

Feb. 14, 1939.

M. S. MEAD, JR

2,147,492

OSCILLATION GENERATOR

Filed Oct. 17, 1935

2 Sheets-Sheet 1

Fig. 1.

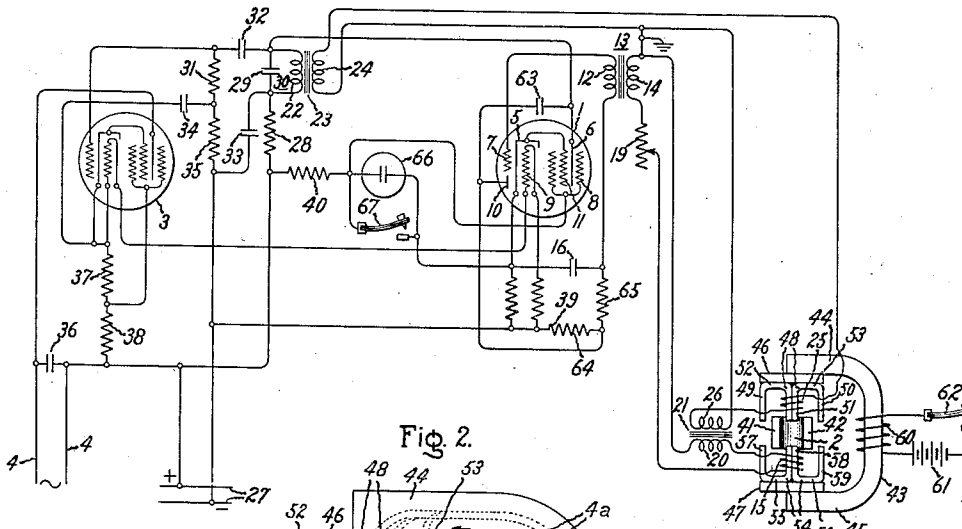


Fig. 2.

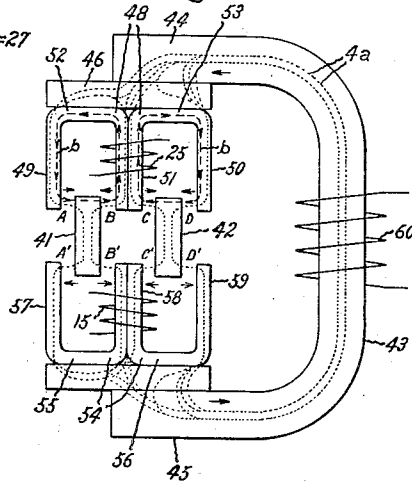


Fig. 4.

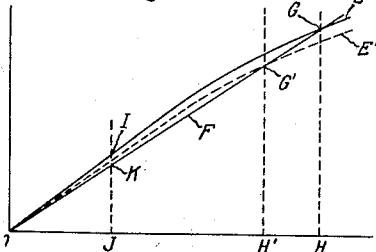
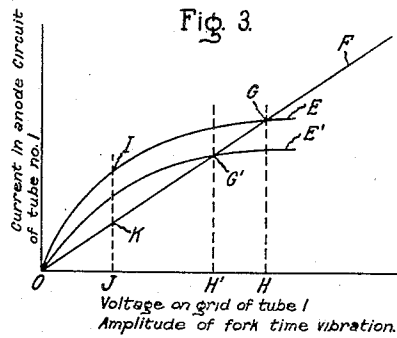


Fig. 3.



Inventor:
Milton S. Mead, Jr.,
by *Harry E. Dunham*
His Attorney

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2 Sheets-Sheet 2

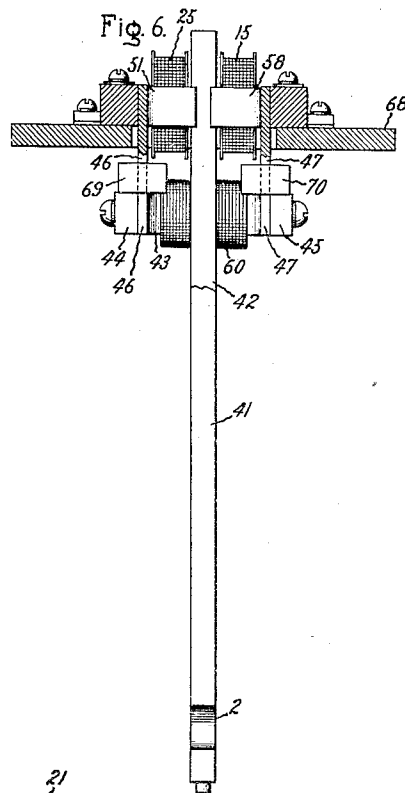
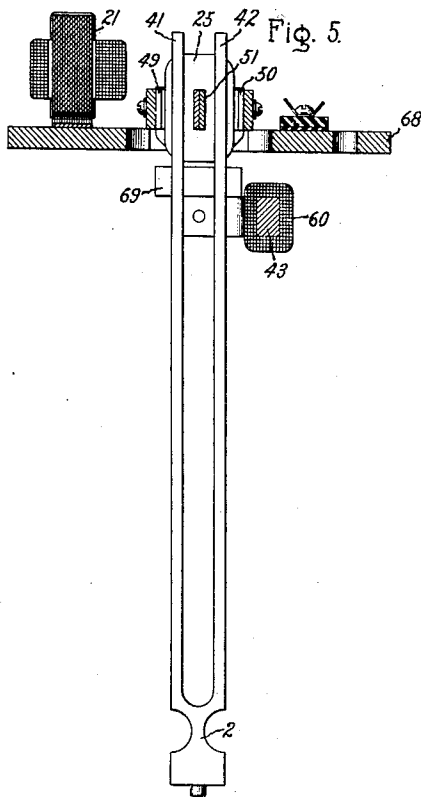
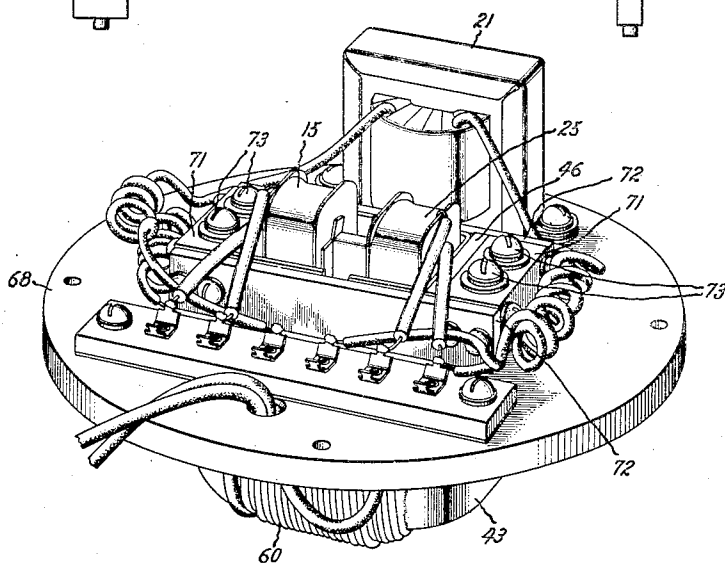


Fig. 7



Inventor:
Milton S. Mead, Jr.,
by *Harry E. Dunham*
His Attorney.

UNITED STATES PATENT OFFICE

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OSCILLATION GENERATOR

Milton S. Mead, Jr., Schenectady, N. Y., assignor
to General Electric Company, a corporation of
New York

Application October 17, 1935, Serial No. 45,379

14 Claims. (Cl. 250—36)

My invention relates to oscillation generators, and more particularly to oscillation generators employing an electron discharge control tube and including a frequency determining system of the mechanically vibratory type.

In certain applications it is necessary to employ oscillators having an output frequency which remains substantially constant over long periods of time and under all operating conditions. One such application is that of clock supervisory systems wherein an oscillator is used to control the frequency of the current supplied to drive the clocks connected in the system. Oscillators adapted for this purpose usually include a mechanically vibratory element as, for example, a tuning fork, having drive and pick-up coils associated therewith; which coils are respectively coupled to the output and input circuits of an electron discharge amplifier and are so arranged that vibration of the element controls the amplifier to produce sustained oscillations in the output circuit thereof. In this type of oscillator a portion of the energy developed in the amplifier output circuit is supplied to the drive coil for the vibratory element to maintain the element in sustained vibration.

It is an object of my invention to provide an oscillation generator of the above-described type which is of improved construction, which is quick starting and which is capable of producing oscillations of extremely constant frequency under all operating conditions and for long periods of time.

It has been found in oscillation generators of the above type that the frequency of the generated oscillations varies in accordance with the amplitude of vibration of the vibratory element. It has further been found that the amplitude of vibration of the vibratory element varies in accordance with the magnitude of current supplied to the drive coil from the output circuit of the electron discharge tube amplifier. It is therefore necessary to provide a suitable means for maintaining substantially constant the intensity of the alternating current supplied to the drive coils if rigid frequency regulation is to be obtained.

In accordance with my invention, the intensity of current supplied to the drive coils of the vibratory element is maintained substantially constant by the provision of a circuit arranged to supply a biasing potential to the amplifier tube control grid which varies in accordance with the magnitude of current in the amplifier output circuit, thereby to maintain the magnitude of current flowing

in the amplifier anode circuit substantially constant.

In oscillators of the above general arrangement it has been found to be desirable to employ a screen grid tube as the amplifier control element. The presence of the extra grid prevents undesired interelectrode coupling between the control grid and anode of the tube. In this type of tube, the magnitude of positive potential supplied to the screen grid determines in large part the amplitude of the current flowing in the anode circuit of the tube. Since the desirability of maintaining this current substantially constant, thereby to maintain the magnitude of current traversing the drive coil constant has been previously pointed out, it will be seen to be desirable to maintain the magnitude of screen grid potential substantially constant.

An additional object of my invention is to provide, in an oscillation generator of the character stated, means comprising a circuit connected to supply a bias potential to the control grid of the amplifier which varies in accordance with the magnitude of current in the amplifier anode circuit for maintaining substantially constant the magnitude of current supplied to the drive coils of the vibration element, thereby to maintain the amplitude of vibration of the element substantially constant.

A still further object of my invention is to provide in an electron discharge oscillator having a mechanically vibratory frequency determining element and including an electron discharge tube having an auxiliary screen grid, means for maintaining substantially constant the value of the potential impressed on the auxiliary grid.

It is extremely difficult to maintain the sensitivity of the coupling amplifier between the drive and pickup coils sufficiently stable to eliminate all variations in the amplitude of vibration of the mechanically vibratory element. In certain types of oscillators known to the art such sensitivity variations are accompanied by a disproportionately greater variation in the amplitude of vibration of the fork tines. By providing a circuit for supplying a biasing potential to the control grid which varies in accordance with the intensity of current in the output circuit, an arrangement is obtained wherein unavoidable variations in the sensitivity of the amplifier are accompanied only by a proportionate change in the amplitude of vibration of the fork tines. In other words, the relation between changes in the amplitude of vibration and changes in amplifier

sensitivity is linear which, of course, represents the smallest obtainable frequency variation for a given amplifier sensitivity change.

Accordingly, a still further object of my invention is to provide an oscillation generator of the type including a frequency determining element comprising a vibratory element in which a substantially linear relation exists between variations in the sensitivity of the amplifier and variations in the amplitude of vibration of the element.

One conventional form of tuning fork oscillator includes means for producing a unidirectional flux which traverses the field structure of the pick-up coil; which flux is varied in intensity during vibration of the fork tines to generate a control potential between the terminals of the pick-up coil. The unidirectional flux may thread the tines of the fork, whereby the stiffness of the fork is altered and the natural period of vibration of the fork tines is changed. In the embodiment of my invention to be described hereinafter the above-mentioned means comprises a permanent magnet which is magnetically connected to the field structure upon which the drive and pick-up coils are wound. It is desirable to employ an arrangement wherein the intensity of the unidirectional flux may be easily varied thereby to change the stiffness of the fork tines and to produce a change in the frequency of vibration thereof. It is further desirable to provide such an arrangement in which the intensity of the unidirectional flux is maintained substantially constant following an adjustment thereof and during operation of the oscillator. In accordance with my invention, the intensity of the unidirectional flux may be varied at will by bucking or boosting the magnetization of the permanent magnet which produces this flux. Uniform intensity is obtained by providing conductors closed circuited on the unidirectional flux path in such a manner that instantaneous changes in the flux intensity are opposed.

It is a further object of my invention to provide in combination with a tuning fork controlled oscillator having the previously described characteristics, improved means for varying the intensity of the unidirectional flux threading the fork tines thereby to vary the stiffness of the fork and the rate of vibration of the fork.

It is a still further object of my invention to provide means associated with the field structure of the frequency determining element for opposing instantaneous changes in the intensity of the unidirectional flux traversing the magnetic circuit provided for this flux.

It has been found that magnetic coupling between the drive and pick-up coils produces voltages in the two coils which cause fundamental and harmonic forces to be set up which influence the vibration of the fork tines. These forces cause the tines to vibrate in such a manner that harmonics are developed in the control potential between the terminals of the pick-up coil. In accordance with my invention, the above-noted undesired features are obviated by loosely coupling the drive and pick-up coils and by providing a transformer having windings connected respectively to the drive and pick-up coil circuits to produce voltages which neutralize the voltages developed by the coupling between the two coils. In this manner undesired forces acting on the fork tines are eliminated and the tines are permitted to vibrate at a frequency determined by the natural period of the fork.

An additional object of my invention is to provide an oscillator controlled by a vibratory system which includes loosely coupled drive and pick-up coils magnetically associated with a vibratory element, and means connected in circuit with the coils for neutralizing potentials generated in either coil due to the coupling between the coils, whereby the voltage generated in the pick-up coil is produced solely by vibration of the vibratory element to vary the unidirectional flux linking the turns of the pick-up coil.

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 the method of operation, together with further objects and advantages thereof, will best be understood by reference to the following specification, taken in connection with the accompanying drawings, in which Fig. 1 illustrates an improved circuit arrangement for an oscillator having my invention embodied therein; Fig. 2 is an enlarged view of an element of the apparatus shown in Fig. 1 illustrating the flux paths in the tuning fork field structure; Fig. 3 illustrates certain of the operating characteristics of my improved oscillator; Fig. 4 illustrates the corresponding characteristics of oscillators typical of the prior art; Figs. 5 and 6 are side views partially in section showing the details of my improved fork field structure assembly; and Fig. 7 is a view in elevation showing the details of the tuning fork control mechanism.

Referring to Fig. 1 of the drawings, I have shown my improved oscillation generator as comprising an amplifier including a tube 1 which is controlled by a vibratory element 2 to generate electrical oscillations having a frequency determined by the frequency of vibration of the element 2. The vibratory element 2 is shown as a tuning fork, although it will be understood that other forms of mechanically vibratory elements may be employed without modification of the circuit illustrated. The output from the tube 1 is impressed on the input circuit of a second amplifier tube 3 which in turn has its output circuit coupled to a utilization circuit (not shown) by the leads indicated at 4.

The electron discharge tube 1 is shown as being of the single diode pentode type and includes a cathode 5, an anode 6, a control grid 7, a screen grid 8, a cathode heater 9, a diode electrode 10, and a suppressor grid 11; the latter grid being directly connected to the cathode 5 and functioning to prevent secondary electron emission within the tube. The electron discharge tube 3 is similar in all respects to the tube 1 with the exception that the single diode electrode is omitted.

The input circuit to the amplifier tube 1 includes the secondary 12 of a coupling transformer 13 having its primary 14 connected to a pick-up coil 15 wound on the field structure of the tuning fork 2. The input circuit is connected between the control grid 7 and the cathode 5 of the discharge device 1 through an alternating current by-pass condenser 16. In order to adjust the phase angle between the current supplied to the tuning fork drive coil and the voltage developed across the terminals of the pick-up coil 15, thereby to adjust the frequency of vibration of the fork tines, an adjustable resistance 19 is connected in the circuit connecting the pick-up coil 15 and with the primary winding 14. One winding 20 of a transformer 21 is also included in this circuit for a purpose to be described hereinafter.

The output circuit of the amplifier includes the primary winding 22 of a coupling device 23 having its secondary winding 24 connected to excite a fork drive coil 25 through a second winding 26 of the transformer 21. The winding 22 is connected between the anode 6 and the cathode 5 of the device 1 in series with a source of high voltage direct current potential 27 and a resistance 28. A condenser 29 is connected in shunt with the winding 22 and functions to tune the inductance of the winding to form an oscillatory circuit 30 having a resonant frequency equal to the normal operating frequency which the apparatus is designed to produce.

The potential developed across the terminals of the oscillatory circuit 30 is impressed upon a resistance 31 connected to the oscillatory circuit by a pair of alternating current by-pass condensers 32 and 33, included in the input circuit of the tube 3. The resistance 31 is connected between the control grid and cathode of the discharge device 3 through a by-pass condenser 34. A resistance 35 connected at one end to the negative side of the voltage source 27 serves to bias the control grid of the tube 3 negative with respect to the cathode thereof.

The output circuit of the discharge device 3 includes the leads 4 connected respectively to the anode and cathode of the device 3 and shunted by the tuning condenser 36. A source of anode voltage comprising the potential drop across a pair of series-connected resistances 37 and 38 is also included in the output circuit between the cathode of the tube 3 and one terminal of the condenser 36.

A cathode heater circuit for the tubes 1 and 3 is provided which includes the respective heaters of the two tubes connected in series with each other and in series with voltage dropping resistors 37, 38, and 39 across the high voltage source 27. A positive potential is supplied to the screen grid of the tube 3 through a circuit which includes the voltage-dropping resistor 38. This resistor serves to maintain the screen grid at a positive potential slightly lower than the positive potential of the anode of the device 3. In similar manner, a biasing potential is impressed on the screen grid of the tube 1 through the circuit lead which includes a voltage dropping resistor 40.

The vibratory frequency determining unit for controlling the amplifier system described in the preceding paragraphs includes the tuning fork 2 having tines 41 and 42 and a field structure upon which the drive and pick-up coils are wound. This field structure comprises a U-shaped permanent magnet 43 having a pair of legs 44 and 45. A magnetic member 46 is electromagnetically connected at one end to the end of the leg 44 and a like member 47 is connected in similar manner to the leg 45. Electromagnetically connected to the other end of the member 46 is a three-legged core structure 48 having outer legs 49 and 50 and a central leg 51 upon which the drive coil 25 is wound. As shown, the core 48 consists of a pair of U-shaped members 52 and 53 mounted side by side with their base portions connected to the free end of the member 46 and their legs extending inward toward the leg 45 of the magnet 43. An identical three-legged core 54 comprising two U-shaped members 55 and 56 is electromagnetically connected to the free end of the member 47 with its three legs 57, 58 and 59 extending toward and in alignment with the legs 49, 51 and 50 of the core 48. The pick-up coil 15 is wound on the

center leg 58 of the core 43 in the manner indicated.

In order better to illustrate the details of the fork field structure and to show the flux paths through the magnetic circuit formed by the structure, reference may be had to the enlarged view of Fig. 2. As shown, the tines 41 and 42 of the tuning fork 2 are disposed within and between the legs of the cores 48 and 54. It will be observed that with the tines 41 and 42 in unstressed condition between the pole faces formed by the ends of the legs 49, 51, 50, 57, 58, and 59, an air gap is provided between each of the leg ends and a side of an associated tine. Thus, the pole face formed by the end of the leg 49 is displaced from the upper left side of the tine 41 by an air gap A; the end of the leg 51 is displaced from the tines 41 and 42 by gaps B and C respectively, and the end of leg 50 is displaced from the tine 42 by a gap D. In like manner gaps A', B', C', and D' are formed between the lower sides of the tines 41 and 42 and the ends of the legs 57, 58 and 59. The unidirectional flux produced by the permanent magnet 43 is indicated by dotted lines 4a and it will be seen that this flux traverses the members 46 and 47, and the gaps A, B, C, D, A', B', C', D' and divides between the legs 49, 50 and 51 and the legs 57, 58, and 59 in accordance with the relative lengths of the air gaps on either side of the tines 41 and 42. Thus, with the tine 41 in its unstressed position midway between the pole faces formed by the ends of the legs 49 and 50 and the legs 57 and 58, the air gaps A, B, A', and B' are all equal in length and the unidirectional flux will be divided equally between the series-related legs 49 and 57 and the series-related legs 50 and 59. This, of course, means that in this position of the tines the flux density in the gaps A, A', B and B' is the same and the net force acting on the tine 41 is zero. The isolated arrows indicate the direction of the unidirectional flux and show that the flux traversing the gaps A and B' is opposite in direction to the flux traversing the gaps A' and B. In like manner, the unidirectional flux traverses the gaps C and D' in a direction opposite to the direction of the flux in the gaps C' and D.

Operation of the above-described apparatus may be initiated by impressing a current impulse on the drive coil 25. Such an impulse produces a flux which may be assumed to traverse the paths in the core structure comprising the legs 49, 50, and 51 in the direction indicated by the arrows on the ends of the dash lines b. It will be observed that this flux traverses the gaps A and B in one direction and the gaps C and D in an opposite direction. The effect of this flux in the gaps A and D is to boost the unidirectional flux thereby to increase the flux density in these gaps. The simultaneous effect of the flux in gaps B and C resulting from the impulse of starting current is to buck down the unidirectional flux in these gaps thereby to decrease the flux density therein. It will be seen that increasing the flux density in gaps A and D while simultaneously decreasing the flux density in gaps B and C results in an unbalance of the forces acting on the fork tines 41 and 42 in such a direction that the tines expand outward toward the outer legs 49 and 50. As the tines expand outward, the reluctance of the gaps B, B' and C, C' is increased thereby causing the unidirectional flux traversing the legs 51 and 58 to be decreased and the unidirectional flux traversing the legs 49, 50, 57, and 59 to be increased. A decrease in the flux in the leg 58 causes a feeble

impulse of electromotive force to be generated in the pick-up coil 15 due to the decrease in the number of flux lines linking the turns of the coil.

5 The impulse of electromotive force generated across the terminals of the pick-up coil is impressed on the control grid 7 of the tube 1 through the coupling transformer 13 and causes an impulse of current to flow in the output circuit of the tube. A portion of the impulse of energy developed in the output circuit is delivered to the drive coil 25 through the transformer 23 and causes a current impulse to flow in the winding 25 in a direction opposite to the direction of current flow of the initial current impulse. This produces a flux which traverses the gaps A, B, C and D in directions such that the forces acting on the tines 41 and 42 cause the tines to contract thereby to increase the flux traversing the leg 58 and to cause a voltage impulse to be generated in the pick-up coil 15 having a sign opposite to that caused by the expansion of the tines. This impulse of voltage exerts a controlling effect on the tube 1 such that the instantaneous current flowing in the output circuit thereof is reversed in direction for the duration of the impulse. The interaction between the fork vibration and amplifier is cumulative, the amplitude of vibration of the fork tines increasing until a condition of equilibrium is reached when the fork is vibrated at a substantially constant frequency determined by the amplitude of alternating current in the drive coil 25, the intensity of the unidirectional flux, and by the natural period of vibration of the fork. After the point of stable operation is reached and during normal operation of the apparatus, an alternating control voltage is generated across the terminals of the pick-up coil 15 by the change in flux density of the flux in the leg 58 caused by the shifting of the flux between the central and outer legs during vibration of the fork tines 41 and 42.

It will of course be understood that the alternating potential developed across the terminals of the primary winding 22 is impressed on the input circuit of the amplifier tube 3 through the coupling condensers 32 and 33. This potential controls the operation of the amplifier 3 in a manner well understood in the art to cause the same to generate an amplified alternating voltage across the output leads 4, 4 having a frequency determined by the frequency of vibration of the fork tines 41 and 42.

In order to increase or decrease the rate of vibration of the fork tines 41 and 42, a means is provided whereby the intensity of the unidirectional flux may be controlled thereby to control the negative compliance, or stiffness of the fork tines. This means comprises a winding 60 on the permanent magnet 43 which is connected in series with a battery 61 and a switch 62. If it be desired to increase the intensity of the unidirectional flux traversing the air-gaps within which the fork tines vibrate thereby to increase the stiffness of the tines and to decrease the rate of vibration, it is only necessary to close the switch 62 to boost the magnetization of the permanent magnet to the correct value. Following an increase in the magnetization of the magnet 43, the switch 62 may be opened and the fork tines will continue to vibrate at the newly determined rate. Conversely, if it be desired to increase the rate of vibration, the polarity of the battery 61 may be reversed and the magnetization of the permanent magnet 43 bucked down to a lower value.

It is desirable to neutralize the effect of voltages generated in the drive and pick-up coils due to the inductive coupling between the two coils. Such voltages are reduced to a minimum by loosely coupling the two coils and by providing a field structure in which a large leakage reactance is obtained between the individual magnetic circuits of the two coils. In accordance with one feature of my invention, effective neutralization of the small voltages generated by such inductive coupling is obtained by the provision of the transformer 21 having its windings 20 and 26 connected respectively in the pick-up and drive coil circuits. The windings are connected in a manner such that a potential is introduced in either of the two circuits which is opposite in phase to a potential generated by the coupling between the windings 15 and 25 and is equal in magnitude to the voltage produced by such coupling. To illustrate in detail the function of the transformer 21, let it be assumed that alternating current in the drive coil 25 generates an undesired voltage in the pick-up coil 15. This current traverses the winding 26 thereby to generate a voltage in winding 20 which is opposite in phase to the voltage generated in the coil 15. By providing the transformer 21 with the correct turn ratio between windings 20 and 26, the neutralizing voltage across coil 26 will be equal in magnitude to the voltage in coil 15. In the above manner, effective neutralization is obtained which eliminates stray currents in the pick-up coil circuit that might adversely affect the controlling action of the voltage developed across the terminals of the coil.

It is well known that the frequency of the output current of a tuning fork is dependent upon the amplitude of vibration of the fork tines. It is also known that the amplitude of vibration of the tines is influenced by the magnitude of current supplied to the drive coil of the fork. It will be seen, therefore, that it is desirable to provide an arrangement wherein the magnitude of the current in the output circuit of the controlled amplifier, from which circuit the current flowing through the drive coil is derived, be maintained as nearly constant as possible.

It has been found that unavoidable sensitivity changes occur in the control amplifier which produce changes in the average anode circuit current for a given potential on the control grid of the amplifier. In other words, the plate current-grid voltage characteristic curve is displaced each time the sensitivity of the amplifier changes. Such sensitivity changes may result from a number of causes such as fluctuations in the voltage of the cathode and anode energy supply source and changes in the tube characteristics. It is desirable to provide a control amplifier in which such changes in sensitivity produce the smallest obtainable change in current amplitude in the output circuit for, as is noted above, such changes produce a change in the amplitude of vibration of the fork tines and an attendant change in the output frequency of the oscillator. If an amplifier be employed having the above operating characteristics, the frequency shift for a given amplifier sensitivity change is considerably minimized.

In accordance with my invention, the above-noted desired operating features are obtained by providing a circuit for supplying a biasing potential to the control electrode 7 of the tube 1 which varies in accordance with the intensity of current flowing in the output circuit connected between the anode 6 and the cathode 5. This circuit functions to maintain substantially constant the

anode current and, in addition, operates to insure a linear relation between changes in the amplitude of fork vibration and variations in the sensitivity of the amplifier. The automatic biasing circuit comprises a diode formed by the element 10 and the cathode 5 of the tube 1, a coupling condenser 63, and resistances 64 and 65.

The above-described circuit operates to exert a controlling influence on the amplifier in the following manner: During normal operation of the oscillator the alternating potential existing between the cathode and anode of the tube 1 is impressed across the element 10 and the cathode 5 by means of the coupling condenser 63. A unidirectional current flows between the two elements noted, thereby to develop a unidirectional electromotive force which is impressed on the resistance 64 connected across the tube elements 5 and 10. The potential developed across the resistance 64 is impressed on the control electrode 7 through the resistance 65 and the secondary 12 of the coupling transformer 13. It will be seen that the potential drop across the diode of the tube 1 corresponds to the drop across the terminals of the anode circuit and, accordingly, is proportional to the intensity of current flowing in the anode circuit. This, of course, means that the biasing potential impressed on the control grid 7 of the tube 1 by means of the resistance 64 varies with, and in proportion to, the magnitude of current flowing in the anode circuit of the amplifier. The controlling effect of this biasing potential is such that as the anode circuit current starts to increase a negative bias is impressed on the control grid 7 which tends to reduce the anode current. Conversely, if the value of the anode circuit current starts to decrease, the negative bias is reduced, thereby to permit an increased current flow in the anode circuit of the apparatus. In this manner, variations in the magnitude of current in the circuit are minimized which, of course, means that fluctuations in the current supplied to the drive coil 25 are lessened. Although I have described the automatic biasing circuit in its preferred form as including a diode formed within the tube 1, it will of course be understood that an additional tube may be employed and that various modifications of the circuit may be made which will operate in a satisfactory manner.

The desirability of using a thermionic tube 1 having a screen grid designed to prevent inter-electrode capacity coupling between the input and output circuits connected to the tube has already been mentioned. Screen grid tubes are ordinarily rendered operative to prevent such undesired capacity coupling by providing a circuit for maintaining the auxiliary grid at a positive potential slightly below that of the anode of the tube. In the circuit arrangement illustrated, this positive potential is supplied to the grid 8 through the circuit lead which includes the voltage dropping resistance 40. It is well known that fluctuations in the magnitude of the positive potential applied to the auxiliary grid produce corresponding fluctuations in the amplitude of current flowing in the anode circuit of the tube.

In accordance with my invention, such fluctuations are minimized by the provision of an electric discharge device 66 which is connected between the screen grid 8 and the cathode 5 and in series with the resistance 40 across the source of potential 27. The device 66 may be an ordinary glow discharge tube of which there are several well-known commercial examples in the art. Briefly,

the tube comprises a pair of spaced apart electrodes positioned within a container filled with an ionizable medium such as neon.

The tube 66 possesses an operating characteristic such that a higher voltage is required to start a glow discharge within the tube than is necessary to maintain the discharge after the tube has once been started. In order to supply a high voltage impulse for starting the tube, a switch 67 is provided having its contacts connected to the terminals of the circuit. When the switch 67 is quickly closed and opened a voltage impulse is developed which is of sufficient magnitude to start a discharge in the tube 66. The impulse is caused by the slight reactance of the impedance element 40 and the reactance of the circuit leads.

When the tube 66 is started, it operates to draw a current which is proportional to the voltage of the source 27. Thus, as the voltage increases the current flowing through the resistance 40 and the tube 66 increases. This increase in current increases the voltage drop across the resistance 40 thereby to maintain the junction point between the screen grid circuit lead, the terminal of tube 66 and the terminal of resistance 40 at the same potential with respect to the cathode 5 as before the change occurred. Conversely, if the voltage of the source 27 decreases, the current through the tube 66 decreases and the potential of the junction point remains unchanged. Thus, by providing the discharge device 66 connected in the manner illustrated fluctuations in the anode current flowing in the output circuit of the amplifiers are minimized, and the magnitude of current supplied to the drive coil 25 is maintained substantially constant.

The desirability of providing the automatic control grid biasing circuit and the voltage regulator 66 in the manner set forth in the immediately preceding paragraphs is emphasized and rendered more clearly understandable by the curves shown in Fig. 3 which illustrate certain of the operating characteristics of my improved oscillation generator. In this figure, the curves E and E' indicate the current flowing in the drive coil 25 as a function of the grid potential on the control grid 7 of the discharge tube 1, and the straight line F illustrates the amplitude of vibration of the fork tines 41 and 42 as a function of the current flowing in the drive coil 25. It will be seen that the curve E is substantially flat along its upper right-hand portion in the region where it intersects the curve F, as at point G. It will be understood that if the current in the anode circuit of the tube 1 be maintained substantially constant so that the characteristic curve E is not shifted from the position shown, the point of intersection G between the curves E and F will remain fixed and the amplitude of vibration of the fork tines will remain absolutely constant. The provision of the voltage regulator 66 and the circuit for supplying a control potential to the control grid 7 which varies in accordance with the intensity of current in the anode circuit of the amplifier 1 tends to maintain this desired stability of the operating point G. However, if for some uncontrollable cause, the sensitivity of the amplifier changes in such a way that the amplifier characteristic curve E is shifted to the position shown in dotted lines at E', the point of intersection G is shifted downwardly along the curve F until the point of stable operation G' is reached. However, due to the flat-topped characteristic of the curves E and E', the change H, H' in the amplitude of fork tine vibra-

tion caused by such a shift of the operating point G is substantially directly proportional to the change in sensitivity of the amplifier. This, of course, means that linear relation exists between a particular variation in the sensitivity of the amplifier and an attendant variation in the amplitude of vibration of the fork tines.

The importance of employing an amplifier having a characteristic curve E with a flat top will be more readily appreciated by reference to Fig. 4 wherein I have shown characteristic curves corresponding to those shown in Fig. 3 for an amplifier typical of those used in connection with oscillation generators now known to the art. In Fig. 4, like reference characters are used to denote characteristic curves corresponding to those of Fig. 3. It will be seen that the curve E is substantially straight throughout its length and that it possesses a slope in the region of point G corresponding to the point of intersection between the curves E and F which closely approaches the slope of the curve F. This means that if the sensitivity of the amplifier changes to shift the characteristic E to a new position E', the operating point G will be shifted a considerable distance along the curve F, thereby producing a change H, H' in the amplitude of fork time vibration which is disproportionately large for the decrease in amplifier sensitivity. By comparing the curves of Fig. 3 with those of Fig. 4, it will be seen that for a given amplifier sensitivity change, the change in amplitude of fork time vibration is substantially less for my improved apparatus. This of course means that the change in the output frequency resulting from such an amplifier sensitivity change is less.

A further advantage attendant upon the use of my improved circuit will be apparent from a consideration of the function of the apparatus during the starting period thereof. Thus, referring again to the curves of Fig. 3, and considering the operation of the apparatus during the starting period, if an impulse of current be generated in the output circuit of the amplifier having a value I, for example, the anode current necessary to produce sustained vibration of the fork tines at an amplitude OJ is JK. The differential of current IK is of considerable magnitude and tends to increase the amplitude of vibration of the tines. However, an increase in the amplitude of vibration produces a coincident increase in the anode current. This differential of current IK produces a cumulative increase in the amplitude of fork time vibration, until the point of intersection G between the curves E and F is reached when the fork tines continue to vibrate with an amplitude OH. The feature of importance to the improved operation of the apparatus is the maintenance of a considerable differential between the anode current flowing in the amplifier output circuit and that necessary to produce an amplitude of vibration corresponding to the current developed. This insures a quick and positive starting of the apparatus and prevents drifting of the operating point G during normal operation of the oscillator.

Considering the curves of Fig. 4 by way of contrast, it will be observed that the curves E and F closely parallel each other and at no time during the starting period when the amplitude of fork time vibration is building up along curve F is there a substantial difference between the anode current developed and the current necessary to produce stable vibration at the amplitude of vibration prevailing at any given instant dur-

ing the starting period. It will further be seen that the two curves intersect at a very small angle. The small current differential between the curves E and F means that the apparatus is sluggish in accelerating to a normal operating condition. The very small angle of intersection between the two curves means poor frequency regulation resulting from a drift in the amplitude of fork time vibration after the normal operating point G is reached.

The desirability of maintaining the intensity of the unidirectional flux produced by the magnet 43 has been previously mentioned. This requirement for satisfactory operation of the apparatus is based on the fact that the intensity of the unidirectional flux determines the stiffness, or negative compliance, of the fork tines which are traversed by this flux. It will be seen that, if during the operation of the apparatus the flux density changes the stiffness of the fork tines will be altered thereby to produce a change in the natural period of vibration of the fork which is accompanied by a change in the output frequency of the generator. It is imperative, therefore, that the intensity of the unidirectional flux be maintained substantially constant at all times during the operation of the oscillation generator.

Referring to Figs. 5 and 6 of the drawings, I have shown side views partially in section illustrating a physical embodiment of my invention in which means are provided for opposing changes in the intensity of the unidirectional flux traversing the field structure of the vibrating system. As shown, the field structure assembly and the transformer 21 are mounted on a supporting plate 68. This plate may form the cover for a thermally insulated container (not shown) within which the tuning fork is mounted. Preferably, the temperature of the fork should be maintained constant to prevent variations in the physical characteristics thereof. An even temperature may be obtained in accordance with the usual procedure by providing thermostatically controlled heating means within the surrounding container.

In order to minimize variations in the intensity of the unidirectional flux produced by the permanent magnet 43, a pair of closed circuited conductors 69 and 70 are provided which surround respectively the field pieces 46 and 47 forming a part of the magnetic circuit of the field structure. The closed circuited conductors 69 and 70 are constructed of nonmagnetic material and, preferably, are formed from small copper blocks provided with openings of sufficient size to accommodate the field pieces 46 and 47. The turns 69 and 70 function to oppose transient changes in the intensity of the unidirectional flux thereby to maintain the flux substantially constant in the desired manner.

This is important since it maintains a constant flux through the magnet notwithstanding vibration of the fork. For example, if we assume an ordinary vibrating reed oscillating in front of a pair of pole pieces of a magnet it will be observed that the flux in the magnet must vary in accordance with the position of the reed. This is undesirable not only because such changes are repugnant to the natural character of the magnet to maintain constant its magnetism, but in addition, equal deflections of the reed in opposite directions produce unequal variations in the flux in the magnet. Thus if a coil be wound on the magnet the electromotive force induced therein is not sinusoidal but is distorted, the amplitude

during positive half cycles being far greater than during negative half cycles. In the device described the unidirectional flux is constant and is maintained so by the arrangement of the fork with respect to the pole pieces as shown and by the heavy conducting rings 69 and 70. Thus the forces applied to the vibratory element and the electromotive force induced in the pick-up coil are more nearly sinusoidal, the undesired harmonic components which otherwise occur being substantially reduced.

In order to permit minor adjustments of the apparatus to be made during the assembly and installation thereof, the tuning fork field structure including the permanent magnet 43 is preferably assembled to form a movable unit in the manner clearly illustrated in the perspective view of Fig. 7 of the drawings. As shown, the field structure is mounted within a rectangular supporting frame comprising a pair of end-pieces 71 and a pair of side pieces 72. The supporting frame is in turn mounted on the plate 68 by stud screws 73 which extend through openings in the end-pieces 71 and are threaded into the cover plate 68. The holes in the end-pieces 71 should be of a diameter slightly larger than the diameter of the stud screws 73, thereby to permit the field unit and the supporting frame to be moved about on the surface of the plate 68. This permits a ready positioning of the field structure to secure the correct lengths of the air gaps A, B, C, D and A', B', C', D' after the vibrating system has been assembled.

From the foregoing description of my improved oscillation generating apparatus, it will be apparent that I have devised an apparatus which is quick starting, which is dependable in operation, and which is equipped to produce at its output terminals an alternating control voltage having a very stable frequency characteristic under all operating conditions. In a specific clock system having my improved oscillation generator embodied therein, the stability and frequency of the generator was such that the deviation in time from the correct time was less than one-tenth of a second over a twenty-four hour period. In addition, my improved apparatus is of simple and economical structure and may be constructed with sufficient mechanical rigidity to withstand hard usage under the most adverse operating conditions.

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 in the circuit arrangement and the structure may be made, and I contemplate by the appended claims to cover all 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. An oscillation generator comprising a vibratory element, an electron discharge device including an anode, a cathode and a control grid, input and output circuits connected to said device, means including a drive coil coupled to said output circuit for vibrating said element, means including a pick-up coil for controlling the frequency of current in said output circuit in accordance with the frequency of vibration of said element, and means for maintaining the amplitude of vibration of said element substantially constant, said last-named means including a circuit for impressing a control potential of said control grid which varies in accordance with the

intensity of current in said output circuit and in such a direction as to reduce the amplification of said electron discharge device when said intensity of output current increases.

2. An oscillation generator comprising a vibratory element, a drive coil for vibrating said element, an electron discharge amplifier connected to energize said drive coil during operation of said generator, said amplifier including an output circuit and a control electrode, a pick-up coil connected to control the frequency of current alternations in said output circuit in accordance with the frequency of vibration of said element, and means for rapidly increasing during the starting period of the generator the amplitude of vibration of said element, said last named means including a circuit for impressing on said control electrode a control potential which varies in accordance with the intensity of current in said output circuit in a direction to reduce the amplification of said amplifier when said intensity of output current increases.

3. An oscillation generator comprising a vibratory element, a drive coil for vibrating said element, an amplifier including an electron discharge device having an anode, a cathode and a control grid, input and output circuits connected to said device, a source of anode potential connected in said output circuit, means for energizing said drive coil in accordance with the alternating current in said output circuit thereby to vibrate said element, means including a pick-up coil coupled to said input circuit for controlling the frequency of current alternations in said output circuit, and means for maintaining a substantially inverse linear relation between variations in the sensitivity of said amplifier and variations in the amplitude of vibration of said element, said last named means including a circuit for supplying a control potential to said control grid which varies in accordance with the amplitude of current in said output circuit.

4. An oscillation generator including a vibratory element, an amplifier, means including a drive coil coupled to said amplifier for vibrating said element, and means for generating a control potential for said amplifier having a frequency determined by the frequency of vibration of said element, said last-named means including a magnetic core having a pair of poles, each pole having a pair of legs, said element being positioned between the legs of both pairs to provide an air gap between each of said legs and said element, said drive coil being mounted on a leg of one of said pairs and said pick-up coil being mounted on a leg of the other of said pairs, and means for producing a unidirectional flux which traverses said legs and extends from one of said poles to the other whereby said unidirectional flux shifts alternately from one leg of each pair to the other during vibration of said element thereby alternately to increase and decrease the flux linking said pick-up coil and generate said control potential.

5. An oscillation generator including in combination, a magnetic core having a pair of poles, each pole having a pair of legs, a pick-up coil on one of said legs of one pole, a vibratory element disposed between said legs of both poles to provide an air gap between each of said legs and said element, means for energizing said core to produce a unidirectional flux which traverses said legs in the same direction and which shifts alternately from one leg of each pair to the other during vibration of said element thereby to gen-

erate an alternating voltage in said coil having a frequency determined by the frequency of vibration of said element, and means for driving said element thereby to vibrate said element at its natural frequency.

6. An oscillation generator including in combination, an amplifier having input and output circuits, a vibratory element, a magnetic core having a pair of poles, each pole having a pair of legs, a pick-up coil on one of said legs of one pole, means for coupling said pick-up coil to said input circuit, said element being disposed between said legs of both poles to provide an air gap between each of said legs and said element, means for energizing said core to produce a unidirectional flux which traverses said legs in the same direction and which shifts alternately from one leg of each pair to the other during vibration of said element thereby to generate an alternating voltage in said pick-up coil having a frequency determined by the frequency of vibration of said element, and means including a drive coil coupled to said output circuit for driving said element to vibrate at its natural frequency.

7. An oscillation generator including in combination, a magnetic core having a pair of poles, each pole having a pair of legs, a pick-up coil on one of said legs of one pole, a vibratory element disposed between said legs of both poles to provide an air gap between each of said legs and said element, means for energizing said core to produce a unidirectional flux which traverses said legs in the same direction and which shifts alternately from one leg of each pole to the other during vibration of said element thereby to generate an alternating voltage in said coil having a frequency determined by the frequency of vibration of said element, means for opposing instantaneous changes in the intensity of said unidirectional flux and means for driving said element thereby to vibrate said element at its natural frequency.

8. An oscillation generator comprising in combination, an amplifier having input and output circuits, a magnetic structure including two U-shaped cores having their legs extending toward each other, a pick-up coil on one of the legs of one of said cores, means for coupling said pick-up coil to said input circuit, a drive coil on one of the legs of the second of said cores, means for coupling said drive coil to said output circuit, said vibratory element being disposed within said legs to provide an air gap between each of said legs and said element, means for energizing said core to produce a unidirectional flux which traverses said legs in the same direction and which shifts between the legs of said one core during vibration of said element thereby to generate an alternating voltage in said pick-up coil having a frequency determined by the frequency of vibration of said element, said legs of said second core being positioned on either side of said element whereby said unidirectional flux traverses the air gaps between said legs and said element in opposite directions, and means including said amplifier for energizing said drive coil to produce an alternating flux which instantaneously traverses said last named gaps in the same direction whereby the flux density in said gaps is alternately increased and decreased in accordance with said alternating flux thereby to produce sustained vibration of said element.

9. An oscillation generator comprising in combination, a vibratory element, a drive coil for vibrating said element, an amplifier including an

electron discharge device having an anode, a cathode, a control grid and a screen grid, input and output circuits connected to said device, a source of anode potential connected in said anode circuit, means for supplying current to said drive coil having a frequency determined by the frequency of the current in said output circuit thereby to vibrate said element, means including a pick-up coil coupled to said input circuit for controlling the frequency of the current in said output circuit, and means for maintaining the intensity of current in said output circuit substantially constant thereby to maintain the frequency of vibration of said element substantially constant, said last-named means including a circuit connected to said screen grid and having a source of potential connected therein, and means connected in said circuit for maintaining substantially constant the potential impressed on said screen grid.

10. In combination, a tuning fork having tines disposed between a pair of pole pieces, each of said pole pieces having three legs, one leg of each pole piece extending between the tines of said fork and the other legs of each pole piece straddling said fork, means to produce a constant magnetic field between said pole pieces and a winding on one leg of each pole piece.

11. In combination, a mechanically vibratory device having an exciting winding and a second winding, an amplifier having an anode, a cathode and a control electrode coupling said second winding and said exciting winding, a source of anode potential and a source of cathode heating current for said amplifier, the amplitude of vibration of said vibratory device being proportional to the magnitude of alternating electromotive force supplied to said exciting winding, means including said amplifier to transmit electromotive force from said second winding to said exciting winding, and means operating independently of variations in said sources to cause the electromotive force supplied to said exciting winding to increase at a progressively diminishing rate with respect to the electromotive force in said second winding during the starting period of said vibratory device, said last named means including a circuit for impressing a potential on said control electrode which varies inversely in accordance with the intensity of current in the anode-cathode circuit of said amplifier.

12. In combination, a mechanically vibratory device having an exciting winding and a second winding, an amplifier including an output circuit and a control electrode coupling said second winding and said exciting winding to transmit the electromotive force induced in said second winding to said exciting winding in amplified form, the amplification of said amplifier when said electromotive force is small being sufficiently great to cause rapid acceleration of said vibratory device into vibration, and means to reduce said amplification when said vibrating device has attained substantially its normal amplitude of vibration to a value sufficient to maintain said normal amplitude of vibration, said means including a circuit for impressing a potential on said control electrode which varies inversely in accordance with the intensity of current in said output circuit.

13. An oscillation generator comprising in combination, a magnetic core having a pair of opposed main poles, each pole including a pair of opposed pole faces, a vibratory element having portions thereof disposed between the pole

5 faces of both said pairs of opposed pole faces to
provide an air gap between each of said pole
faces and said element, said element being ar-
ranged to vibrate in the plane of said main poles
and in such direction as to vary the length of
said air gaps, means for energizing said magnetic
core to produce unidirectional flux which trav-
10 erses the gaps between each pair of oppositely
disposed pole faces and said element in oppo-
site directions, and means for energizing said
magnetic core to produce an alternating flux
which instantaneously traverses the last men-
15 tioned gaps in the same direction whereby the
flux density in said last mentioned gaps is alter-
nately increased and decreased in accordance
with said alternating flux thereby to produce
sustained vibration of said element.

14. An oscillation generator comprising in
combination, a magnetic core having a pair of
20 opposed main poles, each pole including a pair
of opposed pole faces, a vibratory element hav-
ing portions thereof disposed between the pole

faces of both said pairs of opposed pole faces to
provide an air gap between each of said pole
faces and said element, said element being ar-
ranged to vibrate in the plane of said main poles
and in such direction as to vary the length of
said air gaps, means for energizing said mag-
netic core to produce unidirectional flux which
traverses the gaps between each pair of oppo-
sited pole faces and said element in oppo-
10 site directions, means for energizing said
magnetic core to produce an alternating flux
which instantaneously traverses the last men-
tioned gaps in the same direction whereby the
flux density in said last mentioned gaps is alter-
nately increased and decreased in accordance
15 with said alternating flux thereby to produce sus-
tained vibration of said element, and means for
controlling the frequency of said alternating flux
in accordance with the frequency of vibration
of said element.

MILTON S. MEAD, JR.

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