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DEVICE CONTAINING ELECTRON TUBES FOR AUTOMATICALLY
STABILIZING HIGH-VOLTAGE SOURCES WITH
SYMMETRICAL POTENTIAL DISTRIBUTION
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Fig. 1.

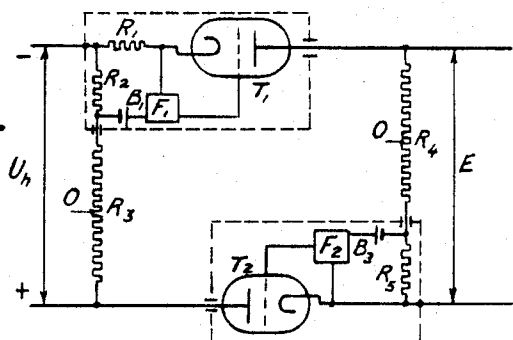


Fig. 2.

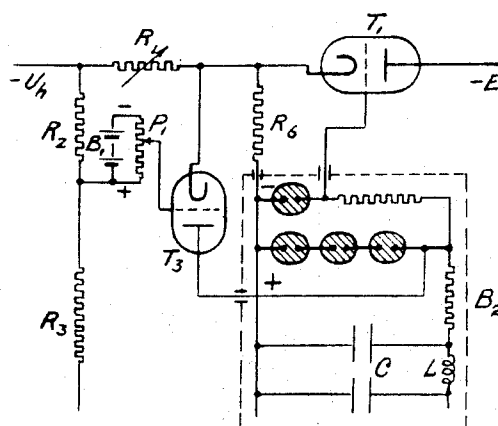
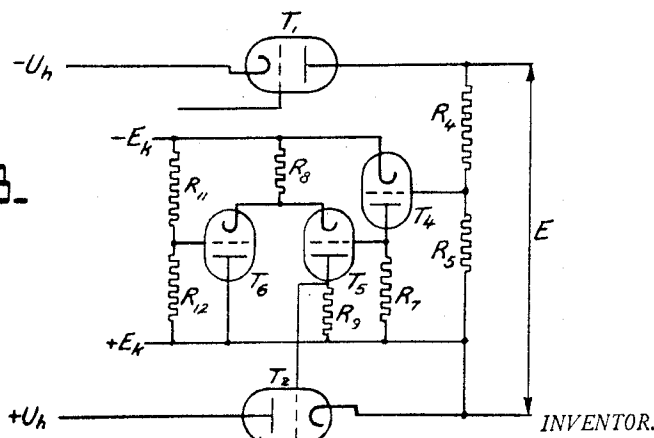


Fig. 3.



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DEVICE CONTAINING ELECTRON TUBES
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The present invention relates to devices for automatically stabilizing high voltage sources by means of electron tubes inserted directly in the high voltage circuit in series with the load and acting to maintain constant the output voltage at a predetermined value and simultaneously to maintain symmetrical the voltage distribution relatively to an earthed center point or a center point with a fixed potential relatively to ground independently of the variations of the input voltage.

The devices are especially intended for stabilizing high voltage sources used for the production of radiation, such as X-rays generators for medical or technical purposes, but the same means may also be used for other purposes in science and technics, without making any principal alterations therein.

The use of electron tubes in voltage stabilization is not new, a variety of different circuits being described in the literature some of which are widely used in practical technics. All different methods, however, are based upon the same fundamental property of grid controlled electron tubes, i. e. that their anode voltage is a function, especially a linear function of their control grid potential, thus the tube can be used as a substitute for an automatically variable ohmic resistance.

This tube operating as a resistance can therefore be inserted in series or in parallel with the output load, the grid potential being varied in a suitable way to maintain constant the output voltage.

Electron tube stabilizers are chiefly used in connection with low or medium voltages, but have also been applied for high voltage in the order of 100 kv. for producing radiations, especially intended for scientific purposes. Those stabilizers are usually provided with a stabilizer tube in the positive branch of the high voltage circuit and are preferably used with the cathode of the electron tube grounded to give a high voltage source with grounded positive pole and negative pole at high tension, an arrangement which is often very advantageous.

In connection with X-ray generators for medical purposes, electron tube stabilizers of the said type are not so much used, in spite of the existing need for the highest possible constancy and exact reproduction of the working conditions. The decisive reason for this fact is that modern X-ray generators usually give a symmetrical high voltage relatively to a grounded center point, an arrangement which is of fundamental importance

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in connection with the so called shockproof X-ray tubes in combination with high voltage cables with earthed metal sheaths. The insertion of an electron tube as a stabilizing means in the positive high voltage lead will always give a non-symmetrical potential distribution which gives unfavourable working conditions for the generator as well as for the X-ray tube and its cables.

This nonsymmetrical potential distribution is especially important when the high voltage source is a charged condenser which is gradually discharged by the X-ray tube. In this case the potential drop across the condenser may be in the order of 30-50 kv. to give a constant output voltage during the whole exposure, the stabilizer tube will have to compensate this total voltage difference and must consequently introduce a nonsymmetry of the same magnitude in the output voltage.

If high voltage generators with electron tube stabilization are to be commonly used in medical X-ray technics, it seems necessary to bring forward stabilizer circuits and devices which can give a constant output voltage with a symmetrical potential distribution relatively to a center at fixed potential relatively to ground. The object of the present invention is to provide such a stabilizing system which is to be described below with reference to the drawing in which

Fig. 1 shows the principal diagram of a stabilizer having a stabilizing device in the positive as well as in the negative lead,

Fig. 2 shows the "positive" stabilizer, and

Fig. 3 shows the "negative" stabilizer.

An independent stabilization of the positive and the negative voltage, so that the potential distribution relative to a fixed potential is kept symmetrical, may be obtained according to this invention by means of two independently working stabilizer tubes T_1 and T_2 as diagrammatically shown in Fig. 1. Said tubes are inserted directly in the high voltage circuit in such a way that T_1 with its cathode is connected to the negative high voltage pole of the generator and with its anode to the cathode of the X-ray tube, whereas the anode of T_2 is connected to the positive pole of the generator with its cathode connected to the anode of the X-ray tube.

The stabilizer tube T_1 is controlled by means of an electronic amplifier F_1 of linear characteristic, the input of which is connected to the variable contact of a non-inductive voltage divider R_2 , R_3 connected across the input of the stabilizing system. The second stabilizer tube T_2 is controlled by means of another electronic amplifier

F₂ the input of which is connected to the variable contact of a non-inductive voltage divider R₄, R₅ connected across the output of the stabilizing system.

This arrangement acts in such a way that the potential of the respective control grids is varied in a proper way by means of the independent D. C. amplifiers F₁ and F₂ with the consequence that the potential drop across the stabilizer tubes is varied automatically in such a way that the output voltage (the voltage drop across the X-ray tube) is maintained constant, and simultaneously a symmetrical potential distribution relative to a grounded center, or a center with a fixed potential to ground is obtained. According to this principal arrangement both stabilizer tubes including their necessary amplifiers and other equipments are as a whole kept at a high negative or positive potential respectively relatively to the symmetry center of the system and are consequently surrounded by electrostatically shielding metal boxes which are maintained at a high potential and preferably connected with the cathodes of the stabilizer tubes T₁ and T₂ respectively.

Let the unstabilized but symmetrical generator voltage be U_h and the stabilized output voltage be E as in Figure 1, the condition for symmetrical potential distribution in the output voltage is that the potential drop across the tubes T₁ and T₂ in every moment is equal to

$$\frac{U_h - E}{2}$$

When U_h varies the potential difference will have to be distributed in equal amounts on the two tubes, but this demand is not absolute. For all practical purposes a symmetry degree of 3-5% will suffice but the total variations in the output voltage E must be much smaller than this, frequently in the order of 0.1% or even less than 0.01% for special scientific purposes.

According to the above described principal manner of operation the control grids of the tubes are to be supplied with a varying voltage causing the anode voltage to vary in a predetermined manner to fulfill the demands as to stability and symmetry. For both stabilizer units this control is obtained by means of high voltage potentiometers R₂, R₃ and R₄, R₅ connected across the unstabilized input and the stabilized output respectively. The variable voltages from these potentiometers are partly compensated by means of constant potential sources and amplified by the two independently working D. C. amplifiers F₁ and F₂, the resulting voltages preferably being applied to the tubes T₁ and T₂ as negative grid potentials.

According to the invention the stabilizer units are acting independently of each other and in a principally different manner. The "negative" stabilizer unit will have to be a "balanced system" dependent on the potentiometer ratio R₂, R₃, the gain f₁ of the amplifier and the amplification factor μ₁ of the tube T₁. The "positive" stabilizer unit is controlled by negative feed back and is accordingly "auto stable" and does not need any critical tuning. The setting of the potentiometer ratio R₄, R₅ has only a small influence upon the degree of stability, but is a convenient method in regulating the stabilized output voltage.

In this paper the two stabilizer units have been named the "negative" and the "positive" stabilizer respectively and will be separately described in detail with reference to the Figures 2 and 3.

a. The "negative" stabilizer

In Fig. 2 a complete circuit is shown for a negative stabilizing system according to the general principles as described above. T₁ is the electronic stabilizer tube the cathode of which is connected in series with an ohmic resistance R₁ placed in the negative high voltage lead. T₃ is an electronic amplifier tube the cathode of which is connected with the cathode of stabilizer tube T₁. R₆ is a load resistance connected between cathodes of tubes T₁ and T₃, and the anode voltage source B₂, in the embodiment shown a voltage regulated power supply in which the voltage drop across the resistance R₆ may be partly compensated by the voltage drop across one or more glow discharge lamps in the power supply unit. R₂, R₃ is the control voltage divider and B₁ a battery or other constant voltage source shunted by a potentiometer P₁ to give a suitable grid bias of the amplifier tube T₃. By varying the potentiometer P₁ the grid bias of the stabilizer tube T₁ may also be adjusted to a decided value.

The cathode of the stabilizer tube T₁ is principally connected with the negative high voltage pole of the generator and is suitably controlled in such a manner that in a fixed ratio, the variations of the unstabilized input voltage U_h are applied to the control grid of the tube in phase opposition. As mentioned above this is attained by means of a preferably non inductive potentiometer R₂, R₃; the potential drop across the resistance R₂ is partly compensated by the battery B₁ or a similar constant potential source and is applied to the D. C. amplifier F₁. The amplified and phase inversed output voltage of this amplifier is suitably compensated and applied to the control grid of the tube T₁ as a preferably negative grid potential, which will have to vary in the decided way.

In order to obtain the stabilizing effect aimed, it is necessary that the amplification factor of the tube T₁ can be considered as constant within the range of regulation, and assumed the anode current is maintained constant, the potential drop U₁ across the tube will be an approximately linear function of its grid potential U_{g1}. If F₁ has a linear working characteristic and a constant gain f₁, the grid voltage U_{g1} of the stabilizer tube consequently is a linear function of the potential drop across the resistance R₂, which is equal to:

$$U_h \cdot \frac{R_2}{R_2 + R_3}$$

and by critically adjusting R₂ according to the equation:

$$R_2 = \frac{R_2 + R_3}{n \cdot f_1 \cdot \mu_1} \quad (1)$$

(where the sum resistance R₂ + R₃ is approximately constant), the "negative" stabilizer will compensate 1/n of the input voltage variations. If the input voltages is exactly symmetrical, n is equal to 2, and mostly it will differ only slightly from this value. But it is principally possible to obtain a symmetrical output voltage even if the input voltage is considerably non-symmetrical.

Above it has been presupposed that the load current I be constant but this is the case seldom only. To a certain degree the effect of small current variations may be reduced by using a stabilizer tube with a high mutual conductance

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S_1 and a low amplification factor. However, generally a special automatic compensation is necessary to obtain a voltage drop across the tube, which is sufficiently independent of the load current. According to the present invention, for this purpose, a variable ohmic resistance R_1 has been inserted between the negative terminal of the resistance R_2 and the cathode of the tube T_1 , and across this resistance the load current I will produce a potential drop $I \cdot R_1$ acting to alter the effective grid potential of the amplifier tube T_3 .

By adjusting the resistance R_1 according to the equation:

$$R_1 = \frac{m}{f_1 \cdot S_1} \quad (2)$$

and when working on a part of the operating characteristic of T_1 , within which its mutual conductance S_1 may be considered as constant, it may be obtained that its grid voltage will vary linearly as a function of the tube current I , in such a manner that the anode voltage (U_1) of the tube will be approximately independent of the anode current. In the special case, shown in Figure 2, the total potential drop $I \cdot R_1$ is applied to the grid of T_3 , and m is equal to one.

Mostly it is difficult to obtain exact balancing of the system according to the Equations 1 and 2, or the balance will be exact within rather narrow limits only. However, as mentioned above, the voltage symmetry in practice mostly is not very critical, differences of a few percent being allowed. Such a degree of stability easily can be obtained, and in general the adjustments of the resistors R_1 and R_2 can be done once for ever. When the variations in load current I are very great, S_1 will not be sufficiently constant, and it is preferred to vary R_1 in a few coarse steps in connection with the regulation of the X-ray tube current to cover the total operating range.

The potential drop (U_1) across the tube T_1 may be varied at will to obtain proper working conditions by regulating the compensating voltage (B_1) defining the grid potential of the amplifier tube T_3 and consequently the anode voltage of the stabilizer tube T_1 .

By this means it is possible to obtain a symmetrical output voltage at different values of E without disturbing the fixed adjustment of the potentiometer ratio R_2, R_3 .

b. The "positive" stabilizer

The positive stabilizer will now be described with reference to Fig. 3.

As mentioned above, the "positive" stabilizer is controlled in the ordinary way by negative feed back by means of the potentiometer R_4, R_5 which is connected across the terminals of the stabilized output voltage. The principal operation of this type of electron tube stabilizer is well known and need not be described here.

Different types of amplifiers may be used even in the symmetrical stabilizer, but on account of the special operating conditions at high positive potential for the stabilizer tube as well for the amplifier etc., it is important to obtain a compendious and very stable unit with as few voltage sources as possible. From a practical point of view it is of special importance to avoid compensation batteries.

Let the compensation voltage of the amplifiers input, the amplification factor of T_2 and the total gain of the amplifier F_2 be E_k, μ_2 and f_2

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respectively, the stabilizing efficiency of the system is approximately:

$$N \approx \frac{E_k}{E} \cdot f_2 \cdot \mu_2 \quad (3)$$

To obtain a good stabilization it is therefore preferable to use a relatively high compensation voltage as well as a high gain amplifier and a tube T_2 with a high amplification factor; the special amplifier needed should have the following specifications: D. C. amplifier without phase inversion, high amplification, high input compensation potential, elimination of special input and output compensation voltage sources, and if possible all the necessary operating potentials delivered from a single, stable voltage source which is independent of load variations.

An efficient amplifier which fulfil the above mentioned requirements, is shown in Figure 3 in its principal form.

The several stages of the amplifier are all driven by a single, stabilized voltage source with a constant potential E_k , its positive pole being connected to the cathode of the stabilizer tube T_2 . The cathode of the input tube T_4 is connected to the negative terminal of the anode voltage source and its control grid is connected directly to the control potentiometer R_4, R_5 , across the resistance R_5 of which is produced a potential drop of nearly the value E_k which gives a suitable input tube grid potential. In this manner a special input compensation voltage source is avoided, and E_k may easily be given a value which is sufficiently high to produce an efficient stabilization.

The output stage of the amplifier is a D. C. differential stage with two preferably identical tubes connected in parallel and with a common cathode resistance R_6 , the negative terminal of which is connected to the negative pole of the anode voltage source. In the following the tubes will be named output tube T_5 and control tube T_6 respectively. In Figure 3 the control grid of the output tube is connected to the anode resistance R_7 of the input tube T_4 with its grid controlled in an ordinary manner. The grid of the control tube has a fixed potential relative to the negative pole of the voltage source and is connected to the voltage divider R_{11}, R_{12} . To obtain maximum sensibility the anode voltage of the control tube preferably should be maintained constant by directly connecting the anode to the positive pole of the voltage source.

The value of the anode resistance R_8 belonging of the output tube is chosen so that the mean anode current delivers directly the negative grid bias for the stabilizer tube T_2 .

The operation of the amplifier described above is as follows; A voltage variation applied to the input tube T_4 , and the voltage variation from the first stage, now amplified and phase inverted, is applied to the control grid of the output tube to cause an anode current variation in this tube and an inversed current variation of about the same amount in the control tube T_6 , whereby the common cathode is maintained at an approximately constant potential. The same resulting effect can also be obtained by the use of a single tube in the output stage, connecting it in series with one or more neon tubes inserted between its cathode and the negative terminal of the voltage source, providing the output tube with a suitable constant cathode potential.

c. Output voltage regulation

As pointed out above, the regulation of the

output voltage of the total stabilizer device may be performed by varying the potentiometer ratio R_4 , R_5 in the negative feed back control system of the "positive" stabilizer, maintaining the compensation voltage E_k constant.

According to this method the system will attain a new stable condition at a new output potential E , the total voltage variation being absorbed by the "positive" stabilizer tube T_2 , which will be given a new mean anode voltage. In this variation, the "negative" stabilizer tube T_1 will not take part, as the two units are working independently. To obtain a symmetrical output voltage it is necessary to have a simultaneous regulation of the potential drop across the "negative" tube T_1 . As mentioned above, this may be done by varying the input compensation voltage of the amplifier F_1 , without disturbing the balance of the system.

The principle of simultaneous voltage regulation is illustrated in Figure 7a, in which each position of the sliding contact K_1 of the "positive" voltage regulator corresponds to a position of the sliding contact K_2 on the "negative" potentiometer P_1 ; and when moving the two contacts synchronously, a symmetrical output potential may always be attained. The two regulators may have a resistance characteristic allowing continuous voltage regulation, but in practice it is generally more convenient to have a regulation in steps, corresponding steps being adjusted to fulfil the symmetry conditions.

In Figure 7b is shown an arrangement allowing continuous regulation by means of a step switch in combination with a fine regulation between the steps.

As shown in the figure each coarse regulator may have two parallelly mounted identical contact fingers K_1' with the resistances inserted between corresponding contact points, the regulators having synchronously moving sliding contacts between which the fine regulation potentiometer P_2 is connected, the contact handle of which is indicated by F_1 .

At low output potentials, this method of voltage regulation may result in rather high voltage drops across the stabilizer tubes. To avoid unfavourable working conditions of the stabilizer tubes the above mentioned coarse regulators K_1' may be combined with a synchronously moving regulator in the primary of the high voltage transformer, allowing a simultaneous regulation in steps of the unstabilized high voltage U_h .

d. Special arrangements

For many purposes it is necessary to vary the the potential drops of the stabilizer tubes within very wide limits, up to 50 kv., and consequently the variation range of the control grid potentials being in the order of 1000 volts. In combination with apparatus for X-ray diagnostics at high X-ray tube currents, the grid voltage variation may be from negative cut off to positive potential of some hundred volts, resulting in considerable grid currents. Ordinary output stages of control amplifiers will not fulfill these extreme requirements, the above described amplifiers, however, may be modified into a suitable form with rather small alterations.

According to the present invention the fixed load resistance in the anode circuit of the output tube may be substituted by a continuous variable resistance, the momentaneous value of which being a function of the anode current. This is realized by inserting a suitable electron tube, act-

ing as a load resistance (here named "resistance tube" T_4 , Figure 8) in the anode circuit of the output tube. In the cathode circuit of the resistance tube is inserted an ohmic resistance across which the common anode current of the two in series connected tubes produce a voltage drop being applied to the control grid giving same a potential which is a linear function of the anode current. The cathode of the resistance tube is connected with the control grid of the stabilizer tube (T_2 , Figure 8) and its anode is connected to a sufficiently high positive potential relative to the cathode of the stabilizer tube. If the resistance tube is a screen grid tube, a special floating screen grid voltage source is needed.

The above arrangement acts as follows: At a sufficiently high anode current in the output tube, the potential drop across the resistance tube attains a high value to the high negative grid potential, the anode voltage being gradually reduced with the anode current. When the grid potential of the stabilizer tube be positive, the grid current passes the resistance tube without disturbing the normal grid control of the tube.

By using suitable resistance tubes with preferably high amplification factors, the arrangement is equivalent to a very high resistance in the anode circuit of the amplifier tube, giving the amplifier a practical voltage gain very near to the amplification factor of the amplifier tube. In Figure 10 is shown the corresponding arrangement of the amplifier F_1 in the "negative" stabilizer.

By means of the above described arrangement the stabilizer can conveniently be used not only for ordinary symmetrical stabilization but as well to stop the load current effectively by giving the stabilizer tubes sufficiently high negative grid potentials. Such an arrangement is shown in Figure 10, in which a magnetically operated switch S_1 is inserted in the lead between the anode of the input tube T_4 and the control grid of the output tube T_5 . With switch S_1 open the grid of the tube T_5 automatically attains, a grid potential giving a very high potential drop across the resistance tube with the switch closed, the output tube attains a grid potential according to the potentiometer ratio R_4/R_5 giving normal working conditions at constant output voltage E . The magnetic switch is suitably operated by means of thyratrons (Re_1 , Re_2), which are fired by means of positive pulses applied to the grids.

I claim:

1. A system for stabilizing high tension direct current electrical systems, comprising in combination a high voltage source to be stabilized, two operatively independent grid controlled stabilizing valves connected in series in the negative and positive high voltage lead respectively connecting the load with said source, which two stabilizing valves form the stabilizing circuit, a potentiometer connected across the input of said stabilizing circuit, the variable contact of which potentiometer is connected to the input of an electronic amplifier the output of which is connected with the control grid of one of said stabilizing valves producing a voltage which is a linear and phase-inverted function of the unstabilized input voltage, a further potentiometer connected across the output of said stabilizing circuit, the variable contact of said second potentiometer being connected to the input of a second electronic amplifier the output of which is connected with the control grid of the other of said stabilizing valves for producing a grid po-

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tential being a direct linear function of the stabilized output voltage which is applied to the load.

2. A system as claimed in claim 1 and in which the potentiometer connected across the input of said stabilizing circuit is permanently adjusted (or balanced) according to the equation:

$$R_2 = \frac{R_2 + R_3}{n \cdot f_1 \cdot \mu_1}$$

R_2 being the part resistance of the potentiometer connected to the negative terminal of the voltage source, R_3 the other part resistance connected to the positive terminal, n a factor generally nearly equal to 2, f_1 the gain of the amplifier controlling the stabilizing valve in the negative lead, and U_1 the amplification factor of said stabilizing tube, the potential drop of said negative part resistance being partly compensated by means of a constant voltage source to give a proper input grid bias for said amplifier and by regulating said compensating voltage equal to the mean potential drop across said stabilizing tube at will without disturbing the balance of said negative stabilizing system.

3. A system according to claim 1 and in which an ohmic resistance is connected in the cathode circuit of the negatively connected stabilizing tube, whereby a potential drop occurs across said

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resistance which is proportional to the output load current being produced, said resistance having the value

$$R_1 = \frac{m}{f_1 \cdot S_1}$$

wherein f_1 is the gain in the amplifier, S_1 the mutual conductance of the negatively connected valve, $1/m$ of the potential drop $R_1 \cdot I$ being applied to the input of the amplifier (F_1), so that the grid potential of the "negative" stabilizer tube varies approximately linearly with the anode current in said tube in such a way that within wide limits the potential drop across the tube is nearly independent of the output load current.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,835,121	Rentschler	Dec. 8, 1931
2,210,393	Braden	Aug. 6, 1940
2,394,891	Bowie	Feb. 12, 1946
2,434,069	Goldberg	Jan. 6, 1948