Jan. 13, 1931. A. G. JENSEN 1,788,720

POLYPHASE VACUUM TUBE OSCILLATOR

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FIG. 1.

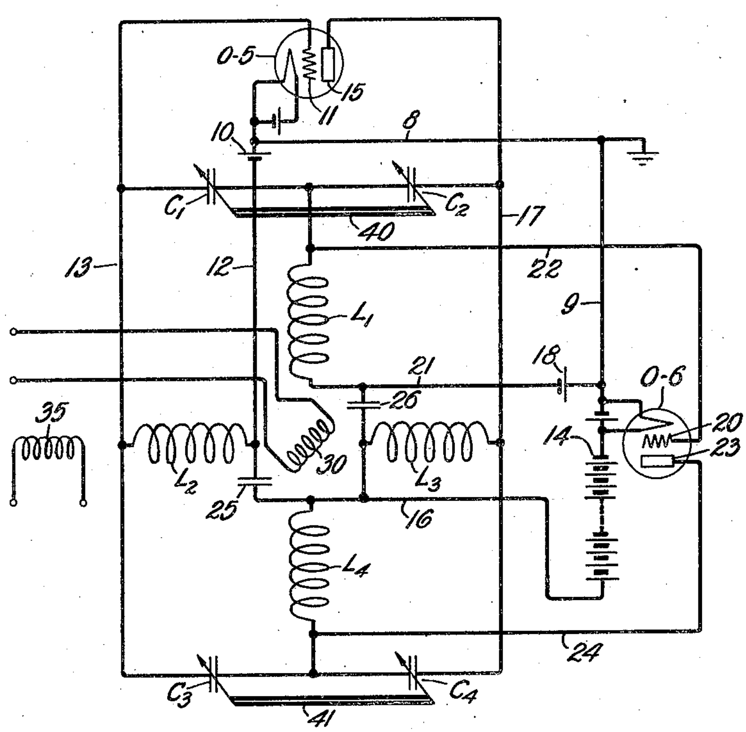

FIG. 5.

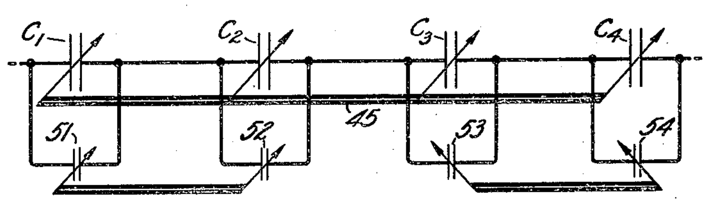

FIG. 5-A.

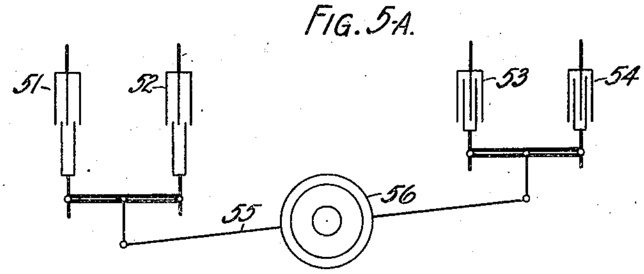

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FIG. 3.

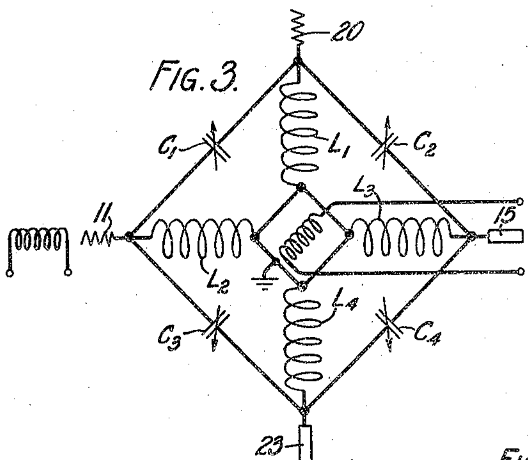


FIG. 4.

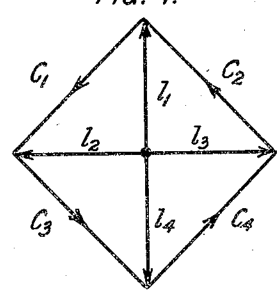
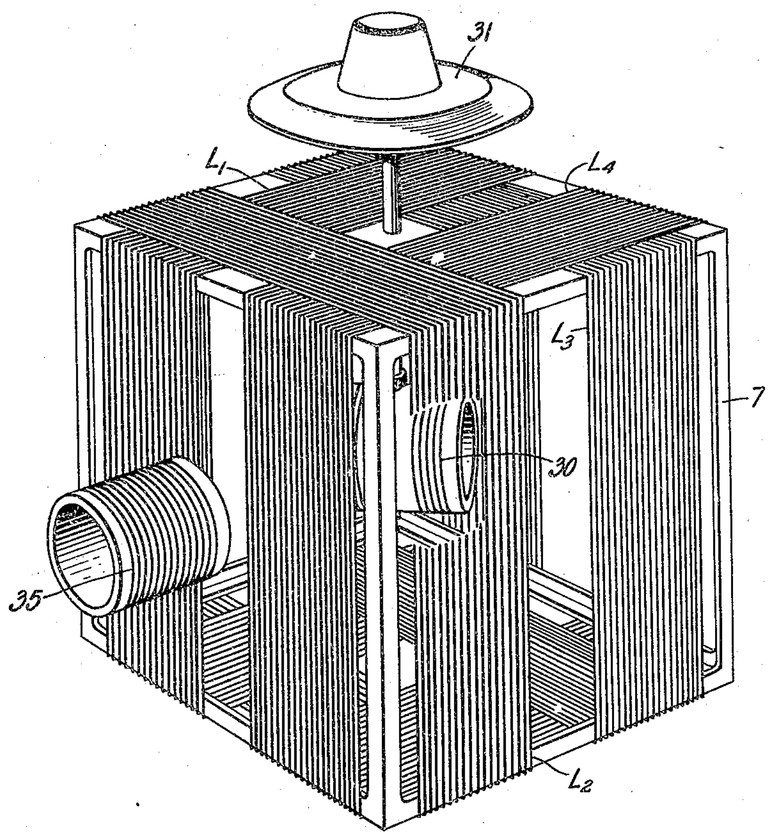


FIG. 2.



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UNITED STATES PATENT OFFICE

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POLYPHASE VACUUM-TUBE OSCILLATOR

Application filed July 6, 1927. Serial No. 203,713.

This invention relates to conversion of electric energy from one form to another, as for example from direct current energy to alternating current energy, and also relates to phase control.

In one specific aspect, the invention relates to an oscillator comprising a plurality of vacuum tubes with a plurality of tuned frequency determining circuits which have elements conjugately related for causing the tubes to generate sustained polyphase oscillations.

In another specific aspect the invention is a polyphase vacuum tube oscillator which generates currents of a greater number of phases than the number of space discharge paths employed.

The oscillator may afford means for varying the phase relation of waves which the oscillator generates, and thus have wide applications in obtaining voltages of variable phase relations. One such application will presently be mentioned specifically.

As is well known, a Hartley oscillator may comprise a vacuum tube with an inductance coil and a capacity element each connecting the grid and the plate of the tube, the electrical mid-point of the inductance coil being connected to the filament of the tube. In the form of the present invention shown in the drawing, by way of example, the capacity element of such an oscillator, instead of being in one unit is made up of four separate units or condensers of equal capacities, two being connected in series with each other across the plate and grid of the tube, and the other two being also connected in series with each other across the plate and the grid. This, of course, does not alter the functioning of the oscillator. A second and like oscillator employs the same four condensers as the capacity element of its oscillation circuit, has its grid connected to the junction of the first two condensers, has its plate connected to the junction of the other two condensers, has its filament connected to that of the first oscillator, and has the inductance coil of its oscillation circuit of inductance equal to that of the first oscillator. The inductance coils have their axes at right angles to each other and intersecting at the center of each coil, and the circuit is symmetrical both mechanically and electrically. The entire system oscillates at one frequency. The voltage, however, across one inductance coil is 90° out of phase with the voltage across the second coil, and the potentials of the four ends of the coils with respect to the common inductance mid-point are 90° apart in phase.

The fluxes from the coils, being in time and space quadrature, constitute a rotating flux of constant amplitude. A secondary winding is rotatably mounted so that its center is at the center of the two inductance coils and its axis can have any direction or angular position in the plane containing the axes of the two coils. As the winding is rotated through 360° the phase of the voltage induced in it by the rotating field of the two coils will vary through a phase angle of 360° in linear proportion to the variation in the angular position of the winding, and the root mean square value of the induced voltage will remain constant.

Another secondary winding, having a fixed angular relation to the two coils, has induced in it from one or both of the coils a voltage of fixed magnitude and phase. Thus, by rotating the movable secondary winding the phase relation between the voltages in the two secondary windings can be varied without changing the magnitude of the voltage in the rotatable winding.

Fig. 1 is a circuit diagram of an embodiment of the invention; Fig. 2 is a perspective view showing the relative space arrangement of the oscillator inductance coils and the fixed phase winding and the rotatable variable phase winding which are coupled to the oscillator inductance coils, a portion of one oscillator coil being shown broken away so that the rotatable winding may be seen more clearly; Fig. 3 is a schematic diagram of the oscillator circuit; Fig. 4 is a vector diagram showing the relative phases and amplitudes of the voltages across the inductance coils and the condensers of the oscillation circuits of the oscillator; Fig. 5 shows a modification of the condenser system of the oscillator; and Fig. 5—A indicates a manner in which the proper relative adjustment of certain condensers of Fig. 5 may be obtained.

Referring especially to Figs. 1 to 3, O—5 and O—6 are two oscillation generating electric space discharge tubes. The oscillating system of these tubes comprises two inductance coils made up of unit coils L_1, L_2, L_3 and L_4, having equal inductances, and four variable condensers C_1, C_2, C_3 and C_4 having equal capacities. The coils are symmetrically arranged on a cubical frame 7 as shown in Fig. 2. In the schematic diagram of Fig. 3, one end of each of the four coils is grounded, and between each two of their other ends is connected one of the condensers, respectively. The filaments of tubes O—5 and O—6 are grounded through conductors 8 and 9 respectively, as shown in Fig. 1. Coil L_2 is connected, in series with a grid biasing battery 10, between the grid 11 and the filament of the tube O—5, through conductors 12 and 13. Coil L_3 is connected, in series with plate current supply battery 14, between the grounded filament and the plate 15 of tube O—5, through conductors 16 and 17. Coil L_1 is connected, in series with a grid biasing battery 18, between the grid 20 and the filament of tube O—6, through conductors 21 and 22. Coil L_4 is connected, in series with the plate current supply battery 14, between the grounded filament and the plate 23 of tube O—6, through conductors 16 and 24. Condensers 25 and 26 of large capacity prevent the voltage of battery 14 from reaching grids 11 and 20, respectively.

When the four condensers C_1, C_2, C_3 and C_4 are alike and the circuit is symmetrical, mechanically as well as electrically, the entire system will oscillate at one frequency only, and the voltages across the coils L_2 and L_3 will be equal in amplitude to, but 90° out of phase with, the voltages across the coils L_1 and L_4.

If the entire oscillatory system is perfectly symmetrical it will represent a balanced bridge circuit, and a voltage impressed across the inductance coils L_1 and L_4 in Fig. 3, will induce no voltage across the coils L_2 and L_3. The system therefore will oscillate at one frequency only, as long as the four coils L_1, L_2, L_3 and L_4 and the four condensers C_1, C_2, C_3 and C_4 are exactly alike, and may oscillate at two different frequencies if one of the coils or condensers is changed slightly.

It has been found in practice, however, that enough coupling will always exist between the two halves of the system to make the entire system oscillate at one frequency only, as long as the four coils and condensers are approximately alike. A proper variation of the condensers may therefore be used in adjusting the phase relations correctly, as in accordance with a method to be described later, without disturbing the synchronism.

The relative phases and amplitudes of the voltages l_1, l_2, l_3, l_4, c_1, c_2, c_3 and c_4 across coils L_1, L_2, L_3 and L_4, and condensers C_1, C_2, C_3, and C_4, respectively are indicated in the vector diagram of Fig. 4. It will be seen that although only two vacuum tubes are employed, four voltages 90° apart are available, as for example voltages c_1, c_2, c_3 and c_4 across condensers C_1, C_2, C_3 and C_4, respectively.

As indicated in Fig. 2, a coil 30 is mounted for rotation by a dial 31 so that the center of the coil is at the center of the cubical frame 7 and the axis of the coil can have any direction or angular position in the plane containing the axes of the coils L_1, L_2, L_3 and L_4. As the coil 30 is rotated through 360° the phase of the voltage induced in it from the coils L_1, L_2, L_3 and L_4 will vary through a phase angle of 360° in linear proportion to the variation in the angular position of the coil 30, and the root means square value of the induced voltage will remain constant.

A coil 35 having a fixed angular relation to the coils L_1, L_2, L_3, and L_4 has induced in it from those coils a voltage of fixed phase. As shown, the coil 35 is coaxial with coils L_2 and L_3, and therefore the voltage induced in it is due substantially entirely to the currents in windings L_2 and L_3, the coil 35 being noninductively related to coils L_1 and L_4, to the axis of which its axis is a right angles. However, the coil 35 may be magnetically coupled to the coils L_1, L_2, L_3 and L_4 in any suitable or convenient way. If its position with respect to coils L_1, L_2, L_3 and L_4 is fixed, the magnitude of the voltage induced in it is constant; but if desired the magnitude may be varied by moving the coil 35 toward or away from the center of the cubical frame 7 while keeping the direction of the coil axis fixed. It will be seen that, by keeping the coil 35 fixed in position and rotating the coil 30 the phase relation between the voltages in these coils can be varied as desired without changing the magnitude of either voltage.

Although the coils L_1, L_2, L_3 and L_4 have been shown arranged on a cubical frame with the rotatable coil 30 mounted in the center of the cube and with the fixed coil 35 mounted coaxial with coils L_2 and L_3, it is possible to use any of various symmetrical arrangements of the coils giving a fairly uniform field at the point where the movable coil is located.

Theoretically, the most convenient way of arranging the circuit would be to have the four variable condensers mounted on a common shaft so that the adjustment of the oscillator to any given frequency would require only one tuning as for ordinary oscillators. However, with such an arrangement it would be found rather difficult to arrange the condensers in such a way that mutual capacities and ground capacities were balanced out; and the result would be that the voltage across coils L_1 and L_4 would not be exactly

90° out of phase with that across coils L_2 and L_3 over the entire frequency range of the oscillator, and therefore the voltage induced in the coil 30 would vary in amplitude as well as in phase, upon rotation of the coil.

In order to avoid this amplitude variation, it is convenient to mechanically couple the condensers in pairs, instead of controlling them all from the same shaft. Thus, the condensers C_1 and C_2 may be mounted on the same shaft and varied simultaneously, as indicated by the connection 40 between these condensers in Fig. 1; and similarly the condensers C_3 and C_4 may be mounted upon the same shaft as indicated by connection 41. If these two sets of condensers are adjusted to widely different capacity values, then the oscillator may oscillate at two different frequencies simultaneously, while oscillations of a single frequency only will be generated as long as the capacities are approximately the same for the two sets of condensers.

As will be pointed out more in detail presently, one use for the oscillator is in connection with double detection radio receivers. Where such a receiver is available, the final adjustment of the phase relation of the voltage across coils L_1 and L_4 to the voltage across coils L_2 and L_3 can be made by connecting the rotatable coil 30 in the input circuit of the intermediate frequency detector, connecting a telephone headset in the plate circuit of this detector, varying the condensers until zero-beat in the headset is obtained as an indication that only a single frequency is being generated, and thereupon adjusting the two sets of condensers slightly until a deflection on a meter inserted in the intermediate frequency detector plate circuit stays constant for all positions of the variable phase coil 30.

In the operation of the oscillator, frequency variation without any appreciable change in phase relations is obtained by turning the two condenser shafts the same amount in the same direction; while a relative phase change between the current in coils L_1 and L_4 and the current in coils L_2 and L_3, without any appreciable frequency change, is obtained by turning the two condenser shafts the same amount in opposite directions, to increase the capacities of two of the condensers a given amount and decrease the capacities of the other condensers the same amount.

Instead of employing a double detection receiver as described above for adjusting the phase relations in the oscillator, the adjustment can be accomplished by connecting coil L_1 across one pair of plates in a cathode ray oscillograph and coil L_2 across the other pair of plates, and then adjusting the variable condensers until the figure shown in the oscillograph is a circle.

Instead of mechanically connecting the variable condensers so that they are varied in pairs, they can, as indicated in Figs. 5 and 5—A, all four be mechanically connected together by a connection, indicated at 45, so that they are varied alike, and then besides, vernier condensers 51, 52, 53 and 54 can be connected in parallel to the four large condensers, respectively, these four vernier condensers being connected together mechanically in such a way that the capacities of two of them are increased when the capacities of the other two are decreased. A variation of the large condensers will then result in a frequency change mainly, while a variation of the vernier condensers will result in a phase change mainly. In Fig. 5—A the means for varying the two pairs of vernier condensers is indicated as a bar 55 connecting the two pairs and rotatable by a dial knob 56. Clockwise rotation of the knob increases the capacities of condensers 51 and 52 and decreases the capacities of condensers 53 and 54. Counter-clockwise rotation of connection 55 has the opposite effect.

One application of the invention is in obtaining from coils 30 and 35 two different heterodyne or beating oscillator voltages of variable relative magnitudes and variable phase difference, for example for use in a directional double detection radio receiving system of the general type described by H. T. Friis, Proceedings of the Institute of Radio Engineers, volume 13, pages 685 to 707, December, 1925. With such beating oscillator voltages available, directional selectivity can be obtained, as explained in the Friis article, by balancing or combining properly two intermediate frequency waves obtained by intermodulating the two oscillator voltages respectively with two signal voltages received from two similar loop antennæ properly positioned with respect to each other. As explained in the article, by controlling the relative magnitudes and the phase relation of the beating oscillator currents in such a system, the relative magnitudes and the phase relation of the two intermediate frequency voltages can be so controlled that they may be combined to neutralize each other or reinforce each other as desired, and thereby cause the system to have a desired directional characteristic as regards the relation between the magnitude of the resultant intermediate frequency voltage and the direction from which the received radio waves are incident upon the antennæ.

What is claimed is:

1. A system for the generation of plural phase current comprising generators, each comprising an electric discharge device and an associated frequency determining circuit, at least a portion of each said frequency determining circuits being in common with the others, said generators being less in number than the number of phases of the resultant polyphase wave directly generated there-

by, and means for associating said generators to maintain them in synchronism and their potentials in the desired phase relation.

2. A polyphase space discharge oscillator system comprising space discharge paths and an equal number of frequency determining oscillation paths associated therewith, at least a portion of each of said paths being in common with the others, said paths being so interrelated that the number of phases of the resultant polyphase voltage directly generated is greater than the number of space discharge paths in the system.

3. The combination with electric space discharge tubes of frequency determining oscillation circuits partially common to all of said tubes, for causing said tubes to generate sustained voltage oscillations, and so associated with each other and with the tubes as to maintain a phase difference substantially less than 180 degrees between two of said voltages.

4. In combination, electric space discharged tubes and tuning circuits for causing said tubes to generate sustained oscillations, said circuits having reactance elements in common to all said tubes and other reactance elements individual to said tubes.

5. In combination, electric space discharge tubes and oscillation circuits for causing said tubes to generate sustained oscillations, said circuits comprising in common a bridge network, the remaining elements of the respective circuits being connected to conjugate points in said bridge.

6. An electric space discharge device, an oscillation circuit for causing said device to generate sustained oscillations, and means included in said circuit for creating a magnetic field rotating in space.

7. A system for the generation of polyphase current comprising a plurality of space discharge generators, frequency determining circuits therefor, and a closed loop circuit included in common and in a similar relation in the frequency determining circuit of each of said generators.

8. A system for converting direct current power into polyphase alternating current power, comprising a plurality of electrostatically controlled valves having anode, cathode and discharge control elements, means for regeneratively controlling said valves and maintaining said valves in synchronism and in polyphase relation, a current path between an anode and a control element of one of said valves, included in said means, and a current path between an anode and a control element of another of said valves, included in said means and partially included in said first path.

9. A system for converting direct current power into polyphase alternating current power, comprising electrostatically and regeneratively controlled valve converters associated with circuit paths which constitute a synchronizing circuit including a closed current path, anode, cathode and discharge control elements included in each of said converters, a portion of said closed current path being connected between an anode element and another of said elements of one of said valves and between an anode element and another of said elements of another of said valves.

10. In a system for converting direct current power into polyphase alternating current power, a valve converter comprising electrostatically and regeneratively controlled valves and means connecting said valves in such symmetrical circuit arrangement as to maintain them in synchronism and cause them to directly generate polyphase current of a number of phases greater than the number of said valves.

11. The combination with an alternating current electric space discharge generator comprising four or more current paths connected in a closed circuit and means for creating voltages in each of said paths, of stationary means producing an additional voltage connected across said circuit at such points that two of the first voltages are in series with the additional means.

12. In combination, an electric space discharge oscillator tube, an oscillation circuit therefor, a second electric space discharge oscillator tube, an oscillation circuit therefor, a closed current path common to said two circuits, a current path in said first circuit connected between two points of said closed path, and a current path in said second circuit connected between two other points of said closed path.

13. In combination, electric space discharge oscillator tubes each having anode, cathode and discharge control elements, a network associated with said elements for causing said tubes to generate polyphase current, an inductance coil included in said network connected between two of said elements of one of said tubes, an inductance coil included in said network connected between two of said elements of said other tube, said coils being so related that their magnetic fields are superposed at right angles.

14. A four-phase oscillator comprising two electric space discharge oscillator tubes, each having anode, cathode and discharge control elements, a closed circuit, four reactance elements having reactances of like sign and equal magnitude in series in said circuit, means connecting two of said elements of one of said tubes between the junction point of two of said reactance elements and the junction point of the other two of said reactance elements, means connecting two of said elements of the other of said tubes between the other two junction points of said reactances, two equal reactance elements of sign opposite that of said first re-

actances, means connecting one of said two reactance elements across said two elements of said one tube, and means connecting the other of said two reactance elements across said two elements of said other tube.

15. In combination, two inductance coils having their axes in a given plane, electric space discharge oscillator tubes, means so associating said tubes and said coils as to cause said coils to produce harmonically varying magnetic fields in time and space quadrature relation and of substantially equal maximum magnitudes at a given point, a third inductance coil, and means mounting said third coil for rotation at said point with its axis in said given plane.

16. An oscillator comprising two electric space discharge tubes, each having anode, cathode, and discharge control elements, four condensers in series forming a closed circuit, means connecting two of said elements of one of said tubes across two of the junction points of said condensers, means connecting two of said elements of said other tube across the other junction points of said condensers, two equal inductance elements, one connected across said two elements of said one tube and one connected across said two elements of said other tube, means for varying the capacities of two of said condensers the same amount in the same direction, and means for varying the capacities of the remaining two condensers relative to the capacities of said first two condensers while maintaining the capacities of said remaining two condensers equal to each other.

17. An oscillator comprising two electric space discharge tubes each having anode, cathode and discharge control elements, four condensers in series forming a closed circuit, means connecting two of said elements of one of said tubes across two of the junction points of said condensers, means connecting two of said elements of said other tube across the other two junction points of said condensers, two equal inductance elements, one connected across said two elements of said one tube and one connected across said two elements of said other tube, means for simultaneously varying the capacities of each of said condensers by substantially the same amount in the same direction, a condenser of relatively small capacity connected across each of said first mentioned condensers and means for simultaneously increasing the capacities of two of said small condensers and decreasing the capacities of the remaining two of said said small condensers.

In witness whereof, I hereunto subscribe my name this 17th day of June, A. D. 1927.

AXEL G. JENSEN.