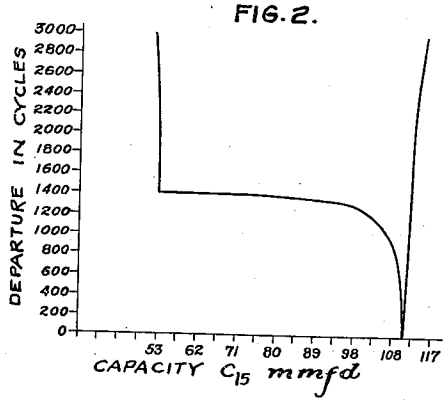
Sept. 13, 1938. W. A. FORD 2,130,272

PIEZOELECTRIC CRYSTAL OSCILLATOR

Filed March 31, 1938

FIG. 2.



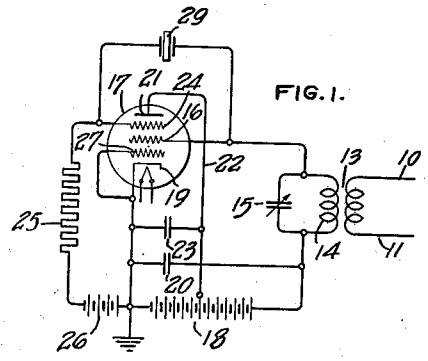




FIG. 1.

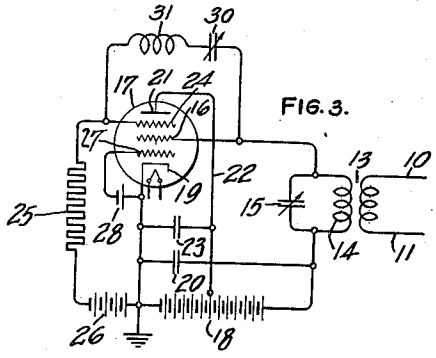



FIG. 3.

Inventor:
Warren A. Ford,
by Harry E. Dunham
His Attorney.

Patented Sept. 13, 1938

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# UNITED STATES PATENT OFFICE

2,130,272

## PIEZOELECTRIC CRYSTAL OSCILLATOR

Warren A. Ford, Schenectady, N. Y., assignor to General Electric Company, a corporation of New York

Application March 31, 1938, Serial No. 200,191

7 Claims. (Cl. 250—36)

My invention relates to electric valve oscillators and more particularly to a piezo electric crystal controlled electric valve oscillator.

Vacuum tube oscillators are commonly provided with a piezo electric crystal which acts as a control element to maintain the frequency of the oscillator substantially constant during operation. Such crystals are subjected during normal operation of the oscillator to high voltages, and, at times, to physical vibration and jars which cause the crystal to crack, chip, or otherwise to break down electrically and thereby to become inoperative and incapable of performing their intended function. It is preferable at such times that the oscillator shall continue after break down of the crystal to perform with as nearly an unimpaired operation as possible.

It is an object of my invention to provide a crystal controlled oscillator which is capable of a high degree of operability after break down of the controlling crystal.

A further object of my invention is to provide a crystal controlled oscillator having extreme stability with the advantages of simplicity and unusual reliability.

A further object of my invention is to provide an oscillator operating, under control of a crystal, with a principle of operation quite similar to that of a dynatron oscillator and one which therefore performs with a high degree of uniformity.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims. My invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawing in which Fig. 1 illustrates an embodiment of my invention; Fig. 2 illustrates graphically an operating characteristic of this embodiment; and Fig. 3 illustrates my invention in a modified form.

Referring more particularly to Fig. 1 of the drawing, my invention is illustrated as embodied in an oscillator used to supply energy to an output or load circuit 10, 11 through a transformer 13. The transformer has a primary 14 which is connected, with a condenser 15, in a parallel-tuned oscillatory circuit. A grid 16 of the electron discharge device 17 is connected through the oscillatory circuit 14, 15 to the positive terminal of a source of high potential 18, the negative terminal of which is connected to the cathode 19. A condenser 20, connected across the terminals of the high voltage source 18, maintains the positive terminal at ground potential for oscillations of the frequency of the oscillatory circuit 14, 15.

The electron discharge device 17 is provided with an anode 21 which is connected by a conductor 22 to a point on the high voltage source 18 of a potential lower than that supplied to the grid 16. A condenser 23 maintains the anode 21 at ground potential for oscillations of the frequency of the oscillatory circuit 14, 15.

A second grid 24 of the electron discharge device 17 is negatively biased from a source of potential 26 through a high resistor 25, the resistor being provided to maintain the grid 24 above ground potential for oscillations of the frequency of the oscillatory circuit 14, 15. A third grid 27 provided in the electron discharge device 17 is connected directly to the cathode 19.

My oscillator in operation is under control of a resonant device or circuit having a constant frequency characteristic. The resonant device may, for example, take the form of a piezo electric crystal 29 which is connected between the grid 16 and the grid 24 of the electron discharge device 17 to control the operation of the oscillator in a manner now to be explained.

Assume that the oscillatory circuit 14, 15 is tuned substantially to the natural frequency, or a desired harmonic frequency, of the crystal 29. A rise in the voltage across the oscillatory circuit 14, 15, is then transmitted by the crystal 29 to the grid 24 which, being maintained by the resistor 25 above ground potential for alternating currents, thereupon has its potential made less negative. The grid 24 is physically positioned between the grid 16 and the anode 21 and, being negative with respect to both the grid 16 and the anode 21, normally operates to repel and turn back some of the electrons which have passed from the cathode 19 through the grid 16. These repelled electrons are attracted to the grid 16. When the grid 24 is made less negative by a potential transmitted through the crystal 29, fewer electrons are turned back by the grid 24, fewer electrons are therefore available to be attracted to the grid 16 and the current of the grid 16 thereupon decreases. It will thus be evident that an increase of potential across the oscillatory circuit 14, 15 results in a decrease in the current flowing through this circuit to the grid 16. This negative resistance characteristic exhibited by the electron discharge

device 17 is conducive to and results in sustained oscillations in the oscillatory circuit 14, 15.

Consider now the effect on this operation of the piezo electric crystal 29. The crystal has a sharply peaked transmission characteristic at its natural frequency and a similar though minor transmission characteristic at each of its harmonic frequencies. The potential drop across the crystal is thus a minimum for an oscillating potential having a frequency substantially that of the natural frequency, or a harmonic frequency, of the crystal but is comparatively high for oscillating potentials of other frequencies. It will then be clear that the crystal 29 transmits a maximum voltage from the oscillatory circuit 14, 15 to the grid 24 when the oscillatory circuit 14, 15 is resonant at a frequency substantially that of the crystal or a harmonic thereof. Conversely, decreasing values of oscillatory potentials are impressed upon the grid 24 as the oscillatory circuit 14, 15 is detuned away from the natural frequency of the crystal 29. This results in a tendency of the oscillator to lock in step with and oscillate at the frequency of the crystal 29 whenever the oscillatory circuit 14, 15 is tuned closed to the frequency of the crystal since, in this condition of operation, the oscillatory voltage transmitted through the crystal 29 to the grid 24 attains a maximum value.

Fig. 2 illustrates graphically the operating characteristic of my invention in the embodiment shown in Fig. 1. This is a graph of the frequency departure in cycles of the oscillator output frequency from the natural frequency of the crystal, which in this case was 4206 kc., as the condenser 15 was varied from its minimum setting to its maximum setting. It will be seen from this graph that the oscillator frequency remains substantially unchanged while the condenser is varied from 53 mmf. to 98 mmf., the frequency departure throughout this range varying from 1300 to 1400 cycles, a frequency departure of only .03 percent. The piezo electric crystal 29 lost control when the condenser 15 was varied beyond the limits of 53 mmf. and 115 mmf., an adjustment to a capacity slightly less than 53 mmf., causing the output frequency immediately to jump to an oscillating frequency of 5400 kc. while an adjustment to a capacity slightly more than 115 mmf., resulted in the oscillatory circuit 14, 15 breaking into oscillation at a frequency 3560 kc. The proper operating frequency of an oscillator having the operating characteristics here shown is perhaps within the range between a condenser setting of 98 mmf. and 108 mmf. A failure of the piezo electric crystal 29 when the setting is within the range mentioned results, as explained above, only in a slight shift in the oscillator frequency to a new frequency determined by the particular tuning of the oscillatory circuit 14, 15.

The grid 27 is directly connected to the cathode in the arrangement of Fig. 1 and, as thus connected, has no effect on the operation of the oscillator.

A modification of my invention is shown in Fig. 3 wherein elements corresponding to like elements of Fig. 1 are designated by like reference characters. In this modification, the crystal 29 of Fig. 1 has been replaced by a series resonant circuit comprised by the condenser 30 and inductance 31. The oscillatory circuit 14, 15 is tuned to a frequency determined by the values of capacity and inductance in the condenser 30 and inductance 31 respectively. The series resonant circuit 30, 31 preferably is sharply resonant at the desired frequency chosen for the operation of the oscillator and controls the operation by controlling the feed back potential from the oscillatory circuit 14, 15 to the grid 24 in the same manner as does the crystal 29 of Fig. 1. The condenser 30 and inductance 31 are preferably enclosed in an atmosphere maintained under constant conditions of temperature and humidity.

In this modification the grid 27 is shown as provided with a small negative bias from a source of biasing potential 28. The effect in providing this grid with a negative bias is that the grid now controls the magnitude of the electronic flow from the cathode and thereby controls the magnitude of the effect produced by the other elements of the electron discharge device 17 during the operation of the oscillator.

The operation of the Fig. 3 embodiment of my invention is the same as that of Fig. 1 and will, therefore, not be explained in detail.

My oscillator arrangement has the very desirable advantage that should a piezo electric crystal be used as a controlling element and should the crystal break down or become inoperative, the oscillator continues to oscillate at substantially its former frequency. This desirable operation is the result of a certain amount of the oscillatory potential from the circuit 14, 15 being transmitted to the grid 24 through the inherent capacity existing between the elements of the crystal holder and associated wiring. The magnitude of the potential thus capacitively transmitted to the grid 24 may be regulated by the size and arrangement of the elements of the crystal holder and associated wiring. This operating characteristic of my oscillator is especially to be desired in certain types of service as, for example, in aircraft communication where consistent communication between a plane and ground is of utmost importance.

While I have shown a particular embodiment of my invention, it will of course be understood that I do not wish to be limited thereto since many modifications may be made both in the circuit arrangement and in the instrumentalities employed, and I therefore contemplate by the appended claims to cover any such modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. A vacuum tube oscillator comprising, in combination, an electron discharge device having an anode, a cathode, and a plurality of grids, a tunable frequency determining network connected between a first of said grids and said cathode, means included in said connection for impressing a positive potential on said first named grid, means for impressing a negative potential on a second of said grids, means for impressing a positive potential on said anode of a value less than that on said first named grid, and means for producing sustained oscillations in said tunable network, said last named means including means resonant at a predetermined frequency for supplying an alternating current potential of substantially said predetermined frequency from said first named grid to said second named grid.

2. An oscillator comprising, in combination, an electron discharge device having an anode, a cathode, a first grid, and a second grid positioned between said first grid and said anode, a tunable oscillatory circuit connected between said first named grid and said cathode, means included in

said connection for impressing a positive potential on said first named grid, means for impressing a negative potential on said second named grid, means for impressing a positive potential on said anode, said anode potential being less than that impressed on said first named grid, an output circuit associated with said oscillatory circuit, and means for producing sustained oscillations in said tunable oscillatory circuit, said last named means including frequency responsive means resonant at a fundamental and one or more harmonic frequencies for supplying an alternating current potential of substantially the fundamental or harmonic frequency determined by said frequency responsive means from said first named grid to said second named grid.

3. The combination, in a vacuum tube oscillator, of an electron discharge device having physically spaced in the order named an anode, a first grid, a second grid, a third grid, and a cathode, a tunable frequency determining network connected between said second grid and said cathode, means in said connection for impressing a positive potential on said second grid, means for impressing a negative potential on said third grid, means including an impedance connected between said first grid and said cathode for impressing a negative potential on said first grid, means for impressing a positive potential on said anode, said anode potential having a value less than the potential supplied to said second grid, means resonant at a fundamental frequency, and means including said last named means for supplying an alternating current potential of substantially said fundamental frequency from said second grid to said first grid.

4. A vacuum tube oscillator comprising, in combination, an electron discharge device having spaced in the order named an anode, a first grid, a second grid, and a cathode, a resistor connecting said first grid to said cathode, means included in said connection for biasing said first grid negatively, a tunable oscillatory circuit connected between said second grid and said cathode, means included in said last named connection for impressing a positive potential on said second grid, means for impressing a positive potential on said anode, said anode potential having a value less than the potential on said second grid, a series resonant circuit having a fundamental frequency, and means including said series resonant circuit for supplying an oscillatory potential having substantially said fundamental frequency from said second grid to said first grid whereby sustained oscillations are produced in said tunable oscillatory circuit.

5. The combination, in an electric valve oscillator, of an electron discharge device having an anode, a cathode, and a plurality of grids, a tunable frequency determining network connected between a first of said grids and said cathode, means included in said connection for impressing a positive potential on said first grid, means for impressing a negative bias on a second of said grids, means for impressing a positive potential on said anode of a value less than the positive potential on said first named grid, and means for producing sustained oscillations in said frequency determining network, said last named means including a piezo electric crystal for supplying an oscillatory potential from said first named grid to said second named grid.

6. A vacuum tube oscillator comprising, in combination, an electron discharge device having physically spaced in the order named an anode, a first grid, a second grid, and a cathode, a resistor connected between said first grid and said cathode, means included in said connection for biasing said grid negatively, a parallel-tuned circuit connected between said second grid and said cathode, means included in said last named connection for impressing a positive potential on said second grid, means for impressing a positive potential on said anode, said anode potential having a value less than the potential of said second grid, and means including a piezo electric crystal having a natural frequency substantially that of said parallel-tuned circuit for supplying an alternating current potential from said second grid to said first grid.

7. A vacuum tube oscillator comprising, in combination, an electron discharge device having physically spaced in the order named an anode, a first grid, a second grid, and a cathode, a resistor connected between said first grid and said cathode, means included in said connection for biasing said grid negatively, a parallel-tuned circuit connected between said second grid and said cathode, means included in said last named connection for impressing a positive potential on said second grid, means for impressing a positive potential on said anode, said anode potential having a value less than the potential of said second grid, and means including a piezo electric crystal having a harmonic frequency substantially equal to the frequency of said parallel-tuned circuit for supplying an alternating current potential from said second grid to said first grid.

WARREN A. FORD.