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PULSE OPERATED GASEOUS ELECTRON TUBE CIRCUITS

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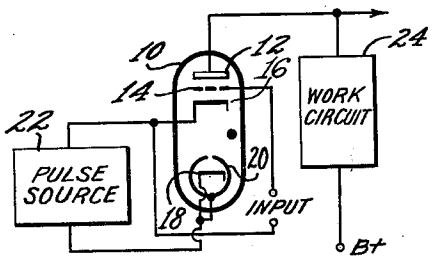


Fig. 1.

Fig. 2.

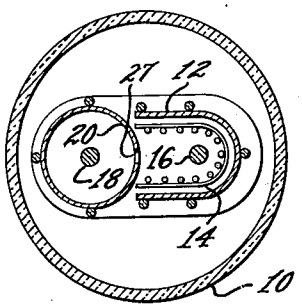
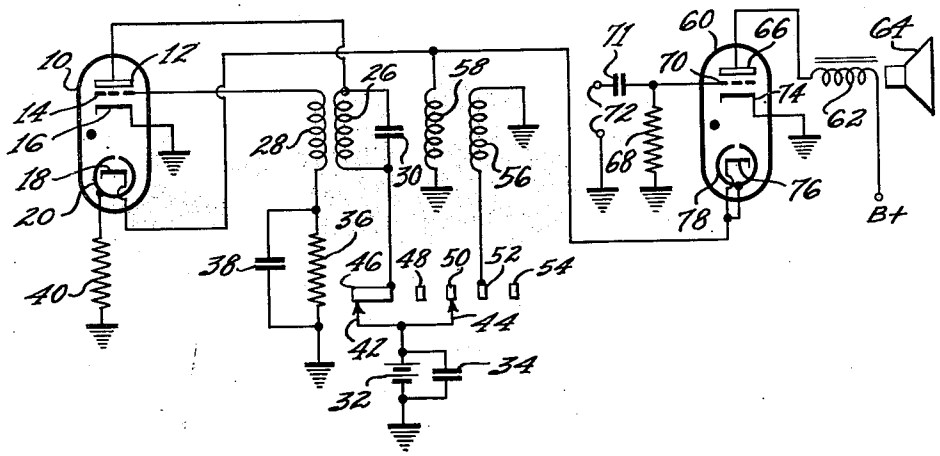


Fig. 3.



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PULSE OPERATED GASEOUS ELECTRON TUBE CIRCUITS

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7 Claims. (Cl. 250—36)

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The present invention relates to improvements in gaseous electron tube systems, and particularly to a method of and an apparatus for operating a gaseous electron tube under conditions such that a relatively high current can be passed through the tube at a potential less than that required to ionize the tube gas.

In a conventional vacuum tube, a control grid placed between the cathode and the anode provides a very efficient means of controlling the tube current. A very small change in the control grid potential will have a relatively large effect on tube current, it being possible to vary the tube current smoothly and continuously within relatively wide limits by varying the control grid potential.

Vacuum tubes, however, are subject to certain limitations due to space charge effects, and usually require high operating potentials. It has been found that these limitations can be overcome by adding a small quantity of gas to the tube and ionizing the gas. If a sufficiently high potential is applied between an emitting and a collecting electrode in the tube, the gas will become ionized by electron bombardment of the gas molecules, thereby developing positive ions which will neutralize the negative space charge of the electron stream. The combined cloud or "plasma" of ions and electrons will act as an excellent conductor, allowing the tube current to rise very rapidly until the full electron emitting capacity of the emitter electrode is being utilized.

In the case of the conventionally operated gas tube, however, it is found that a control electrode has only a "trigger" type of control action. A predetermined negative potential on the control electrode will prevent tube current from flowing. The tube current flow can be started by a suitable decrease in this negative control electrode potential. However, once the tube begins to conduct, the control electrode loses practically all control and the tube current becomes independent of the control electrode potential.

In addition to the loss of control by the control electrode, the conventionally operated gas tube presents a further problem. That is, in general, a certain amount of energy must be given to an atom or molecule in order to cause an electron to be liberated from the energy confines of the atomic structure. In the case of a gas tube, this means that the bombarding electrons must be given a certain minimum velocity in order to provide this minimum amount of energy and thus cause ionization. To give the

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ionizing electrons this minimum velocity, a minimum potential or arc drop must be maintained between the electron emitting electrode and an electron collecting electrode immersed in the gas. This arc drop represents wasted voltage, and is particularly objectionable in any system where voltage is to be transferred from a source to a load through a gas tube transfer circuit with the least possible voltage loss in the transfer circuit.

In a copending application of E. O. Johnson, Serial No. 185,745, filed September 20, 1950, and assigned to the assignee of the present invention, there is described and claimed a gaseous electron tube in which the functions of supplying energy to provide a space charge neutralizing plasma, and of providing a field to draw work current through the plasma, are separated. With a low work circuit energizing potential, it was found that the function of providing plasma would not be taken over by the work circuit. Since the work current is incapable of causing ionization, an auxiliary source of ionizing current is provided to fill the need.

In such a tube structure, it is found that a very high current can be passed between the main emitter electrode and the collector electrode at potentials far below those required to ionize the gas.

It is also found that the current flow between the main emitter electrode and the collector electrode can be controlled in various ways, one of which is by varying the potential of a control electrode as in a conventional vacuum tube.

It is an object of this invention to provide an improved method of and an apparatus for operating gaseous electron tubes which are capable of continuous control grid action.

It is a further object of this invention to provide a gaseous electron tube circuit which is operative from a source of potential having a magnitude which is less than that required to cause ionization of the tube gas.

It is a still further object of this invention to provide a gaseous electron tube circuit which is capable of sustaining ionization by means of the application of A.-C. or D.-C. voltage pulses to the ionizing circuit.

It is another object of this invention to provide a gaseous electron tube oscillatory circuit which is operable from a source of potential of amplitude less than that required to cause ionization of the tube gas.

In accordance with the present invention, there is provided a system wherein space charge

neutralizing ions are generated in a gaseous electron tube by the application of discrete intervals of a potential sufficient to cause ionization of the gas. In accordance with a preferred embodiment of the invention, there is provided an oscillatory circuit and a feedback arrangement such that once the oscillatory circuit has been placed in operation, pulses of sufficiently high potential to cause and sustain ionization will be fed back to the ionizing circuit.

A more complete understanding of the present invention can be had by reference to the following description of illustrative embodiments thereof, when considered in connection with the accompanying drawing, wherein:

Figure 1 is a schematic diagram of a gaseous electron tube system illustrating the general principles of the present invention;

Figure 2 is a view in cross section of a type of gaseous electron tube suitable for use in accordance with the present invention; and

Figure 3 is a circuit diagram of a loudspeaker operating system embodying the present invention.

In the system shown in Figure 1, there is provided a gaseous electron tube **10** having an anode **12**, a control grid **14**, a main cathode **16**, an auxiliary cathode **18** and a focussing electrode **20**. Structural details of the tube **10** are given hereinafter. There is connected between the main cathode **16** and the auxiliary cathode **18**, a pulse source **22**, which may be any convenient source of pulses providing a peak potential or pulse amplitude sufficient to cause ionization of the tube gas. A work circuit **24**, such as an oscillatory circuit, an amplification circuit, a control circuit or any other conventional circuit for operation with an electron tube, is connected between the anode **12** and a voltage source designated "B+".

It has been found that when a gas tube such as the tube **10** is connected as shown, with a pulse source of sufficient amplitude to cause ionization being connected between two spaced electrodes thereof (e. g., the main cathode **16** and the auxiliary cathode **18** of the tube **10**), there will be created and maintained within the tube envelope an effectively "continuous" plasma, provided the amplitude and repetition rate of the applied pulses is sufficiently high. It is, of course, to be understood that the minimum pulse amplitude and repetition rate required to provide a continuous plasma will be determined by the tube geometry, and the particular type and pressure of gas utilized.

Once plasma is provided within the tube envelope, it has been found that the work section of the tube **10** (comprising the anode **12**, the control grid **14** and the main cathode **16**) can be utilized in the manner of conventional electron tubes. An important advantage attained with this arrangement is that the potential drop between the emitting and collecting electrodes immersed in the plasma is very low—of the order of 0.10 volt. Therefore, the voltage loss in such a circuit is extremely small. Furthermore, the current carrying capacities of the work section of the tube are unusually high. The work section of such a tube can be made to handle currents of the order of amperes depending, of course, upon the tube geometry and the type of gas utilized.

One type of gas tube such as may be utilized in accordance with the present invention is shown in cross-section in Fig. 2. Tubes of this type are described in greater detail and claimed in the above-identified copending application of E. O. Johnson.

In the tube shown in Fig. 2, a gas tight envelope **10** is provided with a main cathode **16**. A U-shaped control electrode or grid **14** and a U-shaped anode **12** partially surround the cathode **16**.

Opposite the open ends of the grid **14** and the anode **12** there is mounted a cylindrical focussing electrode **20**, provided with an elongated slot **21** facing the open ends of the grid and anode structures. An auxiliary cathode **18** is mounted coaxially within the focussing electrode **20**.

A tube having a structure such as that shown in Fig. 2 can be operated as follows:

If a voltage greater than the ionizing voltage of the gas in the tube is applied between the auxiliary cathode **18** and the anode **12**, a current will flow which will ionize the gas in the tube. As a result, a highly conductive mixture or "plasma" of ions and electrons will be created within the tube envelope. The focussing electrode **20** is effective to concentrate the ionizing current, making it possible to obtain high plasma densities with very small amounts of current or power. With the tube gas ionized to create plasma in the manner just described, it becomes possible to pass a relatively high current between the main cathode and the main anode with a voltage drop which may be of the order of 0.1 volt or less. Furthermore, it becomes possible to control this main cathode-anode current by means of a control electrode **14** disposed in the space path as shown. In some instances, the focussing electrode is utilized to control the ionizing current in order to control the main tube current. When an A.-C. or D.-C. pulse potential source of sufficient magnitude is connected between the auxiliary cathode **18** and the main cathode **16**, a plasma will be generated within the envelope of the gas tube **10**. Once the plasma has been generated, the work circuit section will operate as a grid-controlled, very low impedance section. It has been found that potentials applied to the control grid **14** will provide control of the work circuit current in the same manner as the grid control provided in the conventional vacuum tube.

The circuit diagram of Figure 3 shows an oscillator circuit with a gas tube **10**, similar to the gas tube **10** illustrated in Figures 1 and 2, for energizing another like tube **60**, used as an amplifier. The oscillator portion of the circuit comprises a pair of inductors **26** and **28** which are inductively coupled to each other and which are respectively connected to the anode **12** and to the control grid **14** of the tube **10**. A capacitor **30** is connected in shunt with the inductor **26** to provide a resonant circuit at any suitable operating frequency. Tests have shown that frequencies as low as sixty cycles or as high as frequencies in the radio range can be employed. A source of direct-current potential, shown as a battery **32** shunted by a bypass capacitor **34**, is connected between a point of fixed reference potential, such as ground, and the tuned resonant circuit **26**, **30** to provide direct-current energizing potential for the gas tube **10**.

In order to provide proper operating bias for the control grid **14**, a high resistance resistor **36** and a shunt connected by-pass capacitor **38** are connected between one end of the grid inductor **28** and ground. The oscillator circuit is completed by connecting a resistor **40** between the focussing electrode **20** and ground.

The battery 32 is connected to the tube 10 by a switch comprising a pair of contact arms 42 and 44 and a plurality of fixed contacts 46, 48, 50, 52 and 54. When the contact arms 42 and 44 are moved to the extreme right, they will engage the fixed contacts 48 and 54, respectively, which will provide an open circuit for the battery 32. As the contact arms 42 and 44 are moved to the left to the position shown in Figure 3, the contact arm 44 first will provide a closed electrical circuit for a starting inductor 56 which is connected between the fixed contact 52 and ground. As this electrical circuit is completed, current will flow through the starting inductor 56. When the switch is moved further to the left to break the circuit through the inductor 56, an induced voltage will be set up in an ionization inductor 58 which is inductively coupled to the starting inductor 56. It is, of course, to be understood that the electrical circuit of the starting inductor 56 is completed only momentarily, as by a switch wiping movement. Accordingly, the change of current through the starting inductor 56 will produce in the ionization inductor 58 a relatively large induced potential having a peak amplitude sufficiently high to cause ionization of the tube gas. At the same time, the other contact arm 42 will remain in engagement with the fixed contact 46 which is connected to the anode 12 of the tube 10.

The ionization inductor 58 is connected between the auxiliary cathode 18 of the tube 10 and ground. Therefore, as current is caused to flow through the starting inductor 56, the induced voltage which is developed in the inductor 58 will be applied between the auxiliary cathode 18 and ground. Since the main cathode 16 of the tube 10 is connected directly to ground, this induced potential is in effect applied between the main cathode 16 and the auxiliary cathode 18 of the gas tube 10. Thus, if the induced voltage is of sufficient magnitude, an ionizing discharge will occur between the main cathode 16 and the auxiliary cathode 18 of the tube 10. Upon ionization of the gas in the tube 10, the oscillator portion of the tube will become operative as a low impedance oscillator.

Oscillatory currents flowing in the oscillator inductors 26, 28 will induce a pulsating voltage in the inductor 58, which is inductively coupled to the oscillator inductors 26 and 28. This voltage induced in the inductor 58 may be the same as or a harmonic of the oscillator frequency. The voltage pulses induced in the inductor 58 readily can be made to be of sufficient magnitudes to cause ionization of the tube gas. If these induced pulses are applied at a sufficiently high rate, the plasma will have not had enough time between pulses to decay below the density required to sustain the work circuit current. If the plasma decay is prevented in this manner, the triode section of the tube 10 will be continuously immersed in a highly conductive plasma and will operate as though plasma were being generated constantly within the tube.

It is, of course, to be understood that the oscillator circuit illustrated in Figure 3 of the drawing is merely representative, and that other well known oscillator circuits could as well be employed in the same manner.

It has also been found that a gas tube energized in the manner disclosed herein can be used to directly drive the voice coil of a loudspeaker because of the low effective impedance of the work circuit section of the tube. For the sake of

clarity, the second gas tube 60 in Figure 3 will be referred to by different reference numerals from those used to refer to the other gas tubes illustrated in the drawing. It is to be understood, however, that this tube is preferably of the same type as illustrated in other portions of the drawing. In Fig. 3, the voice coil 62 of a loudspeaker 64 is connected between the anode 66 of the tube 60 and a source of energizing potential indicated at B+. An input circuit is provided by connecting a grid resistor 68 between the control grid 70 and ground, so that input signals can be applied across the resistor 68 through a capacitor 71 and a pair of terminals 72. The work circuit of the tube 60 is completed by connecting the main cathode 74 directly to ground.

Ionizing pulses are applied between the main cathode 74 and the auxiliary cathode 76 of the tube 60 from the ionizing inductor 58. Of course, this pulse source arrangement is purely illustrative, as any suitable pulse source may be connected between the main and auxiliary cathode of the tube 60. When it is not desired to utilize the focussing electrode 78 as a separate control electrode, it may be connected to the cathode 76, as shown.

As previously described, when pulses of sufficient amplitude and repetition rate are applied between the main cathode 74 and the auxiliary cathode 76 of the tube 60, a plasma will be generated within the tube which will provide a conductive path between the other electrodes immersed in the plasma. Signal potentials applied between the control grid 70 and ground will be effective to control the work current flowing between the main cathode 74 and the anode 76. It has been found that this control is uninterrupted, and is sufficiently linear to provide substantially distortionless output from the loudspeaker 64.

It will be understood that the triode section comprising the cathode 74, the control grid 70 and the anode 66 of the tube 60 can be utilized as a current control device for an electric motor, or for any other purposes for which an electron tube is appropriate.

In the above discussion it has been stated that the repetition rate of the pulses applied to the ionization circuit should be sufficiently high to prevent appreciable decay of the plasma within the tube envelope. Of course, the pulse repetition rate might be less than that required to maintain an uninterrupted plasma. Under these circumstances, however, the triode or work circuit section of the tube will not provide a continuously low impedance path for the work circuit current. If, in a special application, it is desired that the work current be allowed to flow freely only in pulse fashion, it is within the purview of the present invention to use a feedback pulse arrangement of the type disclosed herein as the ionizing pulse source.

It will be appreciated that pulse operation of a gaseous electron tube, as provided by this invention, is predicated only upon the application of pulse energy from a source other than that utilized to energize the work circuit, and not on a particular configuration of electrodes. That is, ionizing pulses of alternating voltage can be applied to a pair of external electrodes, for example, which are so arranged as to establish a pulsed alternating field through the tube gas. It has been found that when discrete pulses of high frequency energy are applied by means of such external electrodes, plasma generation occurs

within the tube gas in substantially the same manner as though the energizing field were established within the confines of the tube envelope.

Due to the inductive "kick" arrangement provided by the coupled inductors **56** and **58**, it is possible to use as an energizing source a battery **32** of potential less than that required to cause ionization of the gas in the tube **10**. After ionization has occurred and the oscillator portion of the tube **10** is oscillating freely, the potential required to cause ionization is provided by the oscillator circuit through the inductively coupled ionization inductor **58**. There is thus provided a gas tube circuit which may be operated from a voltage source as low as six volts and which may provide in its output circuit alternating current voltages in the order of 100 volts and more.

It should be clear from the above discussion that the present invention provides a means for and a method of operating a continuously controlled gas tube with a source of energizing potential less than that required to ionize the gas, as well as a means for and method of maintaining continuous conduction in the work circuit of the tube by pulsing the ionization circuit from a suitable pulse source.

What is claimed is:

1. The method of controlling a flow of electrons from an electron emitter to the electron collector electrode in a gas filled electron tube having a pair of emitter electrodes and a collector electrode, said method comprising the steps of impressing voltage pulses of amplitude sufficient to ionize the tube gas between said pair of electron emitter electrodes, impressing a separate potential between one of said emitter electrodes and said collector electrode, and impressing a variable control potential between one of said electron emitter electrodes and an electrode adjacent to said one electron emitter electrode.

2. A gas tube system comprising a gas filled electron tube having an anode, a main cathode and an auxiliary cathode, a source of voltage pulses of amplitude sufficient to ionize the gas in said tube, a circuit connecting said voltage pulse source between said main cathode and said auxiliary cathode to ionize the gas in said tube in periodic bursts, a load device, and a circuit separate from said first named circuit connecting said anode to said main cathode through said load device.

3. A gas tube system comprising a gas-filled electron tube having an anode, a control grid, a main cathode and an auxiliary cathode, a source of voltage pulses of amplitude greater that that required to ionize the gas in said tube, said pulse source being connected between said main cathode and said auxiliary cathode, a voltage source, a work circuit connecting said main cathode to said anode through said last named voltage source, and means to control the voltage on said control electrode.

4. In a circuit of the type comprising a gaseous electron tube having a plurality of electrodes including an anode, a control grid, a main cathode and an auxiliary cathode, the combination of a pair of oscillator inductors respectively electrically connected with said control grid and said anode, a source of energizing potential connected to said anode inductor and being capable of providing a potential less than that required to cause ionization of the tube gas, and a feedback inductor coupled with said oscillator inductors and electrically connected to said auxiliary cathode to provide between said auxiliary cathode and said main cathode voltage pulses of amplitude sufficient to cause ionization of the tube gas.

5. In a circuit of the type comprising a gaseous electron tube having a plurality of electrodes including a grid controlled section and an auxiliary cathode, the combination of a switch having a plurality of fixed contacts and a pair of movable contact arms, an oscillatory circuit including an inductor coupled between said grid controlled section and one of said contacts, a feedback inductor inductively coupled with said oscillatory circuit inductor and connected between said auxiliary cathode and a point of fixed reference potential, a source of energizing potential less than that required to cause ionization of the tube gas, said source of potential being connected between said switch contact arms and said point of fixed reference potential, and a starting inductor inductively coupled with said feedback inductor and connected between another of said switch contacts and said point of fixed reference potential, the arrangement being such that movement of said contact arms, to respectively engage said one contact continuously and said other contact temporarily, will energize said starting inductor and cause a potential sufficient to ionize the tube gas to be applied between said auxiliary cathode and another of said electrodes.

6. In a circuit of the type utilizing a gaseous electron tube including an anode, a control grid, a main cathode and an auxiliary cathode, the combination of a switch having a plurality of fixed contacts and a pair of movable contact arms, a tuned resonant circuit connected between said anode and one of said switch contacts, an oscillator inductor connected to said control grid and inductively coupled with said tuned resonant circuit, a feedback inductor inductively coupled with said oscillator inductor and connected between said auxiliary cathode and a point of fixed reference potential, a source of energizing potential, less than that required to cause ionization of the tube gas, connected between said pair of movable contact arms and said point of fixed reference potential, and a starting inductor inductively coupled with said feedback inductor and connected between another one of said switch contacts and said point of fixed reference potential so that movement of said contact arms, to sequentially engage said contacts, temporarily will energize said starting inductor and cause a potential sufficient to ionize the tube gas to be developed by said feedback inductor.

7. In a circuit comprising a gaseous electron tube having a plurality of electrodes including a grid controlled section and an auxiliary cathode, the combination of a switch including a pair of contacts and a pair of contact arms, said pair of contacts being so positioned relative to said respective arms that one of said pair of arms continuously engages one of said contacts while simultaneously the other of said pair of arms temporarily engages the other of said pair of contacts, an oscillatory circuit including an inductor connected between said grid controlled section and said one contact, an output circuit coupled to said oscillatory circuit, a feedback inductor inductively coupled with said oscillatory inductor and connected between said auxiliary cathode and a point of fixed reference potential, a source of energizing potential less than that

required to cause ionization of the tube gas, said source being connected between said oscillatory circuit inductor and said point of fixed reference potential, and a starting inductor inductively coupled with said feedback inductor and connected between said other switch contact and said point of fixed reference potential whereby movement of said contact arms, to respectively engage said one contact continuously and to engage said other contact temporarily will connect said source of potential to said oscillatory circuit continuously and to said starting inductor temporarily to produce in said feedback inductor a potential sufficient to ionize the tube gas.

IRVING WOLFF.

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