United States Patent

Matsui et al.

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[54] **AUTOMATIC CONTROL SYSTEM FOR VARYING A D.C. HIGH VOLTAGE FOR ACCELERATING TUBE OF ELECTRON MICROSCOPE AND THE LIKE**

[72] Inventors: **Isao Matsui,** 1030, Ichige; **Yoshihisa Minamikawa,** 663, Ichige, both of Katsuta-shi; **Shinjiro Katagiri,** 73, Daimachi, Hachioji-shi; **Teruo Nakahara,** 663, Ichige, Katsuta-shi, all of Japan

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[51] **Int. Cl.**..........................**H01j 37/26,** G01n 23/00

[58] **Field of Search**.....250/49.5 R, 49.5 A, 49.5 TE, 250/49.5 PE; 219/121 EB, 121 EM; 315/151, 156, 157, 158, 307; 328/233

[56] **References Cited**

UNITED STATES PATENTS

3,435,187	3/1969	Sciaky	219/121
3,491,226	1/1970	Beadle	219/121
3,358,239	12/1967	Franke et al.	328/233
2,883,544	4/1959	Robinson	250/49.5

Primary Examiner—William F. Lindquist
Attorney—Craig, Antonelli and Hill

[57] **ABSTRACT**

The discharge which occurs in an accelerating tube of an electron microscope is detected by a detector and a comparing circuit determines whether or not the value of the detected discharge is larger or smaller than a predetermined value at which a spark occurs to produce a high level signal or a low level signal, respectively. The d. c. high voltage applied to respective accelerating electrodes in the accelerating tube is decreased or increased in response to said high level signal or said low level signal so as to suppress any undesired large discharge in the tube, and thereby prevent sparking therein.

10 Claims, 6 Drawing Figures

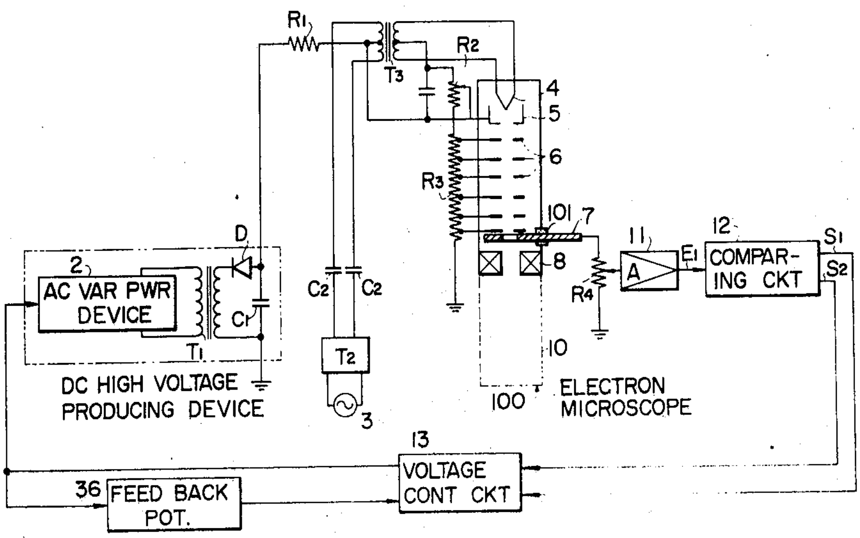


FIG. 1

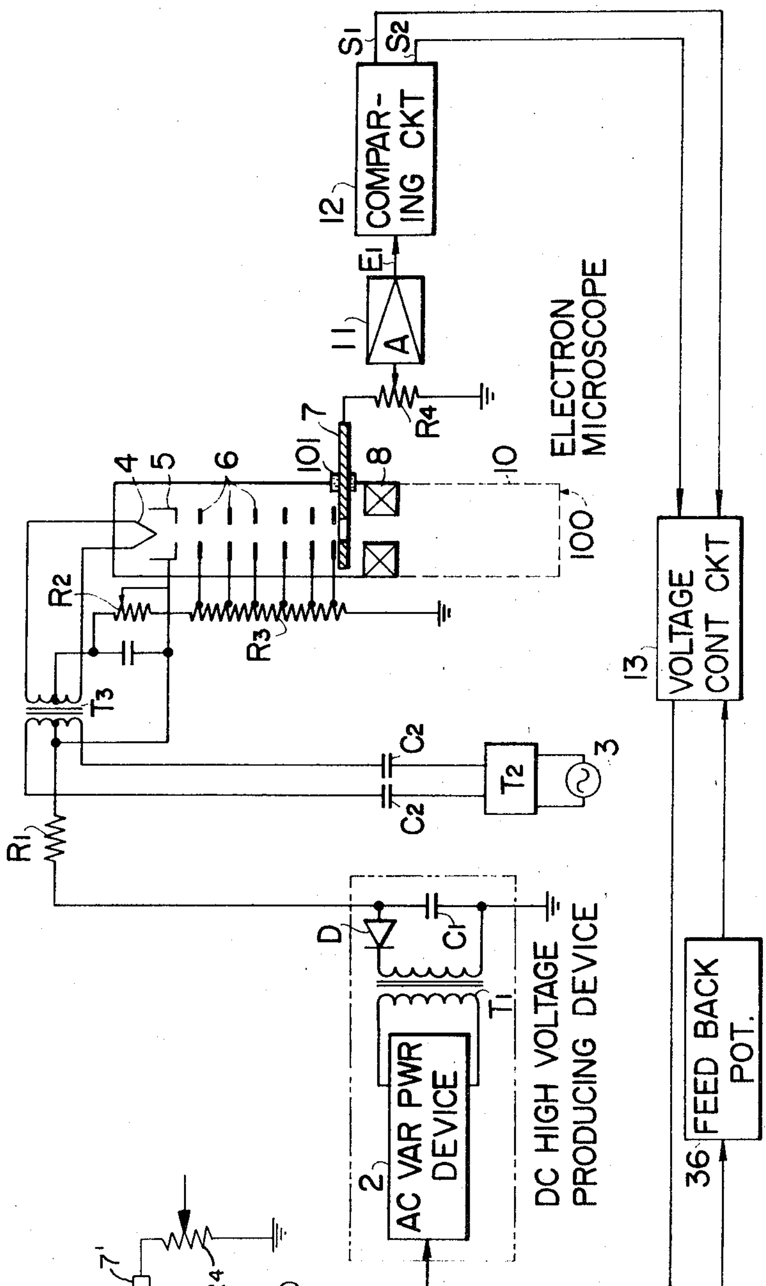
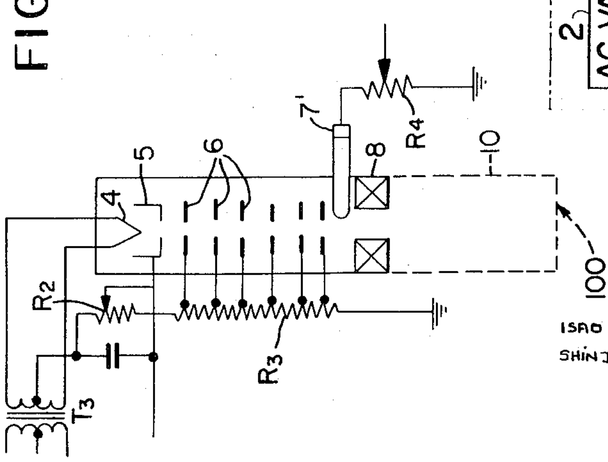


FIG. 6



INVENTORS

ISAO MATSUI, YOSHIHISA MINAMIKAWA

SHINJIRO KATAGIRI AND TERUO NAKAHARA

BY

Craig, Antonelli, Stewart & Hill

ATTORNEYS

FIG. 2

COMPARING CIRCUIT

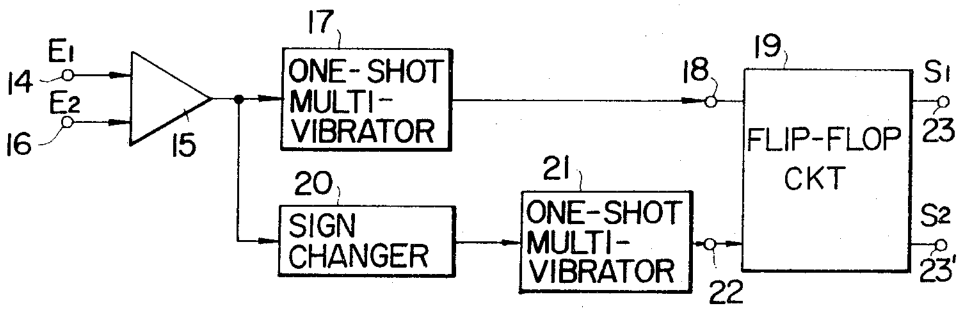
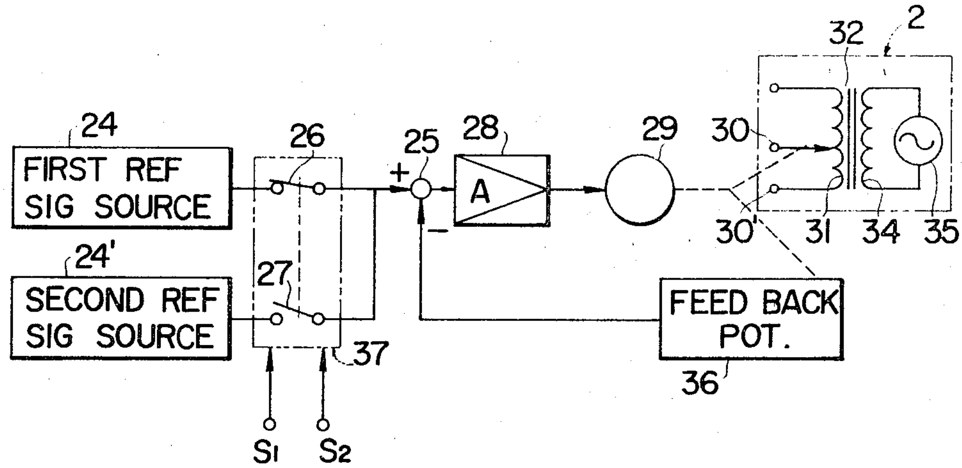


FIG. 3



INVENTORS
ISAO MATSUI, YOSHIHISA MINAMIKAWA,
SHINJIRO KATAGIRI AND TERUO NAKAHARA
BY Craig, Antonelli, Stewart & Hill
ATTORNEYS

FIG. 4

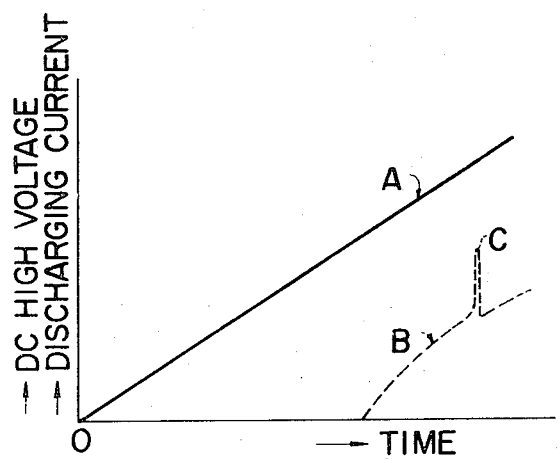
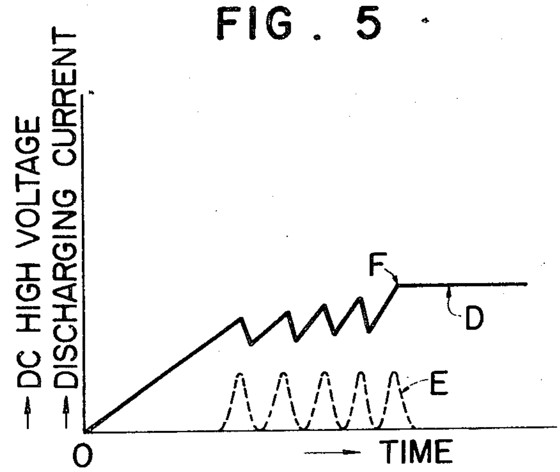


FIG. 5



INVENTORS
ISAO MATSUI, YOSHIHISA MINAMIKAWA,
SHINJIRO KATAGIRI AND TERUO NAKAHARA
BY Craig, Antonelli, Stewart & Hill
ATTORNEYS

AUTOMATIC CONTROL SYSTEM FOR VARYING A D.C. HIGH VOLTAGE FOR ACCELERATING TUBE OF ELECTRON MICROSCOPE AND THE LIKE

This invention relates to an automatic control system for increasing the acceleration voltage for an electron microscope or the like which is particularly capable of preventing discharge in the accelerating tube thereof.

BACKGROUND OF THE INVENTION

As is well known, an electron microscope of the type wherein the electron beam is accelerated by a high accelerating voltage, such as 650 KV~1MV, has an accelerating tube with a plurality of accelerating electrodes, and a d. c. high accelerating voltage of 100 KV or less is applied between each pair of adjacent accelerating electrodes. However, when such a d. c. high voltage is applied to the accelerating tube, undesirable discharge often occurs therein.

Especially when the electron microscope is started up for operation, discharge occurs even if the voltage applied between each pair of accelerating electrodes is of comparatively low value, such as 10 KV. Such undesirable discharge must be prevented or its generation suppressed in the accelerating tube in order to provide a very stable electron beam for the electron microscope or the like, since the discharge produces undesired distortions in the photographs of the electron microscope images and it destroys the inside wall of the accelerating tube due to spark discharge.

A conventional method for preventing such discharge is the so-called aging method. However, since the aging method is effected through manually watching, by an operator, the quantity of the discharge current, it takes several days to complete this method; thus, the method is troublesome and uneconomical. Moreover, fine adjustment is needed in the d. c. high voltage in order to perform the aging method but it is very difficult to attain manually the necessary fine adjustment and there is a great possibility that discharge will occur during this adjustment.

SUMMARY OF THE INVENTION

One object of this invention is to provide an automatic control system for a high voltage accelerating generator, which prevents undesirable discharge from occurring in an accelerating tube of an electron microscope or the like.

Another object of this invention is to provide an automatic control system which automatically and accurately performs said aging method.

The automatic control system according to this invention is so constructed that it employs detecting means for detecting discharge current, or an X-ray produced due to occurrence of the discharge, in the accelerating tube under application thereto of an increasing d. c. high voltage. When the value of a detected signal corresponding to the amount of the discharge becomes larger than a predetermined value, the d. c. high voltage is caused to decrease automatically; and thereafter, consequently, when the value of the detected signal becomes zero, which causes the discharge to disappear, the d. c. high voltage is caused to be increased until the value of the detected signal exceeds the predetermined value again, and the same procedures are repeated so as to cause the d. c. high

voltage to increase gradually up to a predetermined high value without the occurrence of arcing.

Other objects, features and advantages of this invention will be appreciated more readily by reference to the following embodiments shown in the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic block diagram of one embodiment of this invention.

FIGS. **2** and **3** are schematic block diagrams showing construction of the main parts of said embodiment.

FIGS. **4** and **5** are waveform diagrams showing the relation between an accelerating voltage and discharge current in said embodiments.

FIG. **6** is a partial view of a modification of the invention using an X-ray monitor.

DESCRIPTION OF PREFERRED EMBODIMENT

In FIG. **1**, there is provided a d. c. high voltage Producing device **1** which comprises an a.c. variable power device **2**, a high voltage transformer T_1 supplied at its primary with an a. c. variable voltage from the power device **2**, a rectifying diode D and condenser C_1, connected to the secondary of the transformer T_1 to produce a d. c. high voltage.

The d. c. high voltage produced by said device **1** is smoothed by a smoothing resistor R_1 and smoothing condenser C_3 and then is applied through a voltage dividing resistor R_3 to respective accelerating electrodes **6** which are provided in an accelerating tube **9** of an electron microscope **100**.

A.C. power is supplied to a filament **4** to heat the same from an a. c. power source **3** through a transformer T_2, condensers C_2 and a filament transformer T_3. An electron beam emitted from the filament **4** is accelerated by each accelerating electrode **6**.

A part of the accelerated electron beam passes through an aperture of a condenser apertured plate **7** and is then focused by a condenser lens **8** and further is introduced into the objective part **10** of the electron microscope **100** so that the beam is directed to a specimen in a known manner. A bias voltage to adjust the electron beam current is applied to a Wehnelt electrode **5** through a variable resistor R_2 connected between the neutral point of the filament transformer T_3 and the voltage dividing resistor R_3.

As shown in Fig. **4**, a discharge current B is observed to increase in the accelerating tube while the accelerating voltage, namely, the d. c. high voltage A produced by the d. c. high voltage producing device, is increased as shown in the same FIG. **4** until at last a spark C of the discharge may occur as described in the foregoing description.

According to this invention, in order to prevent such discharge the following means are provided in addition to the described construction, The condenser apertured plate **7** can be used as a detector for detecting the discharge in the tube. Namely, said plate **7** is secured to the enclosure wall of the tube **9** by an insulating member **101** and when the discharge occurs, the discharge current is taken out by said plate **7**.

The discharge current from said plate **7** is applied to a variable resistor R_4 whose output voltage is amplified by an amplifier **11** and the output voltage E_1 thereof is applied to a comparing circuit **12**. The comparing circuit **12** produces a high level signal S_1 when the value of the voltage E_1 is larger than a predetermined value and A low level signal S_2 when the value of the voltage E_1 is less than said predetermined value. Both signals S_1 and S_2 are supplied to a voltage control circuit **13** for varying said d. c. high voltage.

The high level signal S_1 is produced, for example, when the discharge current reaches a value between 0.01 μA ~ 0.05 μA. This value is particularly significant since, if the discharge current exceeds this value, an undesired spark may easily occur, so that a decrease in the high accelerating voltage must be effected upon detection of a discharge of such value.

The low level signal S_2 is designed to be produced when the discharge does not exist. Once the low level signal is produced, it operates the voltage control circuit **13** by which said d. c. high voltage is caused to increase gradually. Then when the discharge current becomes larger than said predetermined value, the high level signal S_1 is applied to the voltage control circuit **13** so that said d. c. high voltage is caused to decrease until the low level signal is again produced. Thus, the increase and decrease in the d. c. high voltage is alternately repeated. In this way, said d. c. high voltage D and the discharge current E vary as shown in FIG. **5** and the value of said d. c. high voltage D can be gradually increased up to a desired value F without any spark being generated. Therefore, the aging method is attained automatically in accordance with the present invention.

In the above automatic control system, said comparing circuit **12** and said voltage control circuit **13** are constituted as shown in FIGS. **2** and **3**.

FIG. **2** shows an example of said comparing circuit **12**, wherein a differential amplifier **15** has a terminal **14** connected to the output terminal of the amplifier **11** and another terminal **16** connected to a source of constant voltage E_2. A one-shot multivibrator **17** is connected between the output terminal of the differential amplifier **15** and a "set" terminal **18** of a flip-flop circuit **19**. Moreover, a sign changer or inverter **20** and another one-shot multivibrator **21** are connected in series between the output terminal of the differential amplifier **15** and a "reset" terminal **22** of the flip-flop circuit **19**. The high level signal S_1 appears at the output terminal **23** of the flip-flop circuit **19**, while the low level signal S_2 appears at the other output terminal **23'** of the flip-flop circuit **19**.

Said voltage E_2 represents the predetermined threshold value such as 0.01~0.05 μA which forms the basis for determining whether the discharge current exceeds the predetermined maximum at which sparking occurs. When the voltage E_1 is larger than E_2, the differential amplifier **15** produces an output voltage proportional to the difference between E_1 and E_2 by which the one-shot multivibrator **17** is triggered and produces an output pulse which is applied to the "set" terminal **18** of the flip-flop circuit **19**. Therefore, when the discharge current becomes larger than the predetermined threshold value, the flip-flop circuit **19** is brought into the "set" state so that it produces the high level signal S_1 at the terminal **23**. At this time, the sign changer **20** inverts the polarity of the output signal of the amplifier **15**, so that the one-shot multivibrator **21** is not operated.

Next, when the voltage E_1 becomes less then E_2, the polarity of the output voltage of the differential amplifier **15** is inverted. Thus, the one-shot multivibrator **17** does not operate, but the sign changer **20** operates to invert the polarity of said output voltage. The one-shot multivibrator **22** is, therefore, triggered by the output of said sign changer **20** and produces an output pulse which is applied to the "reset" terminal **22** of the flip-flop circuit **19**. Therefore, when the discharge is prevented or suppressed, the flip-flop circuit **19** produces the low level signal S_2 at the terminal **23**.

FIG. **3** shows an example of said voltage control circuit **13**, wherein **24** is a first reference signal source whose output is applied to a positive terminal of a subtracting circuit **25** through a "break" contact **26** of a switch **37**, while **24'** is a second reference signal source whose output is applied to said positive terminal through a "make" contact **27** of the relay switch **37**. The polarities of both outputs of the first and second reference signal sources are opposite to each other.

A servomotor **29** is driven by the output of an amplifier **28** to which the output of the subtracting circuit **25** is applied, and this motor rotates clockwise or counterclockwise in response to the polarity of the output of the subtracting circuit **25**.

A slide contact **30** is adapted to contact to secondary winding **31** of a slidack transformer **32** whose primary winding **34** is connected to an a. c. power source **35** and is movable along the secondary winding **31** by the servomotor **29** in such manner than an a. c. output voltage obtained between the output terminals **30** and **30'** of the secondary winding of the transformer **32** is either increased or decreased in response to rotation of the servomotor **29** in either the clockwise or counterclockwise directions. This a. c. output voltage between the terminals **30** and **30'** is supplied to the transformer T_1, so that the transformer **32** and the source **35** serve as the a. c. variable power device **2** of the circuit of FIG. **1**.

There is further provided a feed-back potentiometer **36** which generates a feed-back signal which is variable in response to rotation of the servomotor **29** in cooperation with slide movement of the slidable contact **30** on the secondary winding of the slidack transformer **32**. This feed-back signal is negatively fed back to a negative terminal of the subtracting circuit **25** which produces an output signal proportional to the difference between the first or second reference signal applied to the positive terminal and the feed-back signal applied to the negative terminal.

In case of the disclosed embodiment, when the low level signal S_2 is applied to the switch **37**, the "break" contact **26** closes and the "make" contact **27** opens so that an output of the first reference signal source **24** is applied to the subtracting circuit **25** and the servomotor **29** rotates to cause said d. c. high voltage to increase gradually. On the contrary, when the high level signal S_1 is applied to the switch **26**, the "break" contact **26** opens and the"make" contact **27** closes so that said d. c. high voltage decreases.

It is apparent from the above description that the voltage control circuit **13** shown in FIG. **3** constitutes a so-called servomechanism and thereby said d. c. high voltage is caused to increase gradually as shown in FIG. **5**.

In the described embodiment, a suitable X-ray monitor 7′ can be substituted for said plate 7 as a discharge detector, as illustrated in FIG. 6. In such a modification, since an X-ray is produced when the discharge occurs, this X-ray is used as the detectable indicator representative of the discharge occuring in the accelerating tube.

As will be apparent from the above description, according to this invention, since the large undesirable discharge accompanied by sparks in the accelerating tube can be prevented completely, the inside wall of the accelerating tube is safe from being destroyed and the photograph of an electron microscope image can be obtained without disturbance. Moreover, the aging method can be effected automatically, so that long-time manual control is avoided.

While we have shown and described the embodiments in accordance with the present invention, it is understood that the same is not limited thereto but is susceptible of numerous changes and modifications as known to a person skilled in the art, and we therefore do not wish to be limited to the details shown and described herein but intend to cover all such changes and modifications as are obvious to one of ordinary skill in the art.

What is claimed is:

1. An automatic control system for controlling the d. c. high accelerating voltage applied to an accelerating tube of an electron microscope and the like comprising

an accelerating tube having an electron source for emitting an electron beam and a plurality of accelerating electrodes for accelerating the electron beam;

detector means for detecting discharge in the accelerating tube and for producing an output signal representative of the for discharge level;

comparing circuit means for producing a first signal when the output signal of said detector means is larger than a predetermined value and a second signal when the output signal is less than said predetermined value;

a variable d. c. high voltage source for generating a variable d. c. high voltage;

means for supplying said d. c. high voltage from said source to respective accelerating electrodes to cause the electrodes to accelerate the electron beam; and

voltage control circuit means connected between said voltage source and said comparing circuit means for increasing and decreasing said d. c. high voltage in response to receipt of said second signal and said first signal from said comparing circuit, respectively, thereby preventing said accelerating tube from generating an undesired large discharge while gradually increasing said d. c. high voltage to a desired value.

2. An automatic control circuit according to claim 1, wherein said detector means is a conductive plate disposed in said accelerating tube so as to derive a discharge current therefrom, said conductive plate having an electron beam passage therein through which said electron beam passes.

3. An automatic control circuit according to claim 2, wherein said comparing circuit means includes a differential amplifier having one input connected to the output of said detector means and a second input connected to a threshold voltage source, a first one-shot multivibrator and an inverter each connected to the output of said differential amplifier, a second one-shot multivibrator connected to the output of said inverter, and a flip-flop having a set input connected to the output of said first one-shot multivibrator and a reset input connected to the output of said second one-shot multivibrator.

4. An automatic control circuit according to claim 3, wherein said variable d. c. high voltage source includes an a. c. variable power device and rectifier means for rectifying the output of said power device, said power device including a transformer having a primary winding connected to a source of a. c. voltage and a secondary winding having a slideable center contact connected to said rectifier means, the position of said center contact being controlled by said voltage control circuit means.

5. An automatic control circuit according to claim 4, wherein said voltage control circuit means includes a servo system responsive to said first and second signals for adjusting the position of said center contact to progressively increase the level of said d. c. high voltage without generating sparks in said accelerating tube.

6. An automatic control circuit according to claim 1, wherein said detector means is an X-ray monitor disposed in the accelerating tube for detecting X-rays produced by a discharge therein.

7. An automatic control circuit according to claim 6, wherein said comparing circuit means includes a differential amplifier having one input connected to the output of said detector means and a second input connected to a threshold voltage source, a first one-shot multivibrator and an inverter each connected to the output of said differential amplifier, a second one-shot multivibrator connected to the output of said inverter, and a flip-flop having a set input connected to the output of said first one-shot multivibrator and a reset input connected to the output of said second one-shot multivibrator.

8. An automatic control circuit according to claim 7, wherein said variable d. c. high voltage source includes an a. c. variable power device and rectifier means for rectifying the output of said power device, said power device including a transformer having a primary winding connected to a source of a. c. voltage and a secondary winding having a slideable center contact connected to said rectifier means, the position of said center contact being controlled by said voltage control circuit means.

9. An automatic control circuit according to claim 8, wherein said voltage control circuit means includes a servo system responsive to said first and second signals for adjusting the position of said center contact to progressively increase the level of said d. c. high voltage without generating sparks in said accelerating tube.

10. An automatic control system according to claim 1, wherein said voltage control circuit means comprises a servomechanism for controlling the d. c. high voltage.

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