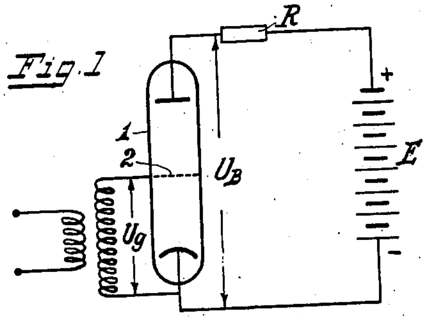
Sept. 29, 1942. **W. O. SCHUMANN** **2,297,256**

TUBE CONTROL

Filed April 10, 1939

Fig. 1



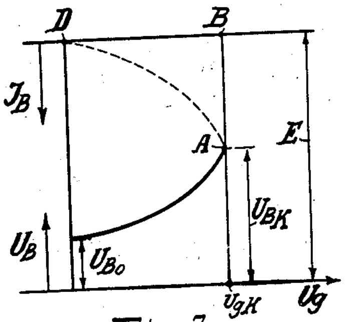
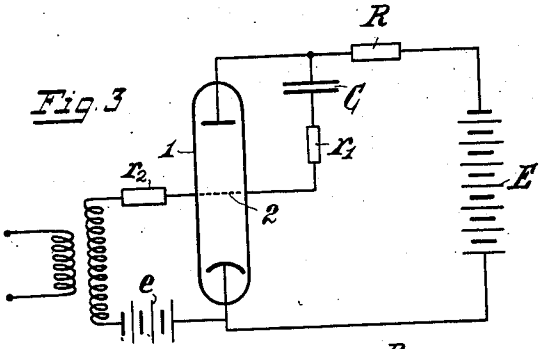


Fig. 2

Fig. 3



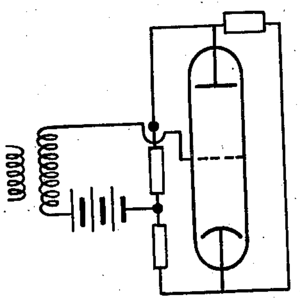


Fig. 6

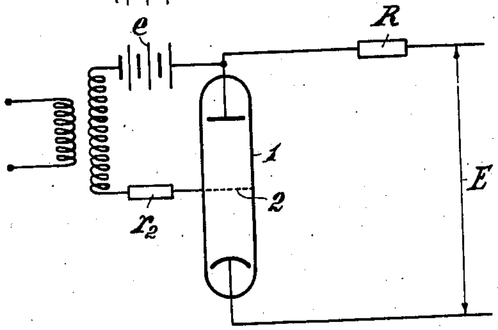


Fig. 4

Fig. 5

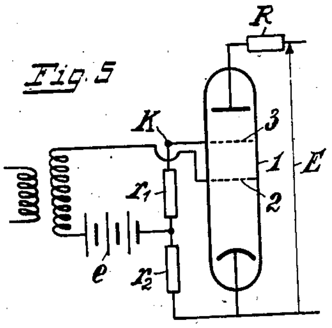
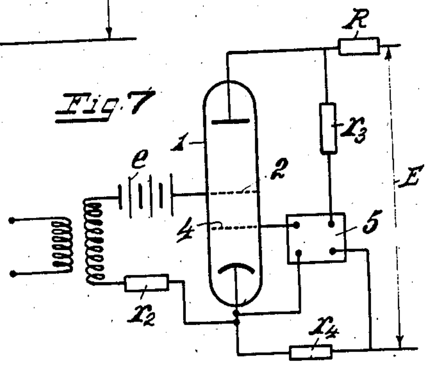


Fig. 7



Winfried Otto Schumann
INVENTOR

By
his ATT'Y.

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UNITED STATES PATENT OFFICE

2,297,256

TUBE CONTROL

Winfried Otto Schumann, Munich, Germany;
vested in the Alien Property Custodian

Application April 10, 1939, Serial No. 267,189
In Germany April 11, 1938

3 Claims. (Cl. 250—27)

The present invention relates to vacuum-arc discharges (e. g. Hg arcs with natural cathode—Hg cathode—or those with artificial cathode—glow cathode—) as well as to arc discharges in gases or other metal vapors at low pressures.

When current of such an arc is regulated by means of a grid which is disposed between anode and cathode and adapted to extinguish the ignited discharge (such as for instance a perforated metal plate or a wire mesh) and which is rendered negative with respect to the arc potential, it will be observed that with the increasing control voltage the burning voltage of the tube grows gradually up to a definite critical value of the grid voltage V_{gK} at which point a sudden breaking off of the current takes place. These proportions are represented diagrammatically in the drawing, in which—

Fig. 1 represents a wiring diagram of a known construction;

Fig. 2 is a graph illustrating the operation of the arrangement shown in Fig. 1;

Figs. 3 to 7 illustrate various embodiments of the present invention.

Fig. 1 shows a circuit arrangement and Fig. 2 a diagram for this circuit arrangement. According to Fig. 1, for instance, a tube **1**, which may be filled with mercury and comprises a grid **2** and a resistance R, are connected in the usual manner to the circuit of a battery E. Instead of the battery, a source of alternating current may of course be used. The grid **2** receives an auxiliary voltage V_g. This voltage may be supplied either by a source of direct current, or as shown by way of example, by a transformer.

In the diagram of Fig. 2 the grid voltage V_g is shown as abscissa and the arc-voltage V_B as ordinate. According to Fig. 1, $V_B=E-J_BR$, in which J_B designates the arc current, so that

$$J_B=\frac{E-V_B}{R}$$

i. e. inasmuch as in Fig. 2, the arc tension V_B is shown as rising from the bottom up, the difference between E and V_B (from the horizontal line with E down to the V_B curve) is proportional to the current J_B.

When working, for instance, with a mercury arc below a certain arc-temperature, the so-called critical temperature, which, if exceeded, entails a very rapid and extremely great diminution of the controlling action of grid **2**, the arc-voltage V_B, at a working voltage E of 110 volts, may be increased up to approximately 50 volts by means of the negative grid voltage, whereupon the current disappears rather quickly. The courses of the arc-voltage V_B and of the arc-current J_B, respectively, are shown in the diagram of Fig. 2, it being assumed that operation takes place below the above-mentioned critical temperature. When using mercury vapor and relatively wide grids of millimeter mesh, this critical temperature lies at about 30 to 40 centigrades. With grids having a closer mesh, the critical temperature lies correspondingly higher. Up to a certain grid voltage V_{gK}, depending on the width of mesh, the current etc., the arc-current may be controlled continuously and in this zone, in the case of mercury arcs, the arc-voltage V_B grows continuously from the ignition voltage V_{BC} (initial voltage) up to approximately 50 volts; this corresponds to the voltage V_{BK}. If one increases the grid voltage still higher, that is if one exceeds the value V_{gK}, the current decreases very rapidly and suddenly disappears in about a few 10^{-5} seconds. In other words, the V_B curve would take a continuous course up to point A shown in Fig. 2, while on passing beyond point A, that is with an increase in the grid voltage V_g beyond the value V_{gK}, the current would suddenly break off. The steadily obtainable maximum arc-voltage V_{EK} is quite independent of the width of mesh of the grid and grows gradually with the source of voltage E in the anode circuit up to about 70 to 80 volts at the most. Heretofore, when it was desired to control the current continuously within the widest possible limits, one had to choose a source of anode voltage E which was not much greater than voltage V_{BK}. But the higher the anode working voltages, the smaller become the current intervals or zones which may be controlled, and the very rapidly disappearing rest of the current (AB in Fig. 2) may cause self-inductions in the anode circuit resulting in excessively high tensions. Special measures were thus required to prevent these excessive tensions.

From the point of view of a continuous control of current as well as for the purpose of avoiding excessively high tensions in the anode circuit it is very desirable to prevent the steep end portion of the current drop (Fig. 2).

The main object of the invention is to prevent the current from breaking off suddenly after reaching point A, while maintaining sufficiently high anode voltages, which according to the embodiment of the invention shown and described lie considerably above the point V_{BK}.

According to the present invention, this result is obtained in such manner that, after the critical zone of control voltage (V_{gK}) is reached, in which upon further increases in the control voltage the current would break off, the control action of the grid is again decreased, by means of the influence of the arc current or the arc voltage, so that the current gradually disappears (curve AB—Fig. 2) with a decrease in the control action (for instance by decreasing grid voltage V_{gK}). The gradual disappearance of the current takes place in accordance with the disappearing grid action, or in other words in the slow manner desired. But if the control action is fixed at any one point on the curve AB, i. e., if it remains constant for a length of time, then the corresponding current J_B remains likewise constant for a length of time. Thus, any desired current may be adjusted between the full value and zero even for any desired length of time.

The appearance of this steep portion of the curve A—B (Fig. 2) is apparently due to the fact that the controlling mechanism becomes unstable when an arc voltage of the critical value V_{BK} is reached. Experiments show that increase in the arc voltage as a result of the control action, namely (V_B—V_{BO}), are caused by changes in the condition of the arc in the apertures of the control grid. Measurements of the voltage distribution along the arc disclose that the portion of the arc, which extends through the grid apertures, as the potential difference of V_B—V_{BO}. Positive ions are withdrawn from the arc at this point by the negative control grid, whereby a decrease in the density of the electrical carriers occurs in the grid apertures. As a result of this decrease in the number of electricity carriers per cubic centimeter, the electrical field, which accomplishes the conveyance of current between anode and cathode, becomes larger at this place, whereby the additional voltage V_B—V_{BO} is created at this place which, in turn, decreases the arc current. Due to the decrease of the arc current the carrier density of the discharge is again decreased which on the other hand, causes an increase in the influence of the grid upon the arc, whereby a further reduction of the carrier density in the grid apertures is produced together with an increase in the value V_B—V_{BO} and simultaneously therewith in the value of the arc voltage. Thus, a decrease in the arc current is produced again etc. In the space between V_{BO} and V_{BK} this process is stable, i. e. to each grid voltage appertains a definite current. However, at point A, this "seesawing" process becomes unstable: the decrease in current and the increase in the grid action are no longer capable of equalizing each other; the positive ionic layers about the grid wires "snap" closed, so to speak, and the current breaks off. (Section AB of the curve in Fig. 2.) The foregoing merely intended to give a fairly clear picture of the processes involved which, in reality are even more complicated.

The ultimate reason for this condition may be that, at this stage, the layers of ions around the wires grow extremely rapidly in thickness with increases in the grid voltage. It might be said that the layers "snap closed," thus breaking the current.

In other words, the grid is too effective in this condition and it must be weakened in its action in order that no "snapping-closed" of the layers of ions may occur.

Such "weakening" of the grid action may be effected in various ways.

The thickness of the layer of ions round the wires depends on the grid voltage supplied, and on the carrier density of the plasma. Influencing either value may lead to the result desired. Thus, any known means may be used for reducing the grid voltage or increasing the carrier density of the discharge, provided these steps are sufficiently dependent upon the arc voltage, the arc current or both.

For instance the voltage at the grid may be influenced in such a way that after reaching the critical value V_{gK} the grid voltage is caused to decrease again, in harmony with the further decrease of the arc current or with the further increase of the arc voltage. Depending upon the length of time required by the grid voltage after passing through V_{gK}, one may achieve that the current either disappears as slowly as desired, or remains constant, or that it increases again, when the grid voltage increases again. Practically this may be done for instance by introducing into the grid circuit a voltage or a voltage limitation derived from the arc current or the arc voltage or their timed increase or from them jointly, which prevent V_g, under any circumstances, from passing beyond V_{gK} so that the layers of ions around the grid wires cannot "snap-closed." Inasmuch as the grid current, generally, is proportional to the arc current in the case of a constant grid voltage, it is possible to influence the current by means of the current of a second grid possessing constant grid voltage. Also, the current of the control grid itself may be used for this purpose, if the control circuit is arranged in such a way that, with decreasing grid current, a sufficient lowering of grid voltage is obtained, for instance by means of resistances dependent on the current. If desired, part of the source of grid current may be arranged in such a way that its voltage depends to a sufficiently large extent on the grid current. In the case of tubes working with highly changeable current, the grid voltage will have to be influenced by the arc current in two ways, so to speak. First, on account of the above mentioned weakening of the grid voltage with disappearing current, and secondly, because higher grid voltages are required for influencing stronger arc currents by means of the grid. In both respects, the influence of the grid voltage on the current requires a corresponding change of the grid voltage with respect to the current, and it is of course desirable to unite them both, if possible, in the same control circuit.

On the other hand, the control grid may also be influenced by means of the arc voltage or alternately, by using the voltage of a conveniently insulated auxiliary grid i. e., a grid which is connected to the cathode for instance across sufficiently large resistances or inductivities (see Fig. 5). During a decrease of the arc current, such a grid imparts a positive voltage to the control grid, i. e. it reduces the negative voltage of the latter against the cathode.

Care should be taken to avoid oscillations for instance by damping resistances connected parallel to coils.

In such cases the current of a vacuum arc may be controlled almost down to zero without break or jump.

A second means of influencing the control grid consists for instance in providing a second grid in the arc. Every control grid has the property of augmenting the carrier density between grid and anode with increasing negative grid voltage, while the carrier density between grid and cathode is influenced comparatively little. Thus, by providing an auxiliary grid between control grid and cathode, the carrier density of the plasma may be adjusted at will between the two grids by means of the voltage of the auxiliary grid. In order to avoid any "snapping" of the layers of ions at the control grid, the plasma carrier density between the two grids must be increased—by increasing the negative voltage at the auxiliary grid—to such an extent during the passage through the critical grid voltage that the layers of ions about the control grid wires cannot "snap-closed." This result may be obtained by coupling the two grid voltages in such a manner that, when the critical voltage V_{gK} at the control grid is reached, the negative voltage at the auxiliary grid increases sufficiently quickly. In this connection the influence of the arc current or of the arc voltage may of course be utilized, as described above. It should be noted that the means for increasing the carrier density of the discharge described above were given merely by way of example.

The methods described are, of course, applicable not only to Hg vapor, but to plasmas in all vapors and gases with direct or alternating current service.

A great many possibilities exist of carrying the inventive thought into practice. All these possibilities have the following in common:

(1) Increase of the grid voltage up to the value V_{gK}.
(2) Pass through this value with constant grid voltage.
(3) After passage through this value, decrease the voltage curve of the grid as desired for any particular purpose.

In other words, it is possible to choose any desired grid voltage curve, but it is not possible to ever go beyond V_{gK} which, nevertheless, must be passed through.

Fig. 2 shows in dotted lines schematically and by way of example the course of a curve after passing through point A up to point D. From this graph it is clear that, when V_{gK} has been reached and the grid voltage decreases again after point A, the arc voltage V_B increases and the current J_B decreases gradually. The course of curve A—D depends on the extent to which the grid voltage decreases. If the grid voltage is maintained at a certain value lying below V_{gK}, one obtains a corresponding constant current value.

It goes without saying that the entire curve of the grid voltage may also be repeated periodically forward or backward by alternatingly reducing the arc current to zero and then bringing it up to its full value, or vice versa. In all these cases breaking off of the current is avoided and the current is continuously controllable within any desired limits.

To prevent breaking off of the current, one may use in the case of high power currents, for instance, relays known by themselves. These relays, which are influenced by the arc current for instance or by the grid current, or by the arc voltage or by the voltage from an auxiliary grid disposed between anode and control grid and connected for instance through a throttle coil or a resistance with the cathode, lower the grid voltage when passing through V_{gK}. Similarly, various back couplings employed in the high frequency field may be used but of course, in differential connection.

Fig. 3 shows for instance a control arrangement for avoiding excessively high voltages. In this arrangement, a condenser C takes care of the return path of the grid voltage. Instead of capacity C an ohm resistance may be used. The resistances r_1 and r_2 serve for proper adjustment.

If in this case the value V_{gK}, that is point A, is reached the anode voltage, as described in connection with Figs. 1 and 2, has the tendency of increasing suddenly and intensively. This growth of the anode voltage affects at once the grid **2**, across condenser C and resistance r_1, in such a way that the negative voltage of the grid decreases as against the cathode. An ordinary preliminary voltage source *e* for grid **2** may be used, if desired.

The embodiment according to Fig. 4 differs from that of Fig. 3 merely in that the reduction of the grid action is effected not capacitively, but directly. The process in itself is the same, that is on reaching V_{gK} the growth of the anode voltage is transmitted directly to the grid circuit so that a reduction of the negative grid voltage is produced.

The form of construction shown in Fig. 5 produces the desired result by means of an auxiliary grid **3** disposed between control grid **2** and the anode. This auxiliary grid **3** is connected to the cathode over point K and the resistances r_1 and r_2.

The two grids **2** and **3** are connected jointly over resistance r_2 with the cathode.

On reaching V_{gK}, i. e. when the tendency exists of passing beyond the value V_{gK}, the voltage of the auxiliary grid **3** increases in the same proportion as the voltage of the anode and acts across resistance r_2 so that a reduction of the grid action of control grid **2** is produced.

If the use of auxiliary grid **3** is not desired, the point K may be connected to the anode, as shown in Fig. 6. In that case, the arc voltage, which increases during a decrease of the current, reacts upon the control grid **2** and reduces the negative voltage of the same as against the cathode.

Fig. 7 shows a modified arrangement in which, by use of an auxiliary grid, the nature of the plasma is altered in such a way that on reaching V_{gK} the control action of the control grid is reduced. The auxiliary grid, designated by numeral **4**, is situated between the control grid **2** and the cathode. Auxiliary grid **4** is connected to a device **5** which is connected in the known manner (for instance amplifier, transformer, compensation circuit etc.) in such a way that the voltage of the auxiliary grid **4** becomes more negative as against the cathode in the breaking off zone. According to this modification, the control action is obtained in dependence upon the anode voltage, across a resistance r_3, as well as in dependence upon the anode current, across resistance r_4. Inasmuch as in this case both the increase of anode voltage and the disappearance of the anode current would render the auxiliary grid **4** more positive if a direct connection with the auxiliary grid **4** existed (a condition which would be favorable if a direct connection with the control grid existed, but which would produce the opposite result in the present case when connected to the auxiliary grid), the device **5** must comprise a means, known in itself, for reversing the direction of these actions.

What I claim is:

1. Method of controlling and extending the field of control over the arc current in a system comprising an arc discharge tube provided with

anode, cathode and control grid, and electricity supplying means for said anode, cathode and grid, which method comprises applying a voltage to the arc discharge tube to form an arc between anode and cathode, applying a voltage to said grid having a negative value as against the discharge plasma, and increasing said grid voltage, whereby the arc discharge voltage is proportionally increased, and continuing to increase said grid voltage until the critical point in the arc voltage is reached, being the point immediately after which the arc current breaks off, and passing through said critical point with a constant grid voltage; thereafter decreasing said grid voltage as slowly as desired and to the desired degree, whereby the arc current may be slowly decreased or maintained at any desired point beyond said critical point, sudden breaking off of the arc current after the critical point being thus prevented.

2. Method of controlling and extending the field of control over the arc current in a system comprising an arc discharge tube provided with anode, cathode and control grid, and electricity supplying means for said anode, cathode and grid, which method comprises applying a voltage to the arc discharge tube to form an arc, imparting a negative voltage to said grid as against the discharge plasma, and increasing this voltage differential between the grid and the plasma, whereby the arc discharge voltage is proportionally increased, and continuing to increase the said differential between grid and plasma until the critical point in the arc voltage is reached, being the point immediately following which the arc current breaks off, and passing through said critical point with a constant grid voltage; thereafter decreasing said differential between grid and plasma as slowly as desired and to the desired degree, whereby the arc current may be slowly decreased or maintained at any desired point beyond said critical point, sudden breaking off of the arc current after the critical point being thus prevented.

3. The method claimed in claim 2, comprising the step of influencing the charge of the plasma in the neighborhood of the grid for the purpose of reducing the influence of the latter.

WINFRIED OTTO SCHUMANN.