The General Radio Experimenter

VOL. V, NO. 5 — OCTOBER, 1930

THE FREQUENCY STABILITY OF PIEZO-ELECTRIC MONITORS

By JAMES K. CLAPP*

THE increasing demand for accurate maintenance of radio transmitters upon their assigned frequency is bringing to light the variations of frequency of the crystal-controlled master oscillators which are being more and more widely used to attain the desired stability. Where a piezo-electric oscillator is used as the master oscillator, economy of apparatus dictates that the oscillator be operated at as high a power level as possible in order to reduce the number of amplifier stages required to reach a given level for transmitter output.

> ". . . The variations of the crystal-controlled transmitter are in general much less than those of the usual tuned-circuit master oscillator, but under extreme conditions the variations may be as great. It is a disappointing, but nevertheless true conclusion that implicit faith in 'crystal control' as the answer to every problem of frequency stability must give way to a modified view which will necessarily involve the application of more complex methods." — From the accompanying article.

Unfortunately, a piezo-electric oscillator so operated loses many of its most desirable characteristics as a constant-frequency device. Under powerful oscillation, heating in the quartz plate may be pronounced. This heating varies with any changes in the load imposed on the piezo-electric oscillator by the succeeding equipment, resulting in a frequency shift due to temperature change indirectly caused by these load changes. In some cases improper design for the plate-holder, or undue forcing of the oscillator, results in a pronounced brush discharge in the air gap resulting in further variations in the master oscillator frequency.

In spite of the undesired frequency changes in the master oscillator over long intervals of time, it is often found that the frequency may be held substantially constant for relatively short intervals. As the frequency of the system is adjustable by several means, among them circuit adjustment and temperature of the plate, it is possible

* Engineer, General Radio Company.

to bring the transmitter frequency into agreement with the frequency of a sub-standard † maintained for the purpose, and this agreement will then be maintained for a considerable period. The variations of the crystal-controlled transmitter are in general much less than those of the usual tuned-circuit master oscillator, but under extreme conditions the variations may be as great. It is a disappointing, but nevertheless true conclusion that implicit faith in "crystal control" as the answer to every problem of frequency stability must give way to a modified view which will necessarily involve the application of more complex methods.

With only reasonable care in operation, a piezo-electric oscillator may be depended upon to maintain its frequency to a degree of precision exceeding present requirements *provided the power level is kept low and the temperature of the quartz plate is kept constant*. If such an oscillator is then set up as a sub-standard and used as a monitor, the crystal-controlled transmitter frequency may be periodically brought back to its assigned value with a comparatively high degree of precision. As the frequency drift of the transmitter is not rapid after it has been in operation long enough to reach steady conditions, only an occasional check-up would be necessary to hold the transmitter frequency within rather close operating limits.

If an operating tolerance of ± 50 cps. is to be maintained, it is of course necessary that the sub-standard piezo-electric oscillator hold its frequency to within a much smaller tolerance, say ± 10 cps. This requirement demands careful temperature control, circuit stability, and low energy level.

In order to determine the frequency stability that can be obtained from a monitor consisting of a stock model piezo-electric oscillator using temperature control and commercially obtainable quartz plates, a thorough study of a typical system is being made by the author in the laboratories of the General Radio Company. Representative broadcast-frequency quartz plates are being studied and the variations in frequency resulting from all the possible influences recorded. The principal factors are:

1. Changes in any of the circuit elements due to age.
2. Replacement of tubes.
3. Mechanical vibrations of the system.
4. Variations in temperature.
5. Variations due to change of plate-circuit load.
6. Variations due to changes in supply voltages.

Of these the largest variations in frequency result from mechanical vibrations of the system, variations in plate load, changes in temperature, and changes in tubes. Of these, with a given system, the operator may largely control the effects of load and tubes. The effect of mechanical vibrations must particularly be reduced by the manufacturer of the system, and the temperature control must be developed by him to maintain substantially constant temperature under ordinary room temperatures and for long periods of time.

In the November issue the experimental results will be presented with particular reference to the causes of frequency variation outlined above.

† Sub-standard is here used in its commonly accepted sense. It is a descriptive term applied to a constant-frequency oscillator, the frequency of which is determined by comparison with a primary standard of frequency.

A primary standard of frequency is one in which the frequency is determined directly in terms of the mean solar second. See, for example, S. C. Hooper, "The Hague Conference," *Proceedings of the I. R. E.*, Vol. 18, No. 5, May 1930, 769.

SYNCHRONOUS MOTOR-DRIVEN CLOCKS

By HAROLD S. WILKINS*

TODAY a remarkably wide field of usefulness is being developed for small synchronous motors. These motors until comparatively recently were regarded perhaps as a curiosity. Now they are available in a wide range of power outputs and can be designed to run at speeds of from a few revolutions a second to several hundred, and on circuits of from 25 cps.† to perhaps 10,000 cps.

Consider for example the increasingly large numbers of electrically operated clocks that are being sold each year. The majority of these are operated by small synchronous motors, some of only a few thousandths of a horse-power, yet they run continuously and dependably. Various modifications in design have been developed, including wound, polarized, and shaded poles.

The simplest type may be represented by a laminated rotor of magnetic material having salient poles properly journaled between one or more pairs of stator poles, the number and size being determined by the frequency, power, and speed characteristics desired. The mechanism of operation in its simplest form may be regarded as a succession of equally spaced magnetic impulses, each one attracting in turn a corresponding rotor pole. When by some means the rotor is brought up to synchronous speed, the magnetic center line of rotor and stator poles coincide in succession at approximately the instant of maximum current and the motor continues to run.‡ The design is such that the reluctance of the magnetic path increases rapidly as the angular displacement of the center lines increases and a positive torque results. Varying power demands cause a variation in lag of rotor tooth behind stator tooth, resulting in an equivalent variation in the input power, making it possible for the rotor to carry varying loads while maintaining synchronous speed. This lag can never be greater than one-half the angular separation between two rotor teeth, which corresponds to 90 electrical degrees.

There is of course no accelerating torque in a synchronous motor of this simple type, which means that the motor must be brought up to synchronous speed by hand. It also means

FIGURE 1. The standard Model B Syncro-Clock enclosed in walnut cabinet

* Engineer, General Radio Company.

† cps., hereafter used to mean "cycles per second."

‡ Note that the magnetic pull between a rotor pole and a stator pole is independent of the *direction* of the current.

that if the system is overloaded or if the power supply fails even momentarily, the motor will stop. While the absence of an accelerating torque may be considered a disadvantage in a clock for domestic use, its absence is a decided advantage for many laboratory purposes. This point will be explained later.

Because such a motor runs in absolute synchronism, it may be considered to be a counter of vibrations. Every pair of poles that passes a given point represents a cycle, or, if the input circuit is properly biased, every pole represents a cycle. To illustrate this, consider Figure 2. In this figure the lower curve shows the original sinusoidal input current. The magnetic field varies similarly but the attraction between rotor and stator teeth will always be positive. If now the negative half of the wave is biased by an opposite current to reduce it practically to zero, a new current curve and magnetic field will be produced as indicated by the upper curve in this figure. The horizontal line represents the biasing current and the new alternating current is indicated by the top curve. It is readily seen that the magnetic field strength is increased and the frequency halved, making it possible to halve the operating speed, reduce the losses, and increase the power.

Fundamentally the motor operates as a tachometer counting every cycle, and when referred to time becomes a measure of frequency. This device, when referred to time indicates frequency, and, conversely, when referred

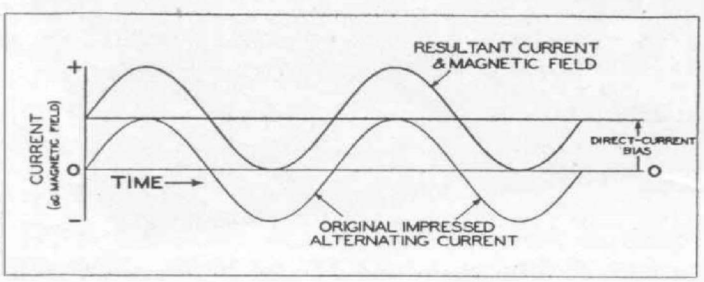

FIGURE 2

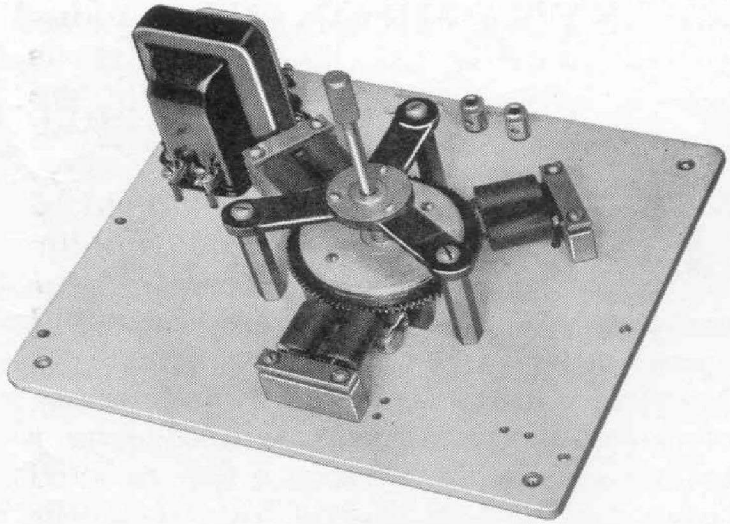

FIGURE 3. The motor assembly which may be employed to drive discs, contactors, and small generators

to a standard frequency, indicates time. Obviously the gearing of a clock dial to the motor offers the user a dual-purpose instrument. A third use is immediately apparent — controlled shaft speeds.

Nearly ten years ago the General Radio Company started to develop a synchronous-motor-operated clock. The first model * answered the purpose at that time, but the wide range of possible uses and demands for greater power output required a design markedly different. After considerable study and numerous experiments the TYPE 511 Syncro-Clock was developed to replace the old model.

Briefly, the rotor consists of a carefully milled laminated iron ring mounted on an aluminum damping disc, the shaft rotating in a jewel bearing and guided by a ball bearing. Power is supplied through three pairs of poles located 120° apart and having milled teeth corresponding to those on the rotor.

A decimal system of shaft speeds has been selected to better increase the adaptability of the motor and clock.

* The TYPE 411 Synchronous Motor, now obsolete, having been replaced by the TYPE 511 Syncro-Clock.

The rotor shaft speed is 10 revolutions per second and the secondary shaft is geared to rotate once a second, the final gearing being such that the clock keeps correct time at rated frequency. One thousand cps. is now generally available in the laboratory and the standard motor has a 100-tooth rotor which runs at 10 revolutions per second on properly biased 1000-cps. circuits.

As an indication of synchronism, a small neon glow tube is mounted under the edge of the rotor. This is lighted from the input circuit and at synchronism the stroboscopic effect causes the rotor teeth to appear stationary. Proper voltage to the tube is regulated by a transformer included with the motor assembly. A switch for controlling the lamp is also provided.

If the natural period of torsional vibration of the rotor is near the natural frequency of the circuit, hunting may become quite serious. This may be greatly reduced by proper design. To minimize hunting and to make starting easier, the damping disc has been developed. The rotating parts have been made as light as possible. To secure a relatively high moment of inertia, weight is provided by the addition of mercury. Due to its mobile nature if in hunting or due to change of load there is a phase shift, synchronism is easily maintained by the immediate shifting of the light rotor. Hunting or periodic vibrations are rapidly damped out by the energy given up or absorbed by the mercury. The mercury is sealed in the damping disc and baffled to increase the friction resulting in any change of speed between the disc and the mercury.

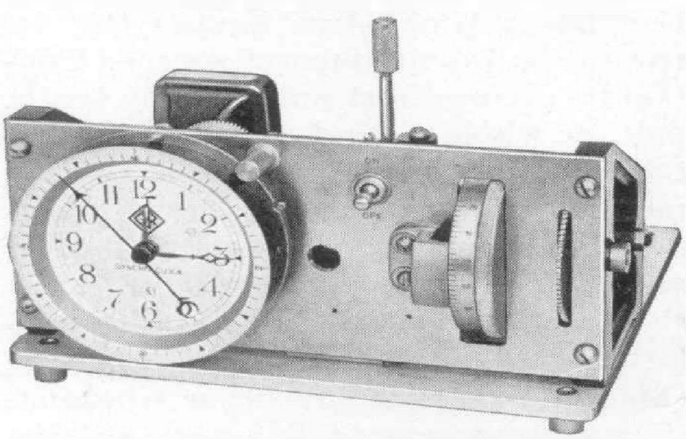

FIGURE 4. TYPE 511-C Syncro-Clock, designed for panel mounting. The micro-dial is shown at the right

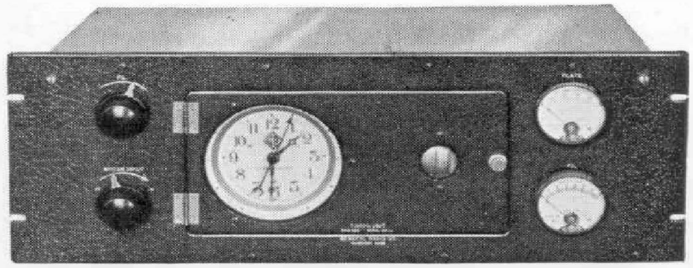

FIGURE 5. The clock and an amplifier may be assembled in one unit and used for relay-rack mounting

We have already mentioned that the stopping of the clock results after even momentary failures of the power-supply circuit and that this is an advantage for many laboratory purposes. When, for instance, one is using the clock to count the number of oscillations executed by a constant-frequency oscillator for comparison with time determined by some other system, it is important that the clock run in synchronism or else not at all, especially when one is making measurements of extremely high precision. It is highly desirable that any momentary perturbation of the circuit be made known at once, if erroneous results are to be avoided.

The motor is normally operated at from 100 to 125 volts at a frequency of 1000 cps. and biased with from 40 to 50 milliamperes of direct current. The rotor is brought up to speed by turning the knurled knob between the fingers until stroboscopic effect indicates synchronism. In many cases the clock will "pull in" itself if turned faster and then allowed to drift down to speed. The output of two 171-A-type tubes operated in parallel with sufficient amplification to bring the voltage up to

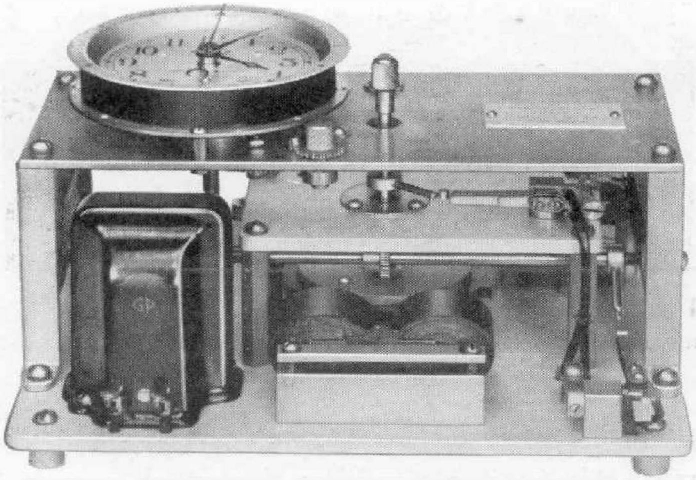

FIGURE 6. This clock designed to run on 60-cycle circuit has both a seconds and 0.1 second contactor

rated figure is recommended for general operating conditions. The direct current in the plate circuit must be allowed to flow through the motor windings. Supplied from such a source the starting is easy, operation is dependable, and satisfactory results are assured. Unless operating under very heavy loads one tube may burn out or tubes may be replaced or changed one at a time without stopping the motor.

The motor of course will run on widely different supply frequencies but standard shaft speeds are obtained only at rated frequencies. Experimentally a 1000-cps. motor has been satisfactorily operated on all frequencies between 250 cps. and 1750 cps. Of course for special purposes rotors can be designed to give standard shaft speeds on any source of from 60 cps. to 5000 cps. In such cases the number of teeth cut in the rotor is changed to meet conditions. The clock movement itself is a standard arrangement of gears to give hours, minutes, and seconds, but for convenience a separate scale graduated in seconds has been added on the outside diameter of the dial. The second hand may be adjusted by half seconds by means of a knob located just outside the dial and controlling an epicyclic gear train by means of which the seconds shaft can be rotated in either direction without interfering with the motor. A spring lock prevents motion of these gears except when manually operated.

The Syncro-Clock, used as a frequency meter, will give an accuracy of better than one part in 100,000 during a 24-hour interval by reading of the seconds hand. To increase this precision the micro-dial attachment makes it possible to check the clock by reference to Arlington Time Signals to within approximately 0.01 second. This makes possible a precision approaching one part in 10,000,000 for a 24-hour interval.

The operation of the micro-dial is quite simple. A revolving arm or cam on the seconds shaft of the clock closes a contact for a period just greater than the duration of the time signal. This point of closing may be made to occur at any point in a complete revolution by rotating the outer drum member. The signals are received by the phones and the dial is adjusted so that only the "nose" of the signal is heard. The difference of dial readings between successive periods indicates the change from true time. When operated on a standard frequency the micro-dial may be used to send seconds impulses and by means of a secondary program wheel almost any series of accurately spaced groups of signals may be obtained. The clock under this condition becomes a time piece having the accuracy of the frequency source. Contactors giving short pulses every tenth, half, or whole second can easily be attached and from these many secondary measurements may be made with surprising accuracy. By combining a seconds and a minutes contactor a very short and accurate minutes pulse may be secured. By choosing appropriate cams and gears many other combinations can be secured. Magneto generators offering a source of relatively low frequency of good waveform of from one to 100 cps. can be designed for operation with the clocks. In every case the precision with which the resulting frequencies and time intervals are known is essentially the same as the precision of the supply source. When a Syncro-Clock is operated from a General Radio standard-frequency assembly, for example, a precision of approximately one part in 1,000,000 may be expected.

To review briefly, the synchronous motor-driven clock may be used as a frequency meter, a standard clock, a sending device of time signals, a generator of impulses or low frequencies, and a constant-speed motor. Impulses are often employed to give a record on tapes or films and the motor may be used as a drive for stroboscopic work. In fact the uses are too varied to enumerate completely and it is hoped these comments will serve as a basis to suggest other applications.

The greater power of the new TYPE 511 Syncro-Clock Motor makes it possible to drive a large number of auxiliary attachments. Figure 7 shows a Syncro-Clock which has a micro-dial reading directly to 0.001 seconds. The hand at the right revolves once a second and under this may be seen the two magneto generator discs designed to give frequencies of 30 and 35 cps. The two adjustable contactors in the lower left corner make and break the circuit one and ten times a second respectively

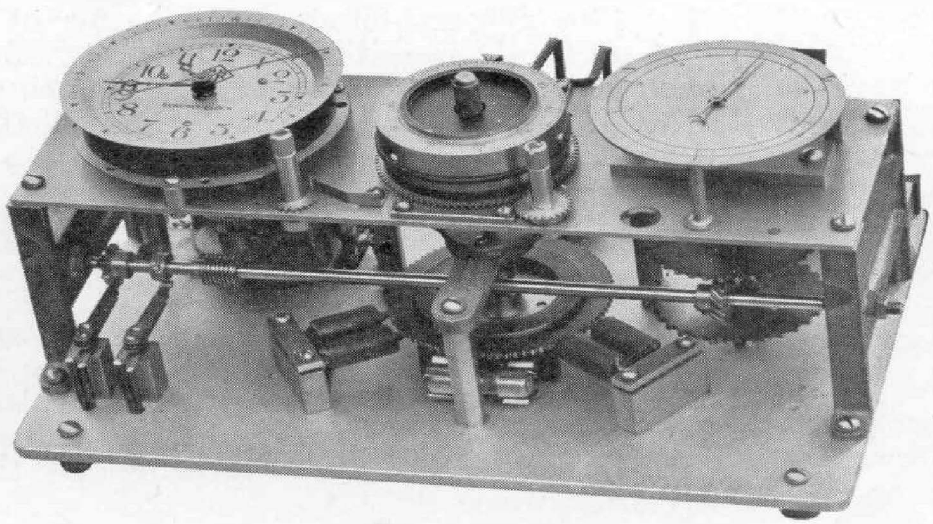

FIGURE 7

The General Radio *Experimenter* is published monthly to furnish useful information about the radio and electrical laboratory apparatus manufactured by the General Radio Company. It is sent without charge to interested persons. Requests should be addressed to the

GENERAL RADIO COMPANY
CAMBRIDGE A, MASSACHUSETTS

What Is a Syncro-Clock?

MORE than ten years ago, before the synchronous motor-driven clock was popularized for domestic use, the General Radio Company began development of such an instrument for use in the laboratory. It was our initial idea that the Syncro-Clock would be driven by a vacuum-tube oscillator having a fairly stable frequency characteristic and that the clock would therefore furnish a means of determining the average frequency of the oscillator during a given time interval. This development has been steadily carried forward, many models built, and now we are able to make commercially available a Syncro-Clock having a number of useful and interesting features:

1. The Syncro-Clock offers one of the most precise methods possible of measuring the frequency of an oscillator. Readings are secured in terms of our Mean Solar Day and are integrated throughout the period of measurement.

2. When operated by a source of exactly 1000 cps. the Syncro-Clock keeps true time, the only error being that of the standard.

3. Shafts rotating with a constant angular velocity are available for turning stroboscope discs, for operating seconds and tenths-of-seconds contactors, and for driving small generators to produce other frequencies the stability of which are definitely determined by the frequency of the driving source.

The General Radio Company makes use of this device in its standard-frequency assembly, our name for a system which determines frequency directly in terms of the Mean Solar Day. Using a Syncro-Clock we compare the time kept by our piezo-electric oscillator — Syncro-Clock system with the time intervals determined daily by the U. S. Naval Observatory and transmitted to us via Arlington Time Signals.

Syncro-Clocks have many applications to time and frequency-measuring problems. If this brief description interests you, we should be glad to send you further details.

Ask for Catalog F–X

GENERAL RADIO COMPANY

OFFICES · LABORATORIES · FACTORY

CAMBRIDGE A, MASSACHUSETTS

PACIFIC COAST WAREHOUSE: 274 BRANNAN STREET, SAN FRANCISCO, CALIFORNIA

RUMFORD PRESS
CONCORD. N.H.