distance corresponding to one tooth. At the same time an impulse from the escape wheel (which is driven by the mainspring) is transmitted to the balance through the lever and pin and thereby keeps the balance in motion. The function of the latter is thus entirely analogous to that of the pendulum in a pendulum clock. The type of escapement illustrated in Fig. 3 is the so-called lever escapement; it was invented about two hundred years ago, and is now widely employed; there are several other types of escapement for watches. The balance performs five to-and-fro movements per second, i.e., the second hand moves in five tiny jerks each second. The escape wheel drives the minute hand and hour hand through a train of gear wheels.

The transmission of the movement of the minute wheel and hour wheel to the hands of the watch is shown in Fig. 4. The minute wheel performs one complete revolution per hour, and so does the minute hand, which is mounted on the same spindle. During the same length of time the hour wheel and hour hand perform only one-twelfth of a revolution.

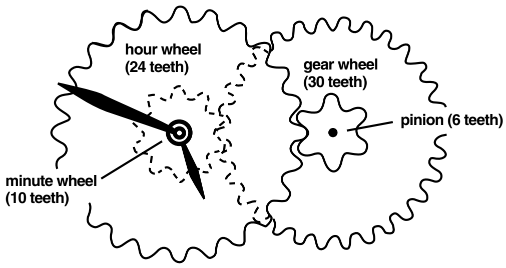

Fig. 4 TRANSMISSION OF MOTION FROM THE MINUTE AND HOUR WHEEL TO THE HANDS

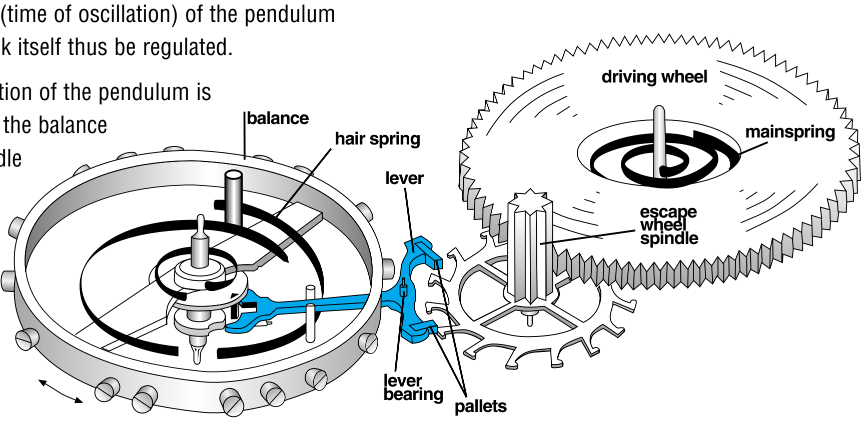

Fig. 3 DRIVE MECHANISM OF A WATCH

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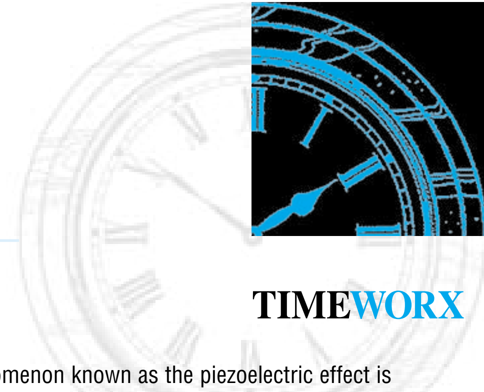
Quartz Clock



TIMEWORX

In every method of measuring time a periodically recurring process is used as the basis of the measurement. In clocks and watches the periodic recurrence is provided by the swinging pendulum or the oscillating balance (see previous page)

Essentially, any periodic process can be used for controlling a timepiece. In the device called the "quartz clock" these consist of the "thickness vibrations" that quartz (and certain other crystals) perform under particular conditions. The principle of such vibrations can best be illustrated by a very simple example: when a jelly pudding is struck with a spoon (Fig-1), it begins to wobble.

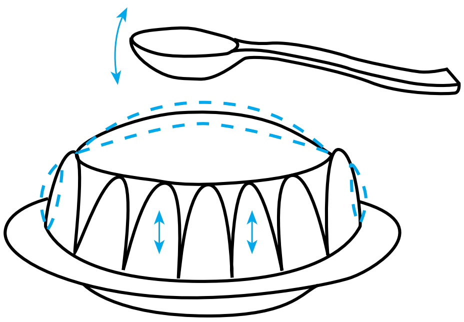


Fig. 1 THICKNESS VIBRATIONS OF AN ELASTIC SUBSTANCE

These movements are a kind of thickness vibrations. If the jelly is struck at regular intervals corresponding to its vibration frequency, the amplitude of the vibrations will increase to such an extent that the pudding may actually break up. A quartz crystal cut in a certain way exhibits a similar effect. In this case, however the excitation of the crystal is not done by mechanical impulses but by periodic electric charging (Fig 2).

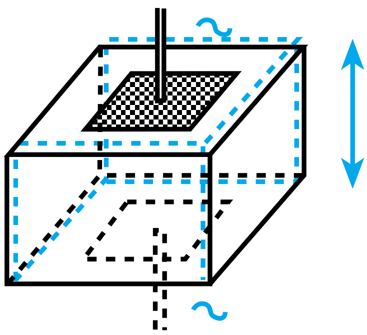


Fig. 2 THICKNESS VIBRATIONS OF A QUARTZ CRYSTAL UNDER THE INFLUENCE OF AN ALTERATING VOLTAGE (OSCILLATOR QUARTZ)

For this purpose a phenomenon known as the piezoelectric effect is utilised: when the crystal is subjected to alternate compressive and tensile strains, opposite electric charges are produced on different faces; conversely, when electric charges are applied to these faces of the crystal the latter undergoes expansion and contraction. By this means the crystal can be set vibrating. The frequency of these thickness vibrations depends solely on the dimensions of the crystal and can be given any desired value by appropriately choosing these dimensions. For a given set of conditions the frequency is extremely constant. A quartz crystal can thus be used as a highlyaccurate regulator for an electric oscillatory circuit (Fig. 3).

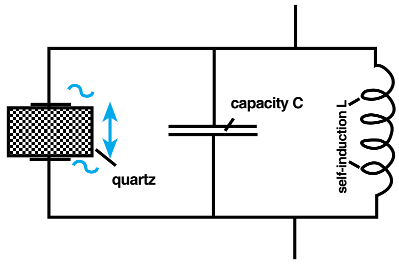


Fig. 3 CONTROL OF AN ELECTRIC OSCILLATORY CIRCUIT (L, C) BY MEANS OF A PIEZOELECTRIC CRYSTAL (OSCILLATOR QUARTZ) SO AS TO ENSURE CONSTANT FREQUENCY

The quartz clock comprises a tube (or valve) transmitter (Fig. 4), or a transistorised transmitter whose oscillatory circuit is controlled by a quartz crystal. At the output end {A) an alternating voltage with a frequency possessing a high degree of constancy is obtained. This output can be fed through frequency reducing circuits, or be supplied to a high-frequency motor, and thus be used to drive a normal clock. The time-keeping accuracy is very high (to within one ten-thousandth of a second over a period of months). Quartz clocks have acquired importance as master clocks for public timekeeping purposes and for keeping the frequencies of radio transmitters constant.

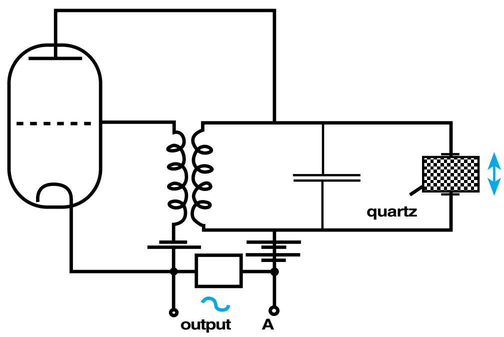


Fig. 4 PRINCIPLE OF THE QUARTZ CLOCK: THE FREQUENCY OF THE ELECTROMAGNETIC OSCILLATIONS OF A TRANSMITTER IS KEPT CONSTANT BY MEANS OF A PIEZOELECTRIC CRYSTAL

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Atomic Clock

TIMEWORX

The atomic clock is the most accurate time measuring device at present known. Whereas the accuracy attainable with high-precision pendulum clocks is about 10^{-7} (i.e., an error of 3 seconds per year), the accuracy of the quartz clock (see previous page) is 100-1000 times greater. However quartz clocks have the great disadvantage that their vibration frequency changes in course of time. Hence the frequency has to be checked from time to time and readjusted. This is done with the aid of an atomic clock, in which the frequency is determined by molecular vibrations and remains constant. The accuracy of the atomic clock is about ten times as great as that of the quartz clock.

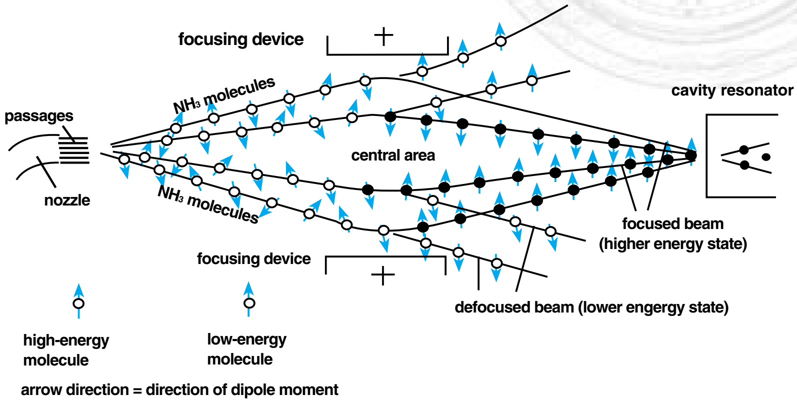

Fig. 1 PRINCIPLE OF ATOMIC CLOCK (viewed at right angles to molecule beam)

The operating principle of an ammonia atomic clock is as follows: Gaseous ammonia (NH_3) is introduced through the nozzle on the left in Fig.1. The nozzle consists of a number of very fine parallel passages, and the molecules travelling to the right enter the focusing device, which consists of a number of metal cylinders (usually four) charged to a high voltage. Among the NH_3 molecules are some with a higher and some with a lower energy content. Both kinds of molecule have a dipole moment, i.e., they align themselves in an electric field in such a manner that the high-energy molecules dispose themselves against the direction of the field. whereas the low-energy molecules dispose themselves in that direction. Because of these properties of the NH_3 molecule, it is possible, with the aid of the very inhomogeneous field in the focusing device, to separate the high-energy molecules from the low-energy ones, so that the former are thrust towards the central area by the electric field, while the latter are thrust outwards (Fig. 2). The high-energy molecules are collected by the focusing device and directed into a cavity resonator. The resonator is a metal box in which a stationary high-frequency wave can be formed with the aid of a feedback system. Activated by this wave, the high-energy NH_3 molecules acquire vibrations of about 24 milliard[1] cycles/sec, and give off their energy to the wave, which is thereby amplified. This high-frequency energy has a frequency which remains very accurately constant, thus providing the basis for the time measurement.

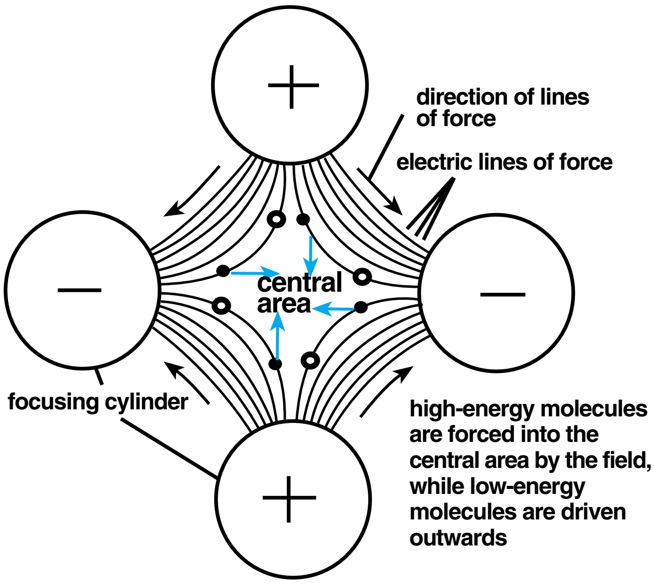

Fig. 2 FOCUSING DEVICE
(viewed in direction of molecule beam)

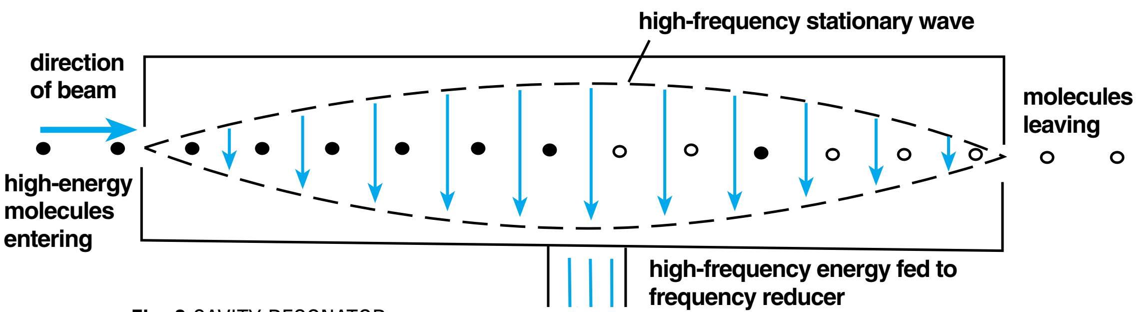

Fig. 3 CAVITY RESONATOR

I. A milliard is equivalent to one billion in U.S.A.

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