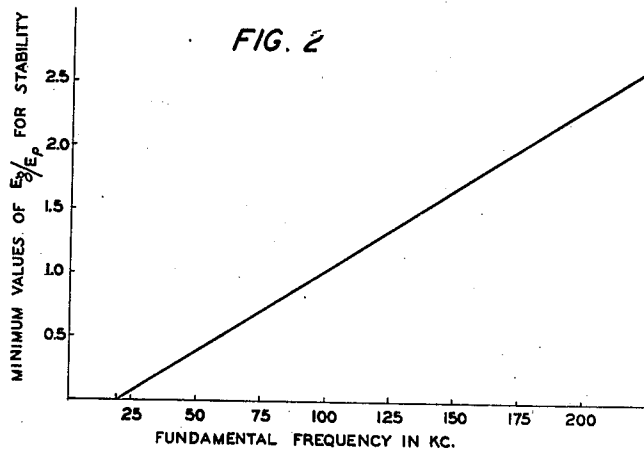


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ELECTRICAL CIRCUIT EMPLOYING GRID-CONTROLLED GAS DISCHARGE TUBES

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ELECTRICAL CIRCUIT EMPLOYING GRID-CONTROLLED GAS DISCHARGE TUBES

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The invention relates to electrical circuits and particularly to such circuits employing gas-filled space discharge tubes of the grid-controlled type, so-called "thyatron" tubes.

Because of their low impedance, relative lack of inertia and ability to handle large currents, "thyatron" tubes have been found useful as switching devices in electrical circuits for many different purposes. Among the important applications of such tubes are in harmonic, subharmonic and pulse generating circuits, and in sweep circuits for cathode ray oscillographs.

An object of the invention is to improve the efficiency of operation of grid-controlled gas-filled tubes in such circuits, particularly at high frequencies.

All circuits employing gas tube switching are eventually limited in the frequency of operation by the time required for the tubes to de-ionize and to a lesser extent by the ionization time, which times in turn depend on the ratio of the amplitude of the grid potential to the amplitude of the plate potential. Applicant has found that at high frequencies stable operation of such circuits requires that the ratio of control grid potential swing to plate potential swing be maintained above a critical value. If this critical ratio is not exceeded the gas tube will fire at different phases of the applied control voltage on successive cycles. This results in some cases in the production of undesired harmonics and in other cases in an excessively noisy output for the circuit. Applicant has also found that the value of this critical ratio increases as the fundamental frequency of the applied control voltage increases. A relatively high vapor pressure of the gas in the tube is often desirable to improve the form of the output wave, and it is found that this increase in pressure increases the critical ratio of grid potential swing to plate potential swing to maintain stability.

A large potential grid swing for a gas tube is desirable since the negative excursion of the potential of the control grid with respect to that of the cathode aids in de-ionizing the tube. The undesirable feature of the large grid potential swing is that during the positive excursion of the grid potential a large electron current will be drawn to the grid which must be dissipated in the grid impedance. This causes a large loss in power and reduces the efficiency of the tube as a switching device.

One might think that the positive excursion of the grid potential with the resultant bad effects could be eliminated by applying a fixed biasing

voltage to the grid so that it could just become sufficiently positive to trigger the tube. However, this is not the case if the grid control voltage is sinusoidal in form, as is usually required in such switching circuits, since under these circumstances the potential of the grid at the instant of firing is changing very slowly. In order to avoid variations of the firing phases caused either by fluctuations of the control wave or the statistical nature of the triggering process of a grid-controlled gas tube, it is necessary that the potential of the grid should be changing rapidly at the instant of firing. Another possible remedy would be pulse triggering but this would require auxiliary equipment the added power losses of which may nullify the advantages of the method. Still another possible remedy would be the inclusion of a large resistance in the grid circuit. However, an increase in the grid resistance requires a corresponding increase in the control potential applied to the grid to maintain stability. That is so because during the interval that the control grid potential is negative a definite amount of charge would be swept from the tube which requires that the potential of the grid be above some definite value. If additional resistance is inserted in the grid circuit the positive ion current will cause a potential drop in the resistance which must be compensated for by further increase in the grid potential swing with a consequent increase in power losses and reduction in efficiency.

In accordance with the present invention the above object is realized without the undesirable features above-mentioned by a circuit arrangement which will provide a low grid circuit impedance for the gas tube when its grid is driven negative, to aid de-ionization, and a high grid circuit impedance during the period in which the grid is driven positive by the applied alternating control voltage, to avoid power losses. In one embodiment, this is accomplished by the use of a properly poled diode shunted by a high resistance, in series with the control grid circuit of the gas tube.

The objects and features of the invention will be better understood from the following detailed description when read in conjunction with the accompanying drawing in which—

Fig. 1 shows schematically a gas tube harmonic producing circuit embodying the invention; and,

Fig. 2 is a curve illustrating an observed requirement for efficient operation of a grid-controlled gas discharge tube fulfilled by the circuits of the invention.

The harmonic producing circuit of Fig. 1 except for modification in accordance with the invention is similar to that disclosed in the U. S. Patent No. 2,174,165 issued September 26, 1939, to Eugene Peterson. In the circuit an alternating sine wave source 1 of fundamental frequency f is connected across a resonant circuit comprising the condenser 2 and the inductance coil 3, tuned to that frequency. The terminals of the inductance 3 are connected in series with the impedance 4, which may comprise a series resistance or such a resistance shunted by an inductance, across a circuit comprising the condenser 5 and the resistive impedance 6 in series, the latter circuit being connected in shunt with the plate and cathode of the three-electrode gas-filled space discharge tube 7. The source 1 is also connected across the control grid and cathode of the tube 7 through the series resistance 8 and the parallel-connected diode rectifier 9.

The wave of the frequency f from the source 1 flowing through the series resonant circuit 2, 3, develops a voltage drop across the inductance 3, which charges the condenser 5 through the impedances 4 and 6. The alternating wave from the source 1 is also impressed on the control grid of the tube 7 through the resistance 8 causing that tube to be made conductive periodically.

The inductance L_1 of coil 3 and the capacitance C_1 of condenser 2 play the double role of a phase shifting network and a means for obtaining a larger voltage between the points A and B. The impedance Z_p of 4 through which the condenser 5 of capacitance C_2 is charged, isolates the phase shifting network from the discharge path of tube 7 during the period in which the tube 7 is conducting. Thus, it prevents the high harmonics in the pulse produced by the tube from being dissipated in the primary circuit and also limits the primary current which will flow through the tube. By suitable selection of the circuit constants, the phase of the voltage E_g appearing between the grid and cathode of tube 7 is adjusted with respect to that of the voltage E_c across the condenser 5 so that E_c is made as nearly at a maximum as possible when the applied voltage E_g causes the tube 7 to fire. When tube 7 becomes conducting at this point, condenser 5 discharges rapidly through the low impedance offered by tube 7 and the impedance R of 6. The current through the resistive impedance 6 is a pulse which rises sharply at a rate determined by the ionization characteristic of tube 7 and then falls off approximately exponentially at a rate determined by the time constant RC_2 . This pulse contains a large number of harmonics of the fundamental frequency f of source 1, which are of uniform amplitudes over a wide frequency range, which may be taken off from the impedance element 6 and separated by the use of parallel filters or tuned circuits, (not shown) respectively tuned to the different harmonics.

When condenser 5 has discharged, the current through tube 7 will be considerably smaller and the de-ionization of the gas in the discharge space of tube 7 will begin. If a continuous cycle is to be repeated this de-ionization must have reached a definite limit when the plate potential becomes positive on the succeeding cycle.

When gas tube harmonic producers of this general type are operated below a certain frequency limit which depends on the type of tube and the circuit constants employed, no difficulties with incomplete de-ionization occurs regardless of the relative amplitude of the grid and plate voltages.

However, at higher frequencies there may be incomplete de-ionization manifested by the tube breaking down at different plate-cathode potentials. The number of periods of the applied fundamental wave required for a complete cycle of the firing potential depends upon the ratio of the amplitude of the grid-cathode potential to the amplitude of the plate-cathode potential. For values of this ratio above a critical minimum the operation of the circuit is stable, i. e. the firing potential retains the same form from cycle to cycle. For values slightly below the minimum the tube will fire at some value of plate-cathode potential on one cycle, a lower voltage on the next cycle and return to the original voltage on the third cycle, etc. For still lower values the period of charge will last over three cycles and so on for decreasing values of the ratio until finally the tube will break down for every cycle at a low value of plate-cathode potential.

Fig. 2 shows graphically the observed variation of the critical ratio of grid potential swing to plate potential swing, E_g/E_p , required for stable operation with frequency of the control wave source 1, in a gas tube harmonic producer circuit such as shown in Fig. 1. For this particular observation a Western Electric tube 287-A was used and the circuit constants were such that $1/RC_2=132 MC$. One very interesting feature of this curve is that there is apparently an intercept frequency below which the ions need not be drawn out by a field on the grid. Below this threshold frequency the thermal drift of the ions to the tube electrodes and walls complete the de-ionization. The threshold frequency would be expected to be a function of the ion density after the discharge, or in other words, to depend on the discharge constants. Other observations indicated that no critical ratio for stable operation existed at low frequencies, i. e. at frequencies below the critical values plotted in Fig. 2, the tube would ionize at the same value of the plate voltage on successive cycles irrespective of the ratio of the grid and plate potentials. Similar observations with tubes containing gas of different vapor pressures showed that the critical ratios at high pressure were larger than at low pressures.

In the general type of harmonic producer circuit shown in Fig. 1, it was found that the operating efficiency was ordinarily low at the very high frequencies, in the order of 300 kilocycles or more, because of the large potentials required on the control grid circuit to maintain stable operation.

Greatly improved efficiency of operation at such high fundamental frequencies may be attained in accordance with the invention by a circuit arrangement which will make the grid impedance low while the grid is negative to aid de-ionization and high while the plate is positive to avoid power loss. As illustrated in Fig. 1 this may be accomplished by including in series in the control grid-cathode circuit of tube 7 the diode 9 poled in such direction that it conducts when the control grid is driven negative by the applied control voltage, and becomes non-conducting when the grid is driven positive by that voltage, so that electron current cannot be drawn to the grid. In order to avoid any charging difficulties which might arise if the control grid were permitted to float as it would tend to do when the applied control voltage is positive, it might be desirable, as indicated in Fig. 1, also to shunt the diode with a large resistance 8 of the order of one megohm, which is many times the permissible

grid circuit resistance value if the parallel diode 9 is not used.

The use of this grid circuit arrangement would increase the efficiency of operation of the harmonic producer by substantially eliminating the power losses in that circuit. For example, if a Western Electric 323-A tube were used for the tube 7 and the source 1 supplied a control wave of a fundamental frequency 60 kilocycles, without the use of the diode 9 and shunting high resistance 8, the power wasted in the grid circuit would be about 2.92 watts out of a total driving power of 3.65 watts whereas the use of the diode and shunting high resistance should permit the saving of, conservatively, 90 per cent of this wasted power thus reducing the input power to about 1.0 watt.

Another means of producing a similar effect would be to drive the grid with a distorted sine wave having the positive lobes eliminated. Such a wave might be obtained by means of a triode driven beyond cut-off in combination with an input transformer to give the right polarity. The diode arrangement, however, provides the simplest means of accomplishing the desired result. Any element whose impedance differs markedly for changes in polarity of the applied currents, for example, a copper oxide or other solid rectifier might be used in place of the diode 9.

The arrangements of the invention are applicable to produce similar improved results for grid-controlled gas tubes employed in circuits other than harmonic producers. For example, applicant has observed that the action of a gas tube sweep circuit for a cathode ray oscillograph fails at high frequencies for the same reasons given above for the gas tube harmonic producer, and may be improved by the circuits of the invention. In general, applicant's arrangements may be used for improving the efficiency of all switching arrangements employing grid-controlled gas-filled tubes in which to provide the desired switching operation it is necessary to drive the grid through the firing point rapidly, to avoid driving the grid positive, and to have a low grid impedance when the grid is negative.

In the system which has been illustrated and described the same alternating current source is employed for producing the charging current for the capacitor in the anode-cathode circuit of the gas tube and for producing the control voltage for application to the control grid-cathode circuit of the gas tube for periodically causing ionization therein. It is to be understood that the arrangements of the invention are applicable also to a system in which separate alternating current sources are used for these purposes, which sources may be synchronized and of the same frequency or may be of harmonically related frequencies, and to a system in which a direct current source is employed for charging the capacitor and an alternating current source of the proper frequency is employed for producing the ionizing control voltage applied to the control grid-cathode circuit of the gas tube.

Various modifications of the circuits illustrated and described which are within the spirit and scope of the invention will occur to persons skilled in the art.

What is claimed is:

1. A switching circuit comprising a gas-filled space discharge device having a cathode, an anode and a control grid, and circuits therefor, an energy storage device in the anode-cathode circuit of said discharge device, a charging source con-

nected to said energy storage device, means to apply to the control grid-cathode circuit of said discharge device an alternating current wave to periodically cause ionization in said discharge device and allow said energy storage device to discharge therethrough during a part of each cycle of the applied wave, and means to make the series impedance of said control grid-cathode circuit low when the control grid is driven negative, to aid de-ionization, and high when the control grid is driven positive, to avoid power loss.

2. A switching circuit comprising a gas-filled space discharge device having a cathode, an anode and a control grid, and circuits therefor, an energy storage device in the anode-cathode circuit of said discharge device, an alternating current wave source of a given frequency, means for charging said storage device from said source, means to apply to the control grid-cathode circuit of said discharge device an alternating current control wave of a frequency which is the same as that of said source or harmonically related thereto, and which is synchronized with the waves from said source, to periodically cause ionization in said discharge device so as to allow said storage device to discharge therethrough, and means to make the series impedance of said control grid-cathode circuit low when said control grid is driven negative by the applied wave, to aid de-ionization, and high when said control grid is driven positive by the applied wave, to avoid power loss.

3. The switching circuit of claim 1, in which the last-mentioned means comprises an asymmetrically conducting device in series with said control grid-cathode circuit, poled in such a direction that it conducts when said control grid is driven negative and becomes non-conducting when said control grid is driven positive.

4. The switching circuit of claim 1, in which the last-mentioned means comprises a properly poled asymmetrically conducting device in series with said control grid-cathode circuit and a linear impedance element of relatively large impedance value in shunt with said asymmetrically conducting device.

5. The switching circuit of claim 2 in which the last-mentioned means comprises a diode in series with said control grid-cathode circuit, poled in such a direction that it conducts when said grid is negative and becomes non-conducting when said grid is positive, and a linear resistance of high value in shunt with said diode.

6. The switching circuit of claim 2 in which the same source is used for charging said energy storage device, and for supplying the control wave for causing ionization in said discharge device.

7. The switching circuit of claim 2 in which the constants of the circuits of said space discharge device are selected so that the ratio of the amplitudes of the potentials on the control grid and anode of said discharge device are maintained above the critical value which must be exceeded to maintain stable operation of said switching circuit.

8. In combination with a harmonic producer employing a gas-filled electron discharge device having a control grid, a cathode and anode, and circuits therefor, to time the charging and discharging of an energy storage device in the anode circuit in response to an alternating current wave of a given base frequency applied to the control grid circuit, to produce impulses containing harmonics of said base frequency, means

to improve the efficiency of operation of said harmonic producer at high base frequencies, comprising means for maintaining the ratio of the amplitudes of the control grid and plate potentials above that critical value which must be exceeded to make the operation of said gas-filled discharge device stable, and means to make the series impedance of said control grid circuit low when said control grid is driven negative by the applied alternating current wave to aid de-ionization in said discharge device, and

high when the control grid is driven positive by the applied wave.

9. The combination of claim 8, in which the last-mentioned means comprises a diode rectifier in series with said grid circuit poled so that it conducts when the grid is driven negative and becomes non-conducting when the grid is driven positive, and a resistance of relatively high value in shunt with said diode.

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