

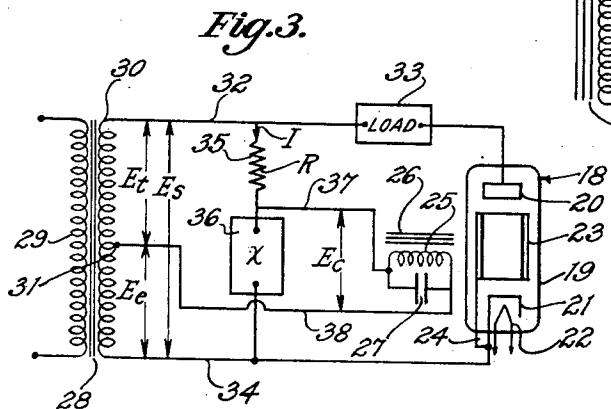
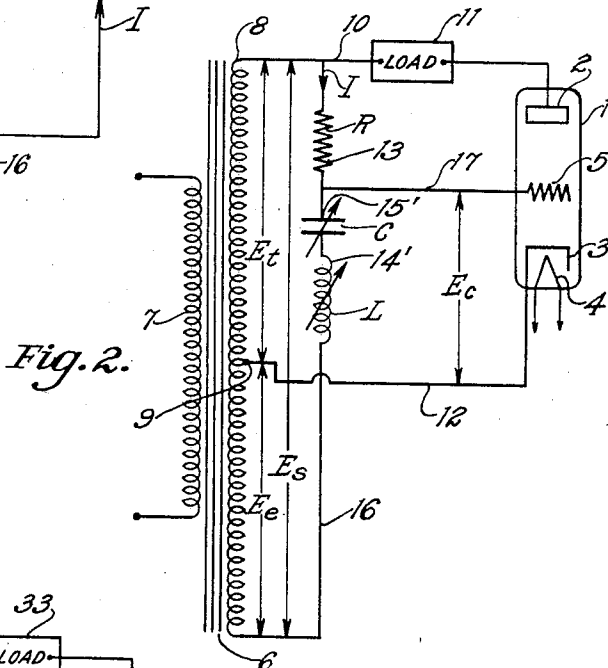
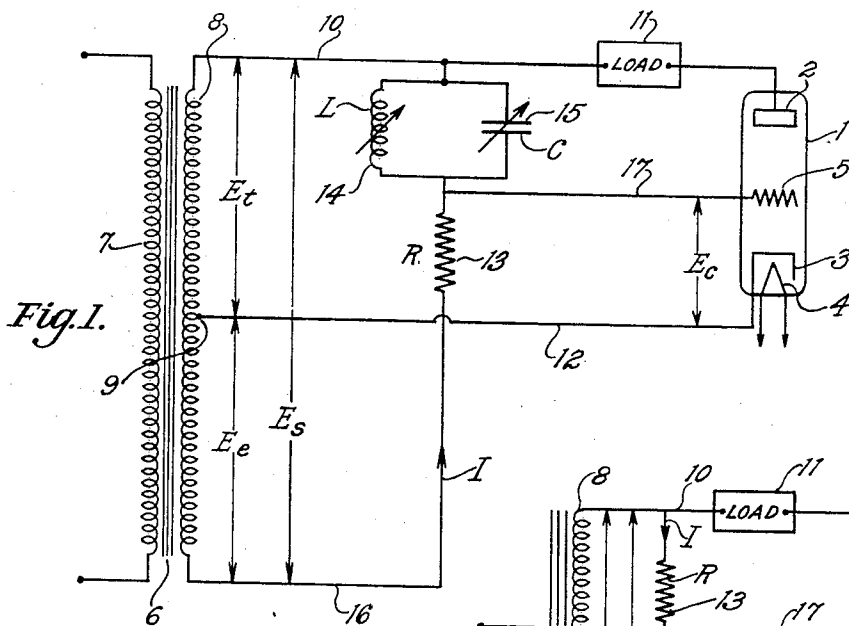
Nov. 5, 1940.

W. P. OVERBECK

2,220,118

RESONANT CIRCUIT PHASE CONTROL OF ELECTRICAL SPACE DISCHARGE DEVICES

Original Filed Jan. 19, 1938 2 Sheets-Sheet 1



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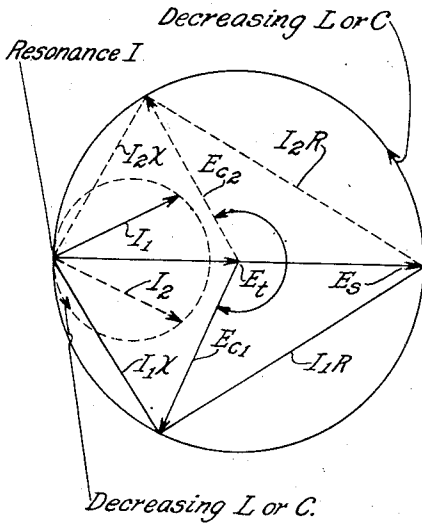
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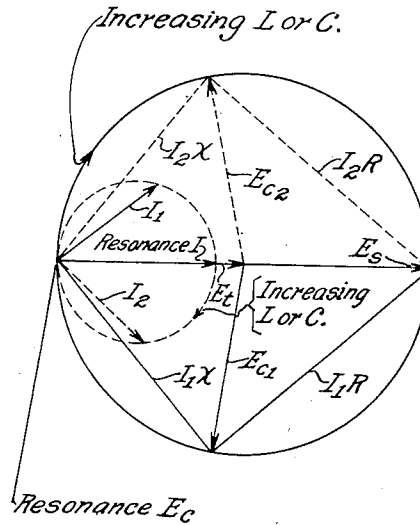
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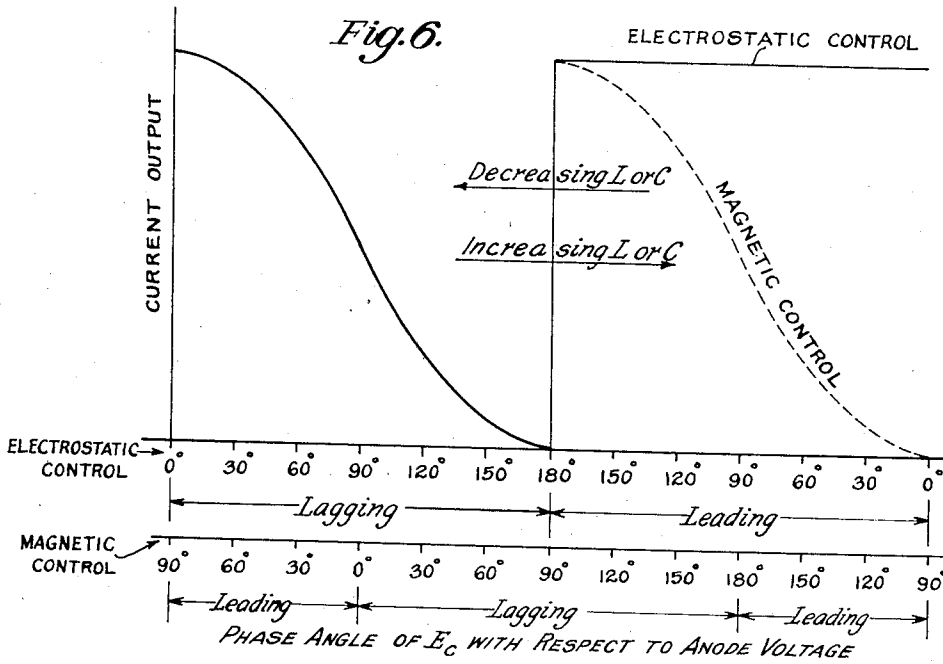
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PARALLEL L-C CIRCUIT
Fig. 4.



SERIES L-C CIRCUIT
Fig. 5.



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UNITED STATES PATENT OFFICE

2,220,118

RESONANT CIRCUIT PHASE CONTROL OF
ELECTRICAL SPACE DISCHARGE DEVICES

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Application January 19, 1938, Serial No. 185,735
Renewed November 27, 1939

8 Claims. (Cl. 250—27)

This invention relates to phase control of electrical space discharge devices, and more particularly to such control as applied to a gas or vapor-filled tube in which the starting of current is determined by an electrostatic grid or by an electromagnetic control element.

In electrical gaseous discharge tubes in which the current output is controlled by varying the phase angle at which the current starts to flow upon the application of an alternating voltage to such a tube, it is often desirable to vary the output continuously from its maximum value to zero. It is also desirable to produce an arrangement so that at one point in the variation of the control element an abrupt change of the current from zero to its maximum value or from its maximum value to zero occurs. With previous arrangements it has been theoretically impossible to produce these results completely. Even where such results were approximated, it was necessary to resort to the use of movable contacts and complicated and massive arrangements. In order for grid-controlled tubes to produce even some of the desired results, it is necessary to shift the phase of the control voltage through a value of zero degrees or 180 degrees. In magnetically-controlled tubes, in order to obtain all of the results including a completely continuous control throughout the entire range of operation, a shifting of the phase applied to the magnet through a value of zero degrees or 180 degrees was also necessary. In a simple phase-shifting circuit using a resistance and a reactance, one of which is variable, it is necessary for the variable element to reach a limit of either zero or infinity in order to produce the desired results. A simple variable inductance or condenser cannot accomplish either of these results and still cover a sufficiently large variation to perform useful control, while with a variable resistance it is impossible to approach either zero or infinity uniformly, and the point of zero current cannot be passed through without an abrupt change from zero to infinite resistance which necessarily means the use of electrical contacts or some other complicated system.

One of the objects of my invention, therefore, is to provide means whereby the output of a controlled discharge tube may be varied continuously from its maximum value to zero by the use of simple continuously-variable impedances.

Another object is to devise an arrangement in which by means of a small continuous impedance change, an abrupt change from zero to maximum current output may be obtained.

A still further object is to devise a system

whereby the phase of the voltage applied to the control element may be varied through 180 degrees or more by utilizing a simple continuously-variable impedance.

An additional object is to provide means for varying through zero or 180 degrees, the phase angle at which the control element of such a tube causes conduction of current to start.

Another object is to provide means for producing a large phase shift in the control voltage with a relatively small impedance variation.

A still additional object is to incorporate the foregoing arrangements in a magnetically-controlled tube, whereby the advantages of said arrangements may be fully utilized.

The foregoing and other objects of my invention will be best understood from the following description of exemplifications thereof, reference being had to the diagrammatic drawings, wherein:

Fig. 1 is a circuit diagram illustrating one embodiment of my invention;

Fig. 2 is a similar diagram representing a variation of the arrangement shown in Fig. 1;

Fig. 3 is a circuit diagram showing an embodiment of my invention as applied to a magnetically-controlled tube;

Fig. 4 is a vector diagram representing the operation of the circuit of Fig. 1;

Fig. 5 is a vector diagram representing the operation of the circuit of Fig. 2; and

Fig. 6 is a curve showing the relationship between the output current of my device and the phase between the variable control factors and the anode voltage.

In Fig. 1 there is represented a controlled tube consisting of an envelope 1 containing an anode 2 and a cathode 3. The cathode 3 may be heated to temperature of thermionic emission by means of a heater 4. Intermediate the cathode and anode is a control grid 5. The envelope 1 is filled with a suitable ionizing gas or vapor so that upon the passage of a discharge between the cathode and anode, said gas or vapor becomes highly ionized and current flows at relatively low voltage drop. In tubes of this kind, if a voltage, preferably of a negative value, is applied to the control grid 5, when the anode becomes positive, the starting of the current between the cathode and anode will be delayed until the voltage on the control grid falls to a predetermined minimum value, which may be substantially zero.

In order to supply the device with power, a transformer 6 is provided. This transformer has a primary winding 7 which may be connected to

a suitable source of alternating current, and a secondary winding 8. This secondary winding may be provided with a tap 9 intermediate the ends thereof and preferably at the center point of said secondary winding. One end of the winding 8 is connected by means of a lead 10 through a suitable load 11 to the anode 2. A lead 12 connects the center tap 9 directly to the cathode 3.

In order to provide the grid 5 with a control voltage and to shift the phase of this voltage, a phase-shifting circuit is connected between the ends of the secondary winding 8. This phase-shifting circuit consists of a resistance 13 connected in series with an inductance 14 and a condenser 15. In the arrangement as shown in Fig. 1, the inductance 14 and the condenser 15 are connected in parallel with each other. The lower end of the resistance 13 is connected directly to the secondary winding 8 through the lead 16, while the upper end of the parallel inductance capacity circuit is connected directly to the conductor 10. The inductance 14 or the condenser 15, or both, may be made adjustable in order to control the output of the tube. A lead 17 extends from the point intermediate the resistance 13 and the inductance capacitance circuit to the control grid 5.

When the transformer 6 is energized and either the inductance 14 or the capacity 15, or both, are varied, the time at which the current starts between the cathode 3 and the anode 2 in each alternating current cycle is delayed to a predetermined extent, and in this way the amount of current or power delivered to the load 11 is controlled.

In order to analyze the operation of the circuit, as illustrated in Fig. 1, the resistance 13 is represented by the symbol R , the inductance 14 by the symbol L , and the capacitance 15 by the symbol C . The voltage between the upper end of the secondary winding 8 and the tap 9 is represented by E_t , the voltage between the lower end of the secondary winding 8 and the tap 9 by E_c , the total voltage across the secondary winding 8 by E_s , and the control voltage impressed upon the control grid 5 by E_c . The current which flows through the resistance 13 is represented by I . The impedance of the inductance 14 may be expressed as $X_L = j\omega L$, the impedance of the condenser 15 may be expressed as

$$X_C = -j\frac{1}{\omega C}$$

and the impedance of the inductance 14 and the condenser 15 in parallel may be expressed as

$$X = \frac{\left(-j\frac{1}{\omega C}\right)(j\omega L)}{j\left(\omega L - \frac{1}{\omega C}\right)} \\ = -j\frac{L}{C\left(\omega L - \frac{1}{\omega C}\right)}$$

The vector diagram shown in Fig. 4 utilizes the various quantities as above designated, and illustrates the operation of the arrangement as shown in Fig. 1. If L and C are adjusted so that X is negative, then a current I_1 will flow through the phase-shifting circuit, and will lead the voltage E_t which is applied across the controlled tube. This current I_1 will produce through the resistance R a voltage drop of $I_1 R$ in phase with the current and a voltage drop of $I_1 X$ through the parallel LC circuit, which voltage drop is at

right angles to the current. As illustrated in Fig. 4, the sum of $I_1 R$ into $I_1 X$ must equal the voltage E_s . The control voltage E_c , therefore, may be determined by the vector E_{c1} , extending from the end of the vector E_t to the intersection of the two vectors $I_1 R$ and $I_1 X$. It will be noted that under these conditions, the control voltage E_{c1} lags the voltage E_t . If L or C is decreased, then the current I will swing more and more out of phase with the voltage E_s , and will get smaller and smaller. The dotted circle represents the locus of the end of the vector I as such variation takes place, and the arrow on said dotted circle represents the direction of change of I as L or C is decreased. As the variation of L or C continues, likewise the control voltage E_c will swing more and more into phase with the voltage E_s , and at the point where X_L is equal to X_C , the voltage E_c will be exactly in phase with the voltage E_s and likewise with the voltage E_t . The point at which X_L is equal to X_C is of course the point at which the parallel LC circuit is resonant at the applied frequency. Although in a practical system it is impossible to make the vector I decrease to zero, as indicated in Fig. 4, yet if the resistance of the parallel LC circuit is small as compared to the value of L , no appreciable difference from the analysis as given in Fig. 4 can be detected in actual operation. As L or C is decreased beyond the resonance point so that X becomes positive, then a current I_2 will flow, lagging the voltage E_s . The current I_2 will produce the voltage drops $I_2 R$ and $I_2 X$, the sum of which equals the voltage E_s . Likewise the control voltage can be determined by the vector E_{c2} extending from the end of the vector E_t to the intersection of the vectors $I_2 R$ and $I_2 X$. It will be noted that under these conditions the control voltage E_{c2} leads the voltage E_t .

The solid circle in Fig. 4 represents the locus of the end of the vector E_c as said vector changes its angular relationship with the voltage E_t . The arrow on said solid circle represents the direction in which the end of the vector E_c moves as L or C is decreased. Reversing the direction of change of L and C will reverse the direction of the arrow both on the solid voltage circle and on the dotted current circle.

In the system as illustrated in Fig. 1, it is substantially impossible to shift the control voltage E_c 180 degrees out of phase with the voltage E_t inasmuch as such a condition would represent either zero or infinite values of L and C . However, an angular displacement between E_c and E_t considerably greater than 90 degrees, both leading and lagging, can be obtained with reasonable values of L , C and R . Thus in the system as illustrated in Fig. 1, a total phase variation between E_c and E_t substantially greater than 180 degrees can easily be obtained.

The vector E_t , as drawn in Fig. 4, is the voltage from the point where lead 10 connects to the secondary 8 to the tap 9, and is consequently opposite to 180 degrees out of phase with the voltage from tap 9 to lead 10 which is the voltage applied to the anode of the tube. Thus, the phase relationship between E_c and E_t , as shown is exactly opposite to that between E_c and the anode voltage $-E_t$. Since E_c is illustrated as varying from a lagging to a leading angle (through zero degrees) with respect to E_t as L or C is decreased, E_c varies from a leading to a lagging angle (through 180 degrees) with respect to the anode voltage $-E_t$ and through a total angle which is still greater than 180 degrees. If the positions

of the parallel inductance capacitance 14 and 15 and the resistance 13 are reversed in Fig. 1, all the vectors in Fig. 4 will be reversed and E_t becomes the anode voltage so that E_c varies from a lagging to a leading angle through zero degrees with respect to the anode voltage.

In Fig. 6 is represented the manner in which the current output from the controlled tube varies as the variations described in connection with Fig. 4 are produced. Along the vertical axis are plotted average current values. Along the upper horizontal axis is plotted the phase angle of E_c with respect to the anode voltage when the controlled grid type of tube illustrated in Fig. 1 is used. The curve represented by the solid line in Fig. 6 represents the characteristic obtained with the system as shown in Fig. 1. If the control voltage lags the anode voltage to any extent, a certain time interval elapses after the anode voltage becomes positive before the control or grid voltage passes from a negative to a positive value, and thus the starting of current is delayed until such time occurs. If the angle or lag is small, this transition from a negative to a positive value occurs relatively early in the cycle, and conduction occurs during the rest of the cycle. Under these conditions the output of the tube has a relatively large value. As the angle of lag becomes greater, the transition of the control voltage from a negative to a positive value occurs later in the anode voltage cycle, and therefore the portion of that cycle during which conduction occurs becomes smaller. This results in a decreased output from the tube. As the angle of lag approaches 180 degrees, the current output likewise decreases to zero, as illustrated in Fig. 6. As the phase displacement between the control voltage and the anode voltage passes through 180 degrees so that the control voltage leads the anode voltage, the control voltage is always positive at the instant the anode voltage becomes positive, and thus conduction occurs throughout the entire half cycle during which the anode has a positive potential applied thereto. This means that under these conditions the output from the tube is a maximum. Thus it will be noted, as shown in Fig. 6, that as the phase angle between the control voltage and the anode voltage passes through 180 degrees, the output jumps suddenly from zero to a maximum and remains at the maximum value as long as the control voltage leads the anode voltage. As discussed above in connection with Fig. 4, the arrangement as shown in Fig. 1 affords means whereby the phase angle between the control voltage and the anode voltage may be varied through 180 degrees. With such a system as shown in Fig. 1, therefore, it is possible to vary the output of the tube continuously down to zero, and also to obtain a sudden transition from zero current output to maximum current output.

Since, however, 180 degrees displacement between the voltage E_c and the voltage E_t is impractical with a continuously variable inductance or capacitance, a displacement of zero degrees between E_c and $-E_t$, the anode voltage, is also impractical. Thus, a continuous smooth control up to the maximum value requires that the positions of the parallel inductance capacitance 14 and 15 and the resistance 13 must be reversed in Fig. 1 as described above. Whether these positions are reversed or not, the direction of shift of E_c with a change in L or C is as indicated by the arrows in Fig. 6, since, if reversed,

the shift from lagging to leading is through zero degrees, and, if not reversed, the shift from leading to lagging is through 180 degrees.

Instead of using the parallel LC circuit illustrated in Fig. 1, a series LC circuit such as illustrated in Fig. 2 can be utilized. In Fig. 2 the reference numerals correspond to identical parts in Fig. 1. However, in Fig. 2 the condenser C is represented at 15' in series with the inductance L represented at 14'. As in Fig. 1, the condenser 15' and inductance 14' of Fig. 2 may be varied or both of these elements may be varied. The impedance of the inductance 14' may be expressed as $X_L = j\omega L$, the impedance of the condenser 15' may be expressed as

$$X_C = -j \frac{1}{\omega C}$$

and the resultant impedance of the series-connected condenser and inductance may be expressed as

$$X = j\omega L - j \frac{1}{\omega C}$$

The operation of the system shown in Fig. 2 is given by the vector diagram of Fig. 5. In this figure the various vectors are marked exactly in the same manner as in connection with Fig. 4. If L and C are so adjusted that X_C is considerably larger than X_L , a current I_1 leading the voltage E_t will flow through the phase-shifting circuit. The current I_1 will produce a drop $I_1 R$ in phase with the current, and a voltage drop $I_1 X$ at right angles to the current. The sum of the two vectors $I_1 R$ and $I_1 X$ must equal the voltage E_s applied to the phase-shifting circuit. The control voltage will appear as E_{c1} and is determined by the vector extending from the end of E_t to the intersection of $I_1 R$ and $I_1 X$, shown in Fig. 5. It will be seen that under these conditions E_{c1} lags the anode voltage E_t . As L is increased or C is increased, the current I will swing more and more into phase with the voltage E_s until X_L and X_C are equal to each other, at which point the current I will be in phase with the voltage E_s . Under these conditions the phase-shifting circuit will be resonant to the applied frequency. While this variation is taking place, the vector E_c will likewise shift more and more out of phase with the voltage E_t until at the resonant point it is exactly 180 degrees out of phase with the anode voltage E_t . As either L or C is increased beyond the resonant point, a current I_2 lagging the voltage E_s will flow in the phase-shifting circuit. The current I_2 will produce the voltage drops $I_2 R$ in phase with the current and $I_2 X$ at right angles to the current. These two vectors again equal the voltage E_s . A control voltage E_{c2} will appear as represented by the vector extending from the end of E_t to the intersection of the two vectors $I_2 X$ and $I_2 R$. From the above it will be seen that in Fig. 5 the dotted circle represents the locus of the end of the current vector I as changes are made in L and C, and the arrow on said dotted circle represents the direction of variation as L or C is increased. Likewise the solid circle represents the locus of the end of the control voltage vector E_c as L or C is varied. The direction of the arrow on the solid circle represents the direction of variation as L or C is increased. Reversing the direction of variation of L or C will reverse the direction of the arrows on both of the circles.

In any practical system it is substantially im-

possible to shift the vector E_c so that it is exactly in phase with the anode voltage E_t inasmuch as such a condition represents zero or infinite values of L and C . However, the control E_c may be shifted from 180 degrees out of phase with the anode voltage to considerably less than 90 degrees out of phase with said voltage, both leading and lagging, with reasonable and practical values of L , C and R . Thus in a practical system it is possible to obtain an overall variation of phase displacement between the control voltage and the anode voltage of considerably more than 180 degrees. In this arrangement, as in that of Fig. 1, it is possible to reverse the positions of the inductance capacity combination and the resistance 13 so that E_c , instead of shifting from lagging to leading E_t through 180 degrees displacement, as L or C is increased, will shift from leading to lagging and through zero degrees as L or C is decreased. In Fig. 5 E_t represents the anode voltage rather than $-E_t$.

The characteristic curve of electrostatic control as shown in Fig. 6 applies with equal force to the arrangement as shown in Fig. 2. As appears from the analysis as given in connection with Fig. 5, it is possible to vary the phase between E_c and E_t through 180 degrees, and therefore it is possible to obtain a continuous and accurate control of the current output of the tube of Fig. 2 down to zero output or to obtain sudden transition from zero to maximum current. Also by reversal of the positions of the series inductance capacity and the resistance 13 , it is possible to obtain a smooth continuous control up to maximum output.

The direction of shift of E_c with respect to the anode voltage as L or C is increased or decreased is identical with that of the arrangement of Fig. 1. As L or C is increased in Fig. 2, E_c shifts from lagging to leading the anode voltage through a displacement of 180 degrees, and if the series LC circuit and the resistance are interchanged in Fig. 2, E_c shifts from leading to lagging through zero degrees as L or C is increased.

From the foregoing it will be seen that the electrostatic type of control, as illustrated in Figs. 1 and 2, accomplishes many of the desired results. However, I have found that when my present invention is applied to a magnetic type of control, all of the desired results are secured by the use of a comparatively simple control circuit. Such an arrangement is illustrated diagrammatically in Fig. 3. In this figure a magnetically-controlled tube is represented at 18 . This tube is preferably of the type more fully described and claimed in the copending application of Percy L. Spencer, Serial No. 612,235, filed May 19, 1932, for an improvement in Electrical gaseous discharge devices. The tube 18 consists of an envelope 19 containing an anode 20 and an indirectly-heated cathode 21 which may be raised to temperature of thermionic emission by means of an electrical heater 22 . Surrounding the discharge space between the anode 20 and the cathode 21 is an auxiliary electrode 23 which may consist of an electrical conducting cylinder, either perforate or imperforate. Instead of completely surrounding the discharge space, the auxiliary electrode 23 may partially surround it. The envelope 19 is filled with a suitable ionizing gas or vapor, preferably argon, at a pressure of the order of one millimeter or less. In any event, the gas pressure is such that if a discharge occurs between the cathode and anode, the gas or vapor becomes ionized, and current flows at a relatively

low voltage drop. The auxiliary electrode 23 is connected to the cathode 21 by means of the conductor 24 .

In order to control the starting of the current between the cathode 21 and the anode 20 , a control winding 25 wound upon a magnetic core 26 is provided. The magnetic core 26 has pole pieces which impress a transverse magnetic field across the discharge path within the auxiliary electrode 23 . In parallel with the winding 25 is connected the condenser 27 . The condenser 27 is preferably selected of such a size as to make the parallel circuit resonant at the frequency of the voltage applied thereto. A magnetically-controlled tube of the type described above operates so that when a positive voltage is impressed upon the anode, starting of current between the cathode and anode will be delayed until the magnetic field created by the control magnet falls from a predetermined value. In many instances this value may be substantially zero. In order to supply the device with power, a transformer 28 is provided. The transformer 28 has a primary winding 29 which may be connected to some suitable source of alternating current, and a secondary winding 30 . The secondary winding is provided with a tap 31 intermediate the ends thereof and preferably at the central point thereof. One end of the secondary winding 30 is connected by means of a lead 32 through a suitable load 33 to the anode 20 . The other end of the secondary winding 30 may be connected by means of a lead 34 to the cathode 21 .

In order to supply the control winding 25 with current, a phase-shifting circuit system of a resistance 35 in series with an impedance network 36 is connected between the conductors 32 and 34 . The impedance 36 may consist of a parallel-connected inductance and capacity as illustrated in Fig. 1, or has a series-connected inductance and capacity as illustrated in Fig. 2. In either event, these impedance elements may be variable in the same manner as described in connection with Figs. 1 and 2. The conductor 37 connects one end of the control winding 25 to the point intermediate the resistance 35 and the impedance network 36 . The other side of the control winding 25 is connected by means of a conductor 38 to the center tap 31 on the secondary winding 30 . The symbols E_t , E_c , E_s and E_a have exactly the same meaning in Fig. 3 as in Figs. 1 and 2. However, in Fig. 3 the voltage E_s is connected directly across the cathode and anode, while the control voltage E_c is connected across the ends of the control winding 25 . In Fig. 3, since the circuit of the control winding 25 may be entirely separate from that of the tube 18 , the voltage impressed across the said tube may be any proportion of that of the secondary winding 30 , or may be supplied to said tube by a separate transformer or transformer winding. An important difference is that although in the case of a grid control tube it is possible to excite the control circuit from a separate transformer, it is not necessary in a magnetic control circuit to have a connection between the midpoint of this secondary and the cathode of the tube.

The vector diagrams of Figs. 4 and 5 apply with equal force to the arrangement as shown in Fig. 3, and represent the variations between the control voltage applied to the control winding 25 and the voltage E_s which is impressed upon the electrodes of the tube 18 .

Fig. 6 also illustrates the characteristics of the arrangement as shown in Fig. 3. In Fig. 6 75

along the lower horizontal axis is plotted the phase angle of the control voltage E_c with respect to the anode voltage. The control in this case is dependent upon the magnetic flux throughout the tube which is in phase with the current flowing through the control winding 25. This current, however, lags the control voltage E_c by 90 degrees, and therefore the control characteristic is shifted 90 degrees along the horizontal axis of Fig. 6. As long as an appreciable amount of flux passes through the discharge path, the starting of the current is delayed. This delay is independent of the direction of the magnetic flux, and therefore displacing the flux 180 degrees makes no difference in the control which is obtained. Therefore, the control characteristic is repeated each 180 degrees when this magnetic type of control is used. Thus in Fig. 6 the falling characteristic which occurs from a value of 90 degrees leading through a value of zero degrees to 90 degrees lagging is repeated from the value of 90 degrees lagging through 180 degrees to 90 degrees leading. The latter part of this characteristic is shown by the dotted curve to distinguish it from the electrostatic control in this region. It will be noted that when an electrostatic tube is used, the current output from the tube is a maximum throughout this latter region.

When a parallel LC circuit is used in Fig. 3, the analysis given in Fig. 4 applies. From this it will be seen that the control voltage E_c may be varied from a value greater than 90 degrees leading through 180 degrees to a value of greater than 90 degrees lagging. Thus the entire drooping curve characteristic shown in Fig. 6 can be secured with complete and continuous control throughout this region. Furthermore, the sudden transition from maximum to zero and from zero to maximum which occurs at the opposite ends of the dotted line control region can likewise be secured. When the series LC circuit is used in Fig. 3, the analysis given with respect to Fig. 5 applies. This shows that the control voltage E_c may be varied from a value of less than 90 degrees leading through a value of 180 degrees to a value of less than 90 degrees lagging. Under these conditions the entire solid line drooping characteristic in the first part of Fig. 6 is obtained. This shows that a continuous and complete control from maximum to zero may be obtained with either a series or parallel LC circuit with the arrangement as shown in Fig. 3. Also under these conditions, the sudden change from maximum to zero and zero to maximum current output which occurs at the ends of the solid drooping characteristic region can likewise be secured. The foregoing demonstrates that with a magnetic control tube and either a parallel or series LC circuit in the phase-shifting network, all of the desired results as described above are obtainable.

In all of the foregoing analysis, ideal conditions were assumed, including the fact that the parallel circuit consisting of the control coil 25 and the condenser 27 is resonant and draws no current. In actual practice, this is substantially true. Moreover, I have found that if the impedance of the parallel circuit of the coil 25 and condenser 27 is three times the value of the resistance R , or more, there is also no appreciable deviation from the analysis as given above. As a matter of fact, in some instances the condenser 27 may be omitted entirely.

Of course it is to be understood that this invention is not limited to the particular details

as described above inasmuch as many equivalents will suggest themselves to those skilled in the art. For example, instead of using the particular magnetic control tube described, any tube in which the starting of current is controlled by a magnetic field could be constructed to utilize the principles of my invention. Furthermore, it will be seen that one of the fundamental features of my invention is the production of a phase shift between the control voltage and the current which flows through the control circuit, as exemplified by the arrangement illustrated in Fig. 3. Therefore, any tube in which the starting thereof is made responsive to the flow of current through a control circuit likewise could be made to utilize the foregoing principles of my invention. Various other modifications of the invention described herein will also suggest themselves to those skilled in the art. It is accordingly desired that the appended claims be given a broad interpretation commensurate with the scope of the invention within the art.

What is claimed is:

1. In combination, a source of alternating current voltage, a gas or vapor-filled space discharge tube provided with electrodes, means for impressing said alternating current voltage across said electrodes, electromagnetic control means for impressing a magnetic field on the discharge path between said electrodes for controlling the starting of current flow between said electrodes, a phase-shifting circuit associated with said source of alternating current voltage, said phase-shifting circuit comprising a resistance in series with an inductance and a capacitance, one of which is adjustable with respect to the other up to a value at which the impedances of said inductance and said capacitance are equal, and means for impressing a phase-shifted control voltage from said phase-shifting circuit upon said control means for energizing said control means.

2. In combination, a source of alternating current voltage, a gas or vapor-filled space discharge tube provided with electrodes, means for impressing said alternating current voltage across said electrodes, control means for controlling the starting of current flow between said electrodes, a control circuit associated with said control means, said control means being responsive to current flowing through said control circuit, a phase-shifting circuit associated with said source of alternating current voltage, said phase-shifting circuit comprising a resistance in series with an inductance and a capacitance, one of which is adjustable with respect to the other up to a value at which the impedances of said inductance and said capacitance are equal, means for impressing a phase-shifted control voltage from said phase-shifting circuit upon said control circuit, and means in said control circuit for producing a substantial phase displacement between said last-named voltage and the current flowing in said control circuit.

3. In combination, a source of alternating current voltage including a transformer winding, a tap on said winding intermediate the ends thereof, a gas or vapor-filled space discharge tube provided with electrodes, means for impressing across said electrodes a voltage substantially in phase with the voltage across said transformer winding, control means for controlling the starting of current flow between said electrodes, a phase-shifting circuit connected across said transformer winding, said phase-shifting circuit

comprising a resistance in series with an inductance and a capacitance, one of which is adjustable with respect to the other up to a value at which the impedances of said inductance and said capacitance are equal, and means for impressing on said control means the voltage appearing between said intermediate tap and the point between said resistance and said combined inductance and capacitance.

4. In combination, a source of alternating current voltage including a transformer winding, a tap on said winding intermediate the ends thereof, a gas or vapor-filled space discharge tube provided with electrodes, means for impressing across said electrodes a voltage substantially in phase with the voltage across said transformer winding, electromagnetic control means for controlling the starting of current flow between said electrodes, a phase-shifting circuit connected across said transformer winding, said phase-shifting circuit comprising a resistance in series with an inductance and a capacitance, one of which is adjustable with respect to the other up to a value at which the impedances of said inductance and said capacitance are equal, and means for impressing on said control means the voltage appearing between said intermediate tap and the point between said resistance and said combined inductance and capacitance.

5. In combination, a source of alternating current voltage, a gas or vapor-filled space discharge tube provided with electrodes, means for impressing said alternating current voltage across said electrodes, electromagnetic control means for impressing a magnetic field on the discharge path between said electrodes for controlling the starting of current flow between said electrodes, a control circuit associated with said control means, said control means being responsive to current flowing through said control circuit, a phase-shifting circuit associated with said source of alternating current voltage, said phase-shifting circuit comprising a resistance in series with an inductance and a capacitance, one of which is adjustable with respect to the other up to a value at which the impedances of said inductance and said capacitance are equal, means for impressing a phase-shifted control voltage from said phase-shifting circuit upon said control circuit, and means in said control circuit for producing a substantial phase displacement between said last-named voltage and the current flowing in said control circuit.

6. In combination, a source of alternating current voltage including a transformer winding, a tap on said winding intermediate the ends thereof, a gas or vapor-filled space discharge tube provided with electrodes, means for impressing across said electrodes a voltage substantially in phase

with the voltage across said transformer winding, electromagnetic control means for impressing a magnetic field on the discharge path between said electrodes for controlling the starting of current flow between said electrodes, a phase-shifting circuit connected across said transformer winding, said phase-shifting circuit comprising a resistance in series with an inductance and a capacitance, one of which is adjustable with respect to the other up to a value at which the impedances of said inductance and said capacitance are equal, and means for impressing on said control means the voltage appearing between said intermediate tap and the point between said resistance and said combined inductance and capacitance.

7. In combination, a source of alternating current voltage, a gas or vapor-filled space discharge tube provided with electrodes, means for impressing said alternating current voltage across said electrodes, control means for controlling the starting of current flow between said electrodes, a control circuit associated with said control means, said control means being responsive to current flowing through said control circuit, a phase-shifting circuit associated with said source of alternating current voltage, said phase-shifting circuit comprising a resistance in series with an inductive and a capacitive reactance, said reactances being relatively adjustable to a value at which said reactances are substantially equal, and means for impressing a control voltage from said phase-shifting circuit upon said control circuit, and means in said control circuit for producing a phase displacement between said last-named voltage and the current flowing in said control circuit.

8. In combination, a source of alternating current voltage, a gas or vapor-filled space discharge tube provided with electrodes, means for impressing said alternating current voltage across said electrodes, control means for controlling the starting of current flow between said electrodes, a control circuit associated with said control means, said control means being responsive to current flowing through said control circuit, a phase-shifting circuit associated with said source of alternating current voltage, said phase-shifting circuit comprising a resistance in series with an inductive and a capacitive reactance, said reactances being relatively adjustable through a value at which said reactances are substantially equal, and means for impressing a control voltage from said phase-shifting circuit upon said control circuit, and means in said control circuit for producing a phase displacement between said last-named voltage and the current flowing in said control circuit.

WILCOX P. OVERBECK.