CONTROL FOR FOCAL SPOT IN X-RAY GENERATORS


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7 Claims.

(Cl. 250—99)

Our present invention relates in general to electronics and has more particular reference to the operation of X-ray generators, the invention applying specifically to the control of an X-ray generator in order to maintain the focal spot configuration as nearly as possible in optimum condition throughout the operating range of the generator.

An important object of the invention is to overcome the space charge effect in an X-ray generator when in operation at low voltages, so as to allow substantial current to flow between the anode and cathode of the order of the current flowing when the generator is operated at high voltages; a further object being to overcome the space charge effect, when the generator is in operation at low voltage, by applying a positive biasing potential on the cathode cup with respect to the electron emitting filament of the cathode.

A further important object of the invention is to provide for the operation of an X-ray generator so as to maintain, throughout the operating range of the instrument of the generator, a focal spot pattern as nearly as possible, and preferably uniformly, in accordance with the optimum or ideal focal spot pattern, the ideal pattern comprising a large, sharply defined area, and the ideal generator operating conditions being such that the spot maintains a constant shape and definition through the operating range of the generator.

Another important object is to control the focal spot pattern in an X-ray generator by applying positive anode bias; a further object being to obtain control of focal spot distribution by positively biasing the cathode focusing cup with respect to the electron emitting filament of the cathode; a still further object being to regulate or adjust the positive biasing potential as an inverse function of generator operating voltage so that maximum positive bias is applied when the generator is in operation at low voltages applied between anode and cathode, the biasing potential being reduced proportionally when the operating voltage is increased.

These and numerous other important objects, advantages and inherent functions of the invention will become apparent as the invention is more fully understood from the following description, which, taken in connection with the accompanying drawings, discloses a preferred embodiment of the invention.

Referring to the drawing:

Figure 1 is a diagrammatic representation of an X-ray generator and means for operating the same in accordance with the teachings of our present invention; Figure 2 is a sectional view taken substantially along the line 2—2 in Figure 1; Figures 3 and 4 are graphical representations of generator operating characteristics; and Figure 5 is a chart illustrating focal spot patterns obtained in operating an X-ray generator at various voltages within its operating range, with various amounts of biasing potential applied between the cathode filament and focusing cup.

To illustrate our invention, we have shown on the drawing an X-ray generator 11 comprising a cathode 13 and a co-operating anode 15 enclosed in suitable hermetically sealed envelope means 16. The cathode includes a focusing cup 17 and electron emitting filaments 19 mounted in the cup in position to discharge electrons toward and upon the anode 15. The anode 15 comprises a tubular member 21 having a cavity 23 facing toward the cathode and has a target 25 at the bottom of the cavity in position to receive electrons emitted by the cathode when the tube is in operation.

It should be understood that X-ray generators are conditioned for operation by exhausting from the envelope means 16 substantially all gaseous and other impurities by evacuating the envelope, as by means of a molecular exhaust pump, and finally sealing the envelope in evacuated condition. X-rays are generated at the target 25 as a result of impingement thereon of electrons emitted as a stream 28 by the cathode filaments 19 when electrically excited. Such electrons are impelled toward the target under the influence of the driving force provided through the application of operating voltage applied between the filament and anode from an external source, the focusing cup 17 of the cathode, through electrostatic action, serving to confine and direct the electron stream in a desired path toward the anode target. The shape and configuration of the cathode cup, to some extent, determines the surface area or focal spot of the target 25 within which the electron stream impinges upon the target. Impingement of the electron stream upon the target 25 results in the generation of X-rays which pass from the target laterally through the walls 21 of the anode structure, which are preferably formed with a window 27 to facilitate the passage of X-rays therethrough. The X-rays thus transmitted from the target form a beam or cone 29, the sectional shape of which
is determined by the pattern of the anode focal spot. It is desirable that the sectional configuration of the X-ray beam be uniform throughout the operating voltage range of the generator, and it is further desirable that the boundaries of the beam be sharply defined and that X-ray intensity be uniform throughout the beam. These factors, in turn, are determined by the uniformity and definition of the target focal spot. We have noted that the size, configuration and marginal definition of the focal spot of any given X-ray generator changes as the operating voltage is varied between anode and cathode. For example, as shown in the upper row of diagrams in Figure 5, the character of the focal spot in a given X-ray tube may improve as the tube operating voltage increases, the focal spot having desirable characteristics when the tube is operating at relatively high voltages and having impaired characteristics at lower voltages. This phenomena is due apparently to changes in electron focus on the target resulting from changes in the operating voltage, it being understood that electrons have optical characteristics analogous to light rays and that the focused pattern of the electrons on the target depends upon the shape of the electron source, which, in the illustrated embodiment, comprises a pair of parallel filaments, the shape of the focusing cup and the voltage applied between filaments and target. In this connection, the top diagram in the left-hand column of Figure 5 represents a sharply focused electronic pattern or image of the electron emission elements on the target, while the other diagrams of Figure 5 represent the filament patterns in varying degrees of soft focus.

In order to improve the character of the focal spot pattern when the tube is in operation at lower voltages, we provide for the application of a positive bias potential between the electron emitting filaments and the focusing cup and have discovered that electron flow may be controlled in this fashion to produce substantially the same focal spot pattern when the generator is operating at low voltage as is produced without biasing the cathode when the generator is operating in a high voltage range.

The three lower rows of diagrams in Figure 5, respectively, illustrate the focal spot patterns developed through the operating range of the generator when biasing the cathode cup, respectively, at 300, 600 and 900 volts, and it will be noted that the character of the focal spot pattern is progressively improved by increasing the biasing potential while the tube is in operation at low voltages; but that the character of the focal spot pattern deteriorates as the biasing potential is increased when the generator is in operation in the higher voltage ranges. The particular generator which produced the focal spot patterns illustrated in Figure 5 was a generator built for normal operation at voltages between filament and anode of the order of 100 kv, and it will be noted that when operating at normal voltage, the application of a positive biasing potential has little, if any effect upon the character of the focal spot pattern.

When in normal operation at a voltage of the order of 100 kv, and without cathode bias, the anode current which may flow is limited by the space charge between anode and cathode, and the focal spot has the usable pattern shown in the second diagram in the first row of Figure 5. As the operating voltage is increased, the effect of the space charge is minimized, with the result that the focal spot pattern is improved, as shown in the third and fourth diagrams in the first row of Figure 5. If, however, the tube is placed in operation at a voltage substantially below its rated voltage, the effect of the space charge increases to such an extent that the focal spot pattern deteriorates, becoming sharp and narrow.

The graph shown in Figure 4 illustrates the space charge limitations of the generator operating at low voltage of the order of 60 kv, with the filament carrying 4.5 amperes. The curve shows the variation of anode current as cathode bias is increased. From this curve, it will be noted that saturation is attained at 39½ milliamperes tube current, with about 800 volts positive cathode bias; and there is relatively little increase in tube current above biasing potential of 360 volts, at which point in the curve the anode current is of the order of 33 milliamperes. Three hundred fifty to four hundred volts, with anode current at 33 amperes, may therefore be selected as the upper limit for standardizing cathode biasing procedure, although, of course, the value may be increased, if desired. The curves shown in Figures 3 and 4 were made from data obtained in operating the particular tube which produced the patterns shown in Figure 5. Corresponding curves, however, may be obtained for any generator and, of course, may vary from the curves shown, depending upon the optical and electrical characteristics of the selected generator.

The curves in Figure 4 show the relationship between cathode biasing current in milliamperes to cathode filament current in amperes for various bias voltages, with the tube in operation at 60 kv. The upper curve represents conditions with cathode bias at 1000 volts. The lower curve represents conditions with cathode bias at 600 volts. The lower curve represents conditions with cathode bias at 320 volts. These curves are of interest, since the upper curve approaches 200 milliamperes required in the cathode biasing circuit at 4.5 amperes in the cathode filament, that is to say, the operating condition for the curve in Figure 3. This means simply that with 600 volts bias at a filament current of 4.5 amperes, 200 milliamperes pass to the cathode, releasing 120 watts of energy, in addition to the normalode heat generated due to filament heating alone, which, at 4.5 amperes of filament current, amounts to about 40 watts. The biasing transformer, therefore, should be several times larger than the filament heating transformer. The focal spot patterns shown in Figure 5, with no cathode bias, are satisfactory when the generator is in operation at voltages in excess of 100 kv. With cathode biased at 300 volts, the spot pattern is only slightly improved when the generator is in operation at 60 kv, and shows deterioration when the generator is operating at voltages above 100 kv, and shows deterioration when the generator is operating at voltages below 100 kv, but particularly deteriorates when the generator is in operation at higher voltages between cathode and anode.

In order to control the X-ray generator for operation with satisfactory focal spot pattern throughout its full operating range, a positive bias of at least 600 volts is needed on the cathode when the generator is in operation within a voltage range up to voltages of the order of 100 kv.
A bias of this magnitude, however, when the tube is in operation at higher voltages across anode and cathode, results in the production of focal spot patterns of diminished size so that for most effective operation, the bias should, when the generator is in operation at the high voltage range, be either removed, or so diminished in order to reduce tube current to thereby avoid overloading the anode heat dissipating capacity of the tube, the following schedule being a satisfactory guide illustrating the desirable variation in bias (expressed in terms of tube current) at various voltages within the operating range of the generator:

<table>
<thead>
<tr>
<th>Operating voltage (kv. p.)</th>
<th>Bias rating in terms of anode current</th>
</tr>
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<tbody>
<tr>
<td>60</td>
<td>33</td>
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<tr>
<td>100</td>
<td>29</td>
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<tr>
<td>150</td>
<td>25</td>
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<tr>
<td>200</td>
<td>20</td>
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<td>250</td>
<td>19</td>
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<td>14</td>
</tr>
<tr>
<td>550</td>
<td>13</td>
</tr>
<tr>
<td>600</td>
<td>12</td>
</tr>
</tbody>
</table>

In order to operate and control the generator in accordance with the teachings of our present invention, we provide a transformer 31, the secondary winding 33 of which is connected, by suitable conductors 35 and 37, between the filament 19 and the anode 21 of the transformer 31 being connected, by conductors 41 and 43, with a suitable source of generator operating power.

The control system also includes filament exciting means which may comprise a filament exciting and biasing transformer 45, a portion 47 of the secondary winding 49 of which is connected to energize the cathode filament 19 through suitable conductors 37 and 51. Biasing potential may be applied between the filament 19 and the cathode cup 17 by means of the transformer 45, a portion 53 of the secondary winding 49 of which may be connected to the filament, through the conductor 51, and to the cathode cup 17 through a conductor 55, which conductor preferably includes switch means 57 for controlling the biasing potential. This switch 57 preferably comprises a slidable blade electrically connected with the cathode cup 17, the blade being movable in order to make contact with the winding 53 in order to apply cathode bias, or to make contact directly with the conductor 51 in order to remove the cathode bias by electrically connecting the cathode cup with the filament circuit. The switch 57 may be controlled by a solenoid 59, operable, when energized, to throw the switch blade 57 into bias applying position. When the solenoid 59 is de-energized, suitable spring means may be utilized to throw the switch 57 into position connecting the cathode cup directly with the filament circuit. Preferably, the switch operating means includes a stem insulated, as at 65, to assure electrical isolation of the switch from the operating circuit of the solenoid 59. The primary winding 61 of the transformer 45 is electrically connected, as by means of the conductor 43 and a conductor 63, with a suitable external electrical power source.

The generator 41, the transformers 31 and 45, the switch 57 and its operating solenoid 59, and the several circuits for connecting the aforesaid control elements with the generator, are preferably all enclosed in and insulated from a container or grounded casing 65; and the mid point of the winding 33 of the transformer 31 may be electrically connected with the ground casing 65, by means of a conductor 67.

The transformers 31 and 45 and the switch control solenoids 59 may be energized in any suitable or preferred fashion, but we preferably utilize a supply system comprising an autotransformer and control switches having rheostats, which are preferably enclosed in and insulated from a grounded container 65, which may be located remotely from the generator casing 65. The autotransformer may comprise a suitable winding 71, one end of which may be connected by means of the conductor 73 with one side of a suitable external power source, the conductor means 43 leading to the primary windings of the transformers 31 and 45 being also electrically connected to the power source through the conductor 73. The other side of the power source may be connected, through a conductor 75 and a control switch 77, to the winding 71 intermediate the ends thereof. The winding 71 may be connected, by means of an adjustable connection 79 through a control switch 81 and an adjustable rheostat 83, to the conductor 41 for energizing the primary winding of the transformer 31. The winding 71 likewise may be connected, through an adjustable rheostat 85, to the conductor 63 for the purpose of energizing the filament heating and cathode biasing transformer 45.

The switch operating solenoid 59 may be connected to the winding 71 through a switch 87 and may also be connected to a remote portion of the winding 71 through means for adjusting the voltage applied to the solenoid, and said means may conveniently comprise the adjustable connection 79. By closing the switch 87, the solenoid 59 will be energized to throw the biasing switch 57 into position applying a bias upon the cathode. This bias, because of the adjustable rheostat 83, may be varied as a function of filament current. The bias will be maintained so long as the solenoid 59 remains energized. The solenoid, however, may comprise a drive adapted to operate at a predetermined voltage in order to throw the switch to a position discontinuing the bias on the cathode. The adjustable contact 79 is a control for determining the operating voltage, applied between anode and cathode, of the tube through the transformer 31, and by utilizing this contact 79 in the operating circuit of the solenoid 59, the system may be adjusted to operate the switch 57 for the removal of the cathode bias whenever the element 78 is manipulated to increase the operating voltage of the generator above a predetermined value, thereby automatically accomplishing the control of the generator in accordance with the teachings of our present invention. It will be apparent, however, that the control of the bias need not necessarily be interlocked with the control of generator operating potential but may be had by separate means if desired.

It is thought that the invention and its numerous attendant advantages will be fully understood from the foregoing description, and it is obvious that numerous changes may be made in the form, construction and arrangement of the several parts without departing from the spirit or scope of the invention, or sacrificing any of its attendant advantages, the form herein disclosed being a preferred embodiment for the purpose of illustrating the invention.

The invention is hereby claimed as follows:

1. The method of operating an X-ray gen-
erator in which the cathode comprises a focusing cup and an electron emitting element which consists in applying positive bias on said cup with respect to said element when the generator is in operation at low voltage and diminishing the bias when the generator is in operation at higher voltages.

2. The method of operating an X-ray generator in which the cathode comprises a focusing cup and an electron emitting element which consists in positively biasing said cup with respect to said element as an inverse function of the operating voltage of the generator.

3. The method of operating an X-ray generator in which the cathode comprises a focusing cup and an electron emitting element which consists in positively biasing said cup with respect to said element of the generator when in operation at relatively low voltage and reducing the biasing effect as the operating voltage is increased.

4. The method of operating an X-ray generator in which the cathode comprises a focusing cup and an electron emitting element which consists in maintaining uniform focal spot pattern throughout the operating voltage range of the generator by positively biasing said cup with respect to said element inversely with respect to generator operating voltage throughout the operating voltage range of the generator.

5. The combination, with an X-ray generator comprising an anode, a cathode including an electron emission element and a mounting head, means to apply generator operating voltage between the emission element and the anode, and means for adjusting said operating voltage, of biasing means for applying a positive bias potential to said head with respect to said emission element, and means operable to control said biasing means whereby to reduce the intensity of bias progressively as the operating voltage is increased.

6. The combination, with an X-ray generator comprising an anode, a cathode including an electron emission element and a mounting head, means to apply generator operating voltage between the emission element and the anode, and means for adjusting said operating voltage, of biasing means for applying a positive bias potential to said head with respect to said emission element comprising a biasing circuit, and means to control the biasing circuit to vary the bias inversely with respect to variation in the generator operating voltage.

7. The combination, with an X-ray generator comprising an anode, a cathode including an electron emission element and a mounting head, and means to apply generator operating voltage between the emission element and the anode, of energizing means for delivering element energizing electrical current to said emission element, biasing means for applying positive bias on said head with respect to said emission element, means for adjusting the energizing current delivered to said emission element, and means for varying the bias as a function of the variation in filament current.