

CLOCKS CONTROLLED BY QUARTZ OSCILLATORS

(Arranged from the article "Quartz Oscillators and their Applications", by Dr. P. VIGOU-REUX, Department of Scientific and Industrial Research, London; 1939).

One of the most important applications of quartz oscillators is the production of accurately known frequencies of great constancy for time measurement.

So-called vibrator clocks are now employed in several standardizing laboratories and astronomical observatories; they compare favourably with pendulum clocks even for long periods, of the order of a year, and are decidedly superior for short periods, of the order of a few hours or less, because the "seconds" obtained from them are more uniform than those of pendulum clocks.

This new technique of time measurement has made great progress during the latter years thanks to the utilisation of quartz oscillators of negligible thermal coefficient of frequency.

It is well known that certain crystalline materials, such as quartz, exhibit the phenomenon of piezo-electricity: that is to say if pieces of such crystals are subjected to mechanical pressure in certain directions relative to the electric faces, electric charges of opposite sign are produced on two opposite sides of the crystal; the crystal becomes electrically polarized. Conversely, if the crystal is polarized by the application of an electric field, i.e. by the application of a voltage to two metal plates placed one on either side of the crystal to serve as electrodes, mechanical stresses are produced in certain directions within the crystal, and accordingly it expands or contracts. If the applied voltage is alternating, the crystal is set into mechanical vibration, and if the frequency is adjusted until it becomes equal to the natural frequency of vibration of the crystal, the phenomenon of resonance occurs: the amplitude of vibration of the crystal becomes very large, and correspondingly large piezo-electric charges are developed on its surfaces. These large charges react very strongly on the source of the applied field, with the result that the resonating crystal is capable of exerting a powerful electrical controlling force, which has many applications of great scientific and industrial importance. The crystal behaves like an oscillating circuit with an efficiency and stability far better than those obtainable by coils and condensers.

The frequency at which the reaction occurs is practically independent of the electric circuit, being almost entirely governed by the elastic constants of quartz and the dimensions of the plate or rod, and this resonator constitutes a very simple and convenient precision standard of frequency.

The frequency of vibration of a quartz plate depends also on the orientation of the plate in the original quartz crystal, and also on other factors, such as electrode configuration and temperature. Although the latter variations are generally very small (from 0.5 per cent to 1 per cent), they must be taken into account in connection with the accurate measurement of time, and, in fact, recent researches have aimed at establishing oscillators where the thermal coefficient of frequency is negligible.

One method consists in maintaining, by the use of a thermostat, the temperature constantly even. Further, the thermal coefficient of frequency depends on the orientation of the plate with respect to the axes of the quartz crystal, and it is therefore possible to reduce this coefficient to zero by a suitable choice of orientation when the crystal is cut.

The following method can also be employed: if the width of a plate be adjusted so that the frequency of an overtone vibration along the width is nearly equal to the frequency of the pure thickness vibration, there is a certain coupling between the two types of vibration, with the result that the resultant vibration has a frequency in the neighbourhood of the other two. The thermal coefficient of this frequency depends on the coefficient of the overtone mode as well as on that of the pure thickness mode, and if these two coefficients are of

opposite sign, the resultant coefficient can be made to vanish at a particular temperature by suitable adjustment of the width of the plate. The final adjustment is effected on the thermostat regulator rather than on the width of the plate.

Instead of exciting the quartz resonator into vibration with an independent electric generator, it is possible to connect the quartz plate to a thermionic tube in such a way that self-maintained oscillations are generated. One of the simplest circuits for the purpose, due to PIERCE (1923) is shown in figure 1. Any small impulse is fed back to the quartz plate

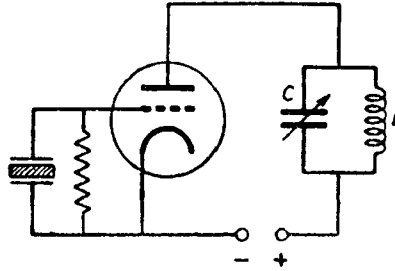


FIG. 1.

through the plate-grid capacitance of the tube; if the capacitance C is less than the value which would make the natural frequency of the oscillatory circuit LC equal to the natural frequency of vibration of the quartz plate, the impulse is fed back in the right phase, and if the damping of the quartz is not large, self-maintained oscillations are produced. The frequency is close to the natural frequency of vibration of the quartz plate, and varies very little with the condenser value.

Whatever be the type of oscillator employed, the holder is kept in a temperature-regulated enclosure at constant pressure, in order to eliminate variations of frequency caused by changes of temperature, pressure and humidity. As the chief requirement is constancy of frequency, and not power, the amplitude of oscillation is kept small by the use of a large air gap and by suitable adjustment of the condenser in the Pierce circuit.

The coil of the Pierce circuit provides a small current alternating with the frequency of the oscillator, say 20 kc/s nominally; the next problem is to obtain hours, minutes and seconds from that current. The coil is coupled to an amplifier followed by a frequency divider, which often takes the form of a multivibrator kept in step by the current in the amplifier. This multivibrator consists of two thermionic tubes (fig. 2) inter-coupled through

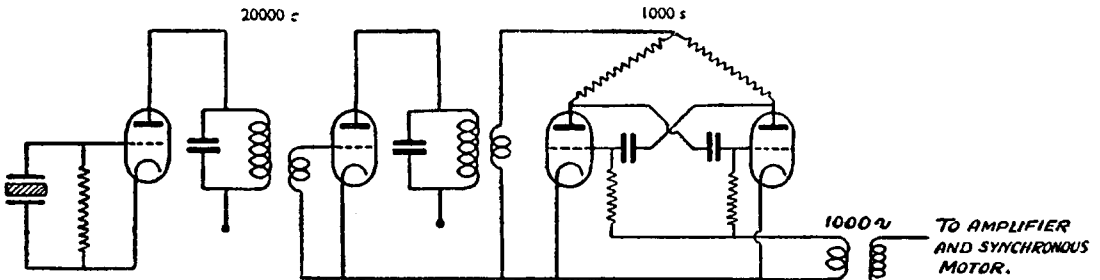


FIG. 2.

resistances and condensers. The latter are adjusted so that the frequency of the relaxation oscillation is nearly equal to a sub-multiple, say a twentieth of the frequency of the oscillator, and a small e.m.f. from the amplifier is injected into the multivibrator, which is thereby dragged into step, and oscillates with a period exactly twenty times that of the vibrator for a considerable range of its capacitances. If the frequency of the quartz oscillator is 100 kc/s, instead of 20 kc/s two multivibrators are employed, and the reduction of frequency is effected in two steps, for example 100 to 10, and 10 to 1 kc/s respectively.

The output at 1 kc/s is amplified and applied to a synchronous motor, which can only run when it is in synchronism with this supply, so that there is no doubt that the period of rotation of the motor is an integral multiple of the period of the oscillations of the multivi-

brator, and, therefore, an integral multiple of the period of the quartz oscillator, for if there was a sudden jump in the frequency, the motor, on account of its inertia, cannot adapt itself to this sudden change: it falls out of step and ultimately stops ,

By means of appropriate gearing, the motor is made to drive pinions which rotate once every nominal second, nominal minute and nominal hour respectively; these pinions can be connected to hands on a clock dial. The seconds pinion is equipped with an electric contact and comparisons with the pendulum clocks of various observatories can thus be obtained through a rotating-drum chronograph. The accuracy is limited only by the accuracy of the radio time signals, which is of the order of 10 milliseconds.

To compare instantaneous frequencies of two oscillators, supplies controlled by them at a nominal frequency of, say, 20 kc/s, are led to the two pairs of plates of a cathode-ray oscillograph, and the beat frequency is observed.

Tests of the kind described above indicate that quartz oscillators can provide at any time for periods of the order of a year frequencies accurate to 2 parts in 10^8 , which correspond to a rate of only about 2 milliseconds per day for the clocks which they drive.

The quartz clock designed by DYE and described by ESSEN (1936) is controlled by an oscillator in the form of a ring, the axis of which merges into the principal ternary axis of the crystal. Six pairs of electrodes disposed along the circumference are used to excite the ring, alternate pairs being cross-connected, as shown in fig. 3, so that the applied potential

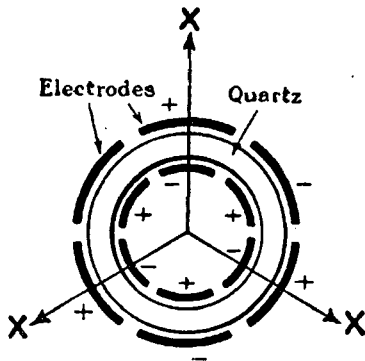


FIG. 3.

causes simultaneous expansion or contraction of all six segments. In this mode of vibration, the ring, which must be suspended by three stirrups, expands and contracts radially as a whole, the frequency being approximately equal to $1/ds_{11}\rho$ in which d is the mean diameter, ρ the density and s_{11} the elastic constant in the direction perpendicular to the axis. From this formula we find that the frequency in kc/s is equal to 5440 divided by the mean circumference in mm.

The figure 4, represents the holder designed by ESSEN (1938) for the ring oscillator which controls one of the vibrator clocks of the National Physical Laboratory. The ring is supported on three chisel-ended phosphor bronze screws carried by radial arms projecting from the inner cylindrical electrode; location is secured by means of three V-shaped radial grooves cut in the lower face of the ring along the lines where it is intersected by the nodal planes. In order to make the holder portable, three screws with round polished ends are locked at a distance of 0.01 mm. from the upper face of the quartz; thus, although they do not constrain the ring, they ensure that the phosphor bronze screws remain in the radial V grooves. The insulation between the interior and exterior electrodes is of fused quartz.



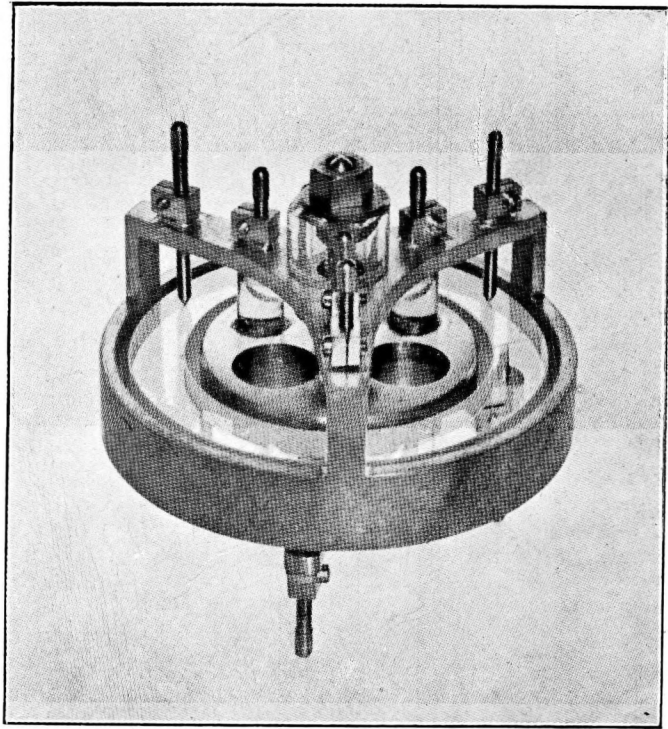


FIG. 4.