

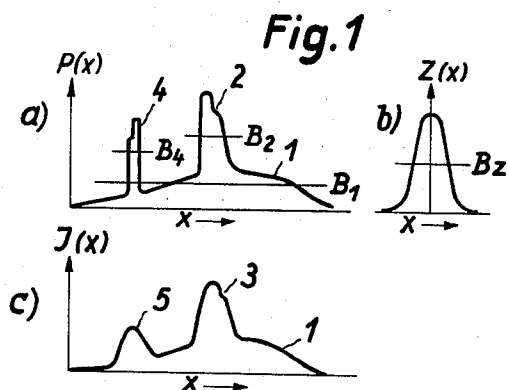
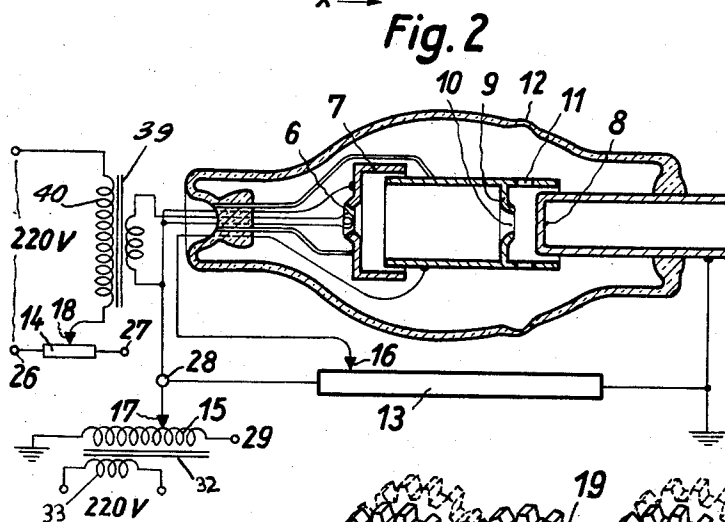
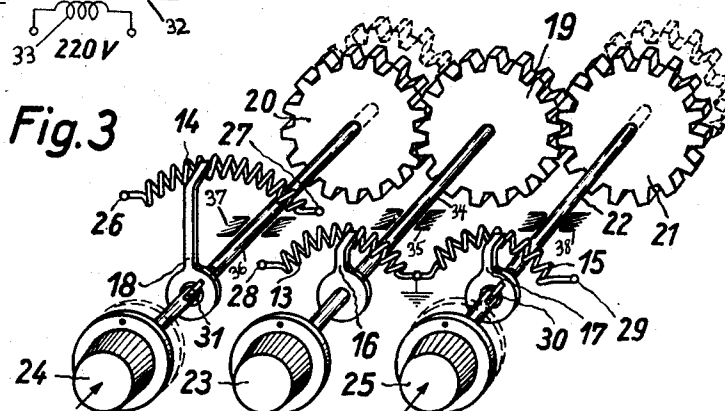
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X-RAY APPARATUS

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1

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X-RAY APPARATUS

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The present invention relates to X-ray apparatuses, and more particularly to X-ray apparatuses for diagnostic purposes and for examinations of structure.

It is an object of the present invention to provide an X-ray apparatus combining with a maximum brightness of the image an adjustable sharpness of drawing so as to be able to show details having a minimum extension.

It is another object of the present invention to provide an X-ray apparatus for examining the angular diffraction of highly dispersed colloid substances.

It is a further object of the present invention to provide an X-ray apparatus for macroscopical purposes which gives rather finely detailed images.

It is still another object of the present invention to provide an X-ray apparatus which is suitable for the diagnosis of cracks in bones.

It is a still further object of the present invention to provide an X-ray apparatus for measuring strains of materials without damaging or destroying the same.

It is still another object of the present invention to provide an X-ray apparatus suitable for examining albumins, fibers and the like which are coarsely dispersed colloids.

An X-ray apparatus according to the present invention comprises in its broadest aspect an X-ray tube including a cathode, an anode, and an intermediate hollow electrode arranged between the cathode and the anode so as to direct electrons emitted by the cathode to the anode and to produce a focal spot thereon, means for generating a heating current flowing through the cathode so that the same emits electrons, means for producing a large potential difference between the anode and the cathode, means for producing a potential difference between the intermediate electrode and the cathode being smaller than the large potential difference produced between the anode and the cathode, and means for adjusting any one of said generating means, said means for producing the large potential difference between the anode and the cathode, and the means for producing the potential difference between the intermediate electrode and the cathode so as to obtain the maximum permissible brightness of the focal spot produced by the intermediate electrode on the anode.

Preferably the X-ray tube is a fine focus tube and the intermediate electrode acts as an electrostatic lens.

In a preferred embodiment of the present invention means for producing the large potential difference between the anode and the cathode include a high voltage potentiometer whereas the means for producing the potential difference between the intermediate electrode and the cathode include a tap cooperating with the high voltage potentiometer and connected with the intermediate electrode.

A preferred embodiment of the present invention comprises a stepdown transformer having a primary and a secondary connected to the cathode, an adjustable rheostat connected in series with the primary of the stepdown transformer so as to change the heating current flowing through the cathode by adjustment of the rheostat, a step-

2

up transformer having a secondary producing a high alternating voltage, an adjustable tap arranged for cooperation with the secondary of the step-up transformer so as to be at an adjustable high alternating potential, means for applying the high alternating potential of the tap of the step-up transformer to the cathode, the anode being grounded, a potentiometer inserted between the tap of the step-up transformer and ground, an adjustable tap cooperating with the potentiometer and connected with the intermediate electrode so as to adjust the size of the focal spot on the anode and thus the drawing sharpness of the X-ray tube, and means for coupling the adjustable tap of the potentiometer with the adjustable rheostat and the adjustable tap of the secondary of the step-up transformer so as to obtain the maximum permissible brightness of the focal spot produced by the intermediate electrode on the anode.

Preferably a preferred embodiment of the present invention comprises a first rotatable shaft, a second rotatable shaft arranged parallel to the first shaft, a third rotatable shaft arranged parallel to the first and second shafts, the first shaft being arranged centrally between the second and third shafts, a rheostat arranged along a circular arc concentric with the second shaft, a tap connected to the second shaft and connecting the primary of the stepdown transformer in series to the rheostat so as to change the heating current flowing through the cathode by adjustment of the tap connected to the second shaft, a step-up transformer having a secondary producing a negative high voltage, the secondary of the step-up transformer being arranged along a circular arc concentric with the third shaft, a tap connected to the third shaft and cooperating with the secondary of the step-up transformer so as to be at an adjustable negative high potential, means for applying the negative high potential of the tap connected with the third shaft to the cathode, the anode being grounded, a potentiometer arranged along a circular arc concentric with the first shaft and being inserted between the tap connected to the third shaft and ground, a tap connected to the first shaft and cooperating with the potentiometer, the tap connected with the first shaft being connected with the intermediate electrode so as to adjust the size of the focal spot on the anode and thus the drawing sharpness of the X-ray tube, and means for coupling the shafts with one another so as to obtain the maximum permissible brightness of the focal spot produced by the intermediate electrode on the anode.

Preferably the first shaft is arranged axially undisplaceably whereas the second and third shafts are axially displaceable, the taps connected to the second and third shafts being shiftable whereas the tap connected to the first shaft is rigidly connected thereto.

Preferably first, second and third toothed wheels are rigidly connected, respectively, to the first, second and third shafts, the second and third wheels meshing in one end position of the second and third shafts with the first toothed wheel so as to form a disengageable coupling between the shafts.

The novel features which are considered as characteristic for the invention are set forth in particular in the appended claims. The invention itself, however, both as to its construction and its method of operation, together with additional objects and advantages thereof, will be best understood from the following description of specific embodiments when read in connection with the accompanying drawings, in which:

Figs. 1a, b, and c are diagrams for explaining the basis of the invention;

Fig. 2 is an X-ray tube together with the wiring diagram of the electrical accessories, the X-ray tube being shown in a sectional side elevation and corresponding to the copending United States application Serial No.

300,587, filed July 24, 1952, for "X-ray Tube," now Patent No. 2,683,223; and

Fig. 3 is a perspective view of a practical embodiment of some parts of the electrical accessories shown diagrammatically in Fig. 2.

Referring now to the drawings and first to Figs. 1a, b, and c, let x be a radius vector lying in the plane of the X-ray film supposed to be plane. Let $Z(x)$ be the intensity distribution of the primary X-ray beam, crossing the film in watt/cm², $Z(x)$ being measured either in microscopy with no object being inserted into the path of the rays (zero photograph) or in microscopic or diagnostic photography if the object to be penetrated by rays is punctiform and the equivalent of a point aperture. Particularly if the primary beam of rays in fine structure photography is diaphragmed out infinitely finely or by other suitable means is made to converge on the film at the point $x=0$, $Z(x)$ has the form of a point function. In microscopic photographs $Z(x)$ is a point function if the focal spot is punctiform. Therefore, the following relation holds:

$$Z(x) \rightarrow P(x)$$

where $P(x)=0$ for any $x \neq 0$. In consequence thereof one obtains for the total primary intensity W_0 , which impinges on the film

$$\int Z(x) df_x \rightarrow \int P(x) df_x = W_0 \text{ (watt)} \quad (1)$$

where df_x is a surface element of the X-ray film at the point x . Using this punctiform distribution of the primary intensity it will be seen that the object brought into the path of the X-rays causes on the film a distribution of intensity:

$$J(x) = W_0 p(x) \quad (2)$$

$p(x)$ having the dimension cm.⁻² and being a function characterizing the object to be X-rayed or photographed. However, in the general case of a finite primary beam of rays the distribution of the intensity on the X-ray film is given by the folding product of Z and p :

$$J(x) \equiv Z(x)p(x) = \int Z(y)p(x-y) df_y \quad (3)$$

In this equation y is the radius vector lying in the plane of the film which starts at $x=0$ and ends at the surface element df_y . The surface integral (3) is to be extended over the entire area of the film.

The distribution of the intensity according to Equation 3 is blurred in a characteristic manner in comparison to the sharp image given by Equation 2. If, for instance, for X-raying of the diagram shown in Fig. 1a which is a plotting of $p(x)$ against x , a primary beam of rays having the intensity of distribution $Z(x)$ shown in Fig. 1b is used, a diagram of the intensity distribution is obtained by using Equation 3 which is represented by the curve $J(x)$ shown in Fig. 1c. Figs. 1a and 1c show that the curve for $J(x)$ copies the diffused background 1 true to shape. However, already the reflex 2, the integral width B_z of which is comparable to the integral width B_p of the primary beam (Fig. 1b) appears much distorted at 3 so that the true shape of the reflex 2 is hardly recognizable. The same holds even with greater force for the reflex 4 having an integral width B_4 being small in comparison to the integral width B_z and being represented by the portion 5 of the curve in Fig. 1c which affords no chance of analyzing the original curve 4 represented by Fig. 1a. If generally B_r is the integral width of a reflex or cavity or any other detail of the object to be X-rayed it has been discovered that in many practical cases a true reproduction by the image is secured if approximately the following relation holds:

$$B_z \leq 0.3 B_r \quad (4)$$

In this case it can be deduced from equation that practically the following relation holds:

$$J(x) \sim W_0 p_r(x) \quad (5)$$

where $p_r(x)$ is the value of the function $p(x)$ within the range of the reflex r . Since an upper limit is set to the loading capacity of the surface of the anode of the X-ray tube by the melting point of the material of the anode, $Z(0)$ cannot exceed a certain maximum value Z_m under given external conditions.

$$Z(0) \leq Z_m$$

Thus in Equation 5 is

$$W_0 \leq Z_m B_z \quad (6)$$

Thus in order to obtain a sufficient brightness of the image B_z should be chosen as large as possible. The conditions (4) and (6) to be satisfied for an X-ray tube giving sharply drawn and bright images evidently counteract each other.

The present invention allows to obtain an X-ray tube for producing sharp and simultaneously bright images by adapting the sharpness of drawing to the object to be photographed by choosing

$$B_z \sim 0.3 B_r \quad (7)$$

and simultaneously adjusting the surface load Z_0 of the tube to its maximum value Z_m :

$$Z_0 = Z_m \quad (8)$$

by controlling the anode current, the heating current, the anode voltage, or these three quantities in combination. The requirement to be satisfied by the tube and given by Equation 7 means a width of the focal spot which is variable over a large range. For instance in many problems of macroscopy, the wide-angle-microscopy and in diagnostics widths of the focal spot amounting to about 1 mm. are sufficient. However, for examining the small-angle-dispersion of highly dispersed colloid materials, for very finely detailed macrostructures and cracks of bones etc., widths of the focal spot down to 0.1 mm. are required unless a major part of the X-ray radiation is screened off by an additional diaphragm which can be done of course only at the expense of the brightness of the image. In a similar manner for many problems of the measurement of mechanical strains of working materials by reflex photography focal spots having a width of 0.1 mm. are required. With coarsely dispersed colloids such as albumins, fibers or the like even more narrow focal spots are required.

Referring now to Fig. 2, an X-ray tube with the electrical accessories thereof according to the invention is shown diagrammatically. The tube shown in the diagram has an electrostatic lens system 9 comprising an aperture 10 as more fully disclosed in the copending United States application Serial No. 300,587, filed July 24, 1952, for "X-ray Tube," now Patent No. 2,683,223. The electrostatic lens system 9 is formed by an intermediate electrode arranged between the cathode 6 and the anode 8 the active surface of which is arranged in the right-hand part of the intermediate electrode 9 which is provided with openings or windows 11 for the X-ray radiation which leaves the tube through windows 12. The index of refraction of the lens system 9 can be changed from the outside of the tube by controlling the potential differences between the electrodes, viz., the intermediate electrode 9 and the cathode 6, and the anode 8 and the cathode 6.

The heating current for the cathode 6 is supplied by the secondary of a stepdown transformer 39, the primary 40 of which is connected to the mains of e. g. 220 volts through a rheostat 14 with terminals 26 and 27 which is tapped by an adjustable tap 18 connected to one end of the primary 31.

A step-up transformer 32 has a primary 33 connected to the 220 volts mains and a secondary 15 which is grounded at one end thereof whereas the other end 29 is left open. The step-up transformer 32 generates for instance a voltage of 50 kilovolts. An adjustable tap 17 cooperates with the secondary 15 so that the terminal 28 connected to the tap 17 is at an adjustable high alternat-

ing potential. The terminal 28 is connected to the cathode and to the Wehnelt cylinder 7 surrounding the cathode. A potentiometer 13 is inserted between the terminal 28 and the grounded anode 8. An adjustable tap 16 cooperating with the potentiometer 13 is connected to the intermediate electrode or lens system 9.

The operation of this device is as follows:

The anode 8 of the tube is always at ground potential which can be taken as zero. The terminal 28 has alternately positive and negative potentials against ground and the anode 8. Furthermore the intermediate electrode 9 has an alternating potential which is not quite as large as the potential of the terminal 28 but always of the same sign. The heating current supplied by the secondary of transformer 39 heats the cathode 6 to electron-emitting temperature and the electrons emitted by the same are accelerated toward the anode 8 when the terminal 28 is negative against ground. By impinging on the anode 8 the electrons generate an X-ray radiation in well known manner.

The brightness of the focal spot produced by the electrons on the anode 8 can be controlled by the heating current supplied by the stepdown transformer 39 and/or the secondary voltage produced by the step-up transformer 32. The heating current is controlled by adjusting the tap 18 on the rheostat 14 where the potential differences between the anode and cathode is controlled by the tap 17 cooperating with the secondary 15 of the step-up transformer 32. The width of the focal spot produced at the anode 8 and thus the sharpness of the image made by the X-ray tube is controlled by the potential of the electrostatic lens 9 which can be adjusted by means of the adjustable tap 16 cooperating with the potentiometer 13. If, for instance, a particularly fine focal spot is to be produced the potential of the electrostatic lens 9 is controlled by means of the tap 16 so that the virtual image of the glow cathode is on the anode 8. However, if the potential of the electrostatic lens 9 is changed with respect to the potential difference between the anode 8 and the cathode 6 the virtual image of the latter is displaced from the surface of the anode 8 along the axis of the tube so that the focal spot becomes larger.

Referring now to Fig. 3 showing a practical embodiment of the rheostat 14 with the tap 18, the secondary 15 with the tap 17 and the potentiometer 13 with the tap 16 it will be seen that the tap 16 is rigidly secured to a first shaft 34 held in stationary bearings 35 so as to be rotatable. The potentiometer 13 is arranged along a circular arc concentric with the first shaft 34. A knob 23 allows to turn the shaft and thereby to adjust the tap 16 with respect to the potentiometer 13. A second shaft 36 is arranged parallel to the first shaft 34 and is axially displaceable in stationary bearings 37. The second shaft 36 carries a knob 24 for rotating the same. The rheostat 14 is arranged along a circular arc concentric with the second shaft 36 and the tap 18 is connected by a key and groove connection 31 with the second shaft 36 so as to be rotatable with the same but shiftable thereto in axial direction so that the tap 18 always cooperates with the rheostat 14. A third shaft 22 is arranged in stationary bearings 38 parallel to the first shaft 34 and the second shaft 36, the first shaft 34 being disposed in the central position with respect to the second shaft 36 and the third shaft 22. The secondary 15 is arranged along a circular arc concentric with the third shaft 22 which carries an operating knob 25. The tap 17 is connected to the third shaft 22 by a groove and key connection 30 similar to the groove and key connection 31. Furthermore, at the ends of the first shaft 34, the second shaft 36 and the third shaft 22 are arranged, respectively, a first toothed wheel 19, a second toothed wheel 20 and a third toothed wheel 21 meshing with one another in one end position of the second and third shafts 36 and 22 so as to form a coupling. However, the coupling can be disengaged by displacing the second shaft 36 and the third shaft 22

axially as indicated in dotted lines. If the coupling is engaged a rotation of one of the knobs 23, 24, 25 entails a rotation of all three shafts together whereby the taps 16, 17, 18 are adjusted with one operation so that the X-ray tube is automatically controlled for maximum loading. However, if the clutch is disengaged each tap can be individually adjusted and the heating current, the potential of the lens system 9 and the anode voltage can be controlled separately.

If the X-ray apparatus according to the invention is to be used for diagnostic purposes or for macroscopic examinations, the automatic coupling should be used for controlling principally the tube voltage by means of the knob 25. The tube produces then a softer X-ray radiation together with an increase of the drawing sharpness transversely to the direction of the rays and of the distinguishability of the minimal dimensions of cavities or the like in direction of the rays.

It will be understood that each of the elements described above, or two or more together, may also find a useful application in other types of X-ray apparatuses differing from the types described above.

While the invention has been illustrated and described as embodied in an X-ray apparatus for diagnostic purposes and for examinations of structure, it is not intended to be limited to the details shown, since various modifications and structural changes may be made without departing in any way from the spirit of the present invention.

Without further analysis, the foregoing will so fully reveal the gist of the present invention that others can by applying current knowledge readily adapt it for various applications without omitting features that, from the standpoint of prior art, fairly constitute essential characteristics of the generic or specific aspects of this invention and, therefore, such adaptations should and are intended to be comprehended within the meaning and range of equivalence of the following claims.

What is claimed as new and desired to be secured by Letters Patent is:

1. An X-ray apparatus comprising, in combination, an X-ray tube including a cathode, an anode, and an intermediate hollow electrode arranged between said cathode and said anode so as to direct electrons emitted by said cathode to said anode and to produce a focal spot thereon; a stepdown transformer having a primary and a secondary connected to said cathode; an adjustable rheostat connected in series with said primary of said stepdown transformer so as to change the heating current flowing through said cathode by adjustment of said rheostat; a step-up transformer having a secondary producing a high alternating voltage; an adjustable tap arranged for cooperation with said secondary of said step-up transformer so as to be at an adjustable high alternating potential; means for applying said high alternating potential of said tap of said step-up transformer to said cathode, said anode being grounded; a potentiometer inserted between said tap of said step-up transformer and ground; an adjustable tap cooperating with said potentiometer and connected with said intermediate electrode so as to adjust the size of said focal spot on said anode and thus the drawing sharpness of said X-ray tube; and means for coupling said adjustable tap of said potentiometer with said adjustable rheostat and said adjustable tap of said secondary of said step-up transformer so as to obtain the maximum permissible brightness of the focal spot produced by said intermediate electrode on said anode.

2. An X-ray apparatus comprising, in combination, a fine focus X-ray tube including a cathode, an anode, and an intermediate hollow electrode arranged between said cathode and said anode and acting as an electrostatic lens so as to direct electrons emitted by said cathode to said anode and to produce a focal spot thereon; a stepdown transformer having a primary and a secondary con-

nected to said cathode; an adjustable rheostat connected in series with said primary of said stepdown transformer so as to change the heating current flowing through said cathode by adjustment of said rheostat; a step-up transformer having a secondary producing a high alternating voltage; an adjustable tap arranged for co-operating with said secondary of said step-up transformer so as to be at an adjustable high alternating potential; means for applying said high alternating potential of said tap of said step-up transformer to said cathode, said anode being grounded; a potentiometer inserted between said tap of said step-up transformer and ground; an adjustable tap cooperating with said potentiometer and connected with said intermediate electrode so as to adjust the size of said focal spot on said anode and thus the drawing sharpness of said X-ray tube; and means for coupling said adjustable tap of said potentiometer with said adjustable rheostat and said adjustable tap of said secondary of said step-up transformer so as to obtain the maximum permissible brightness of the focal spot produced by said intermediate electrode on said anode.

3. An X-ray apparatus comprising, in combination, an X-ray tube including a cathode, an anode, and an intermediate hollow electrode arranged between said cathode and said anode so as to direct electrons emitted by said cathode to said anode and to produce a focal spot thereon; a step down transformer having a primary and a secondary connected to said cathode; a first rotatable shaft; a second rotatable shaft arranged parallel to said first shaft; a third rotatable shaft arranged parallel to said first and second shafts, said first shaft being arranged centrally between said second and third shafts; a rheostat arranged along a circular arc concentric with said second shaft; a tap connected to said second shaft connecting said primary of said stepdown transformer in series to said rheostat so as to change the heating current flowing through said cathode by adjustment of said tap connected to said second shaft; a step-up transformer having a secondary producing a negative high voltage, said secondary of said step-up transformer being arranged along a circular arc concentric with said third shaft; a tap connected to said third shaft and cooperating with said secondary of said step-up transformer so as to be at an adjustable negative high potential; means for applying said negative high potential of said tap connected with said third shaft to said cathode, said anode being grounded; a potentiometer arranged along a circular arc concentric with said first shaft and being inserted between, said tap connected to said third shaft and ground; a tap connected to said first shaft and cooperating with said potentiometer, said tap connected with said first shaft being connected with said intermediate electrode so as to adjust the size of said focal spot on said anode and thus the drawing sharpness of said X-ray tube; and means for coupling said shafts with one another so as to obtain the maximum permissible brightness of the focal spot produced by said intermediate electrode on said anode.

4. An X-ray apparatus comprising, in combination, an X-ray tube including a cathode, an anode, and an intermediate hollow electrode arranged between said cathode and said anode so as to direct electrons emitted by said cathode to said anode and to produce a focal spot thereon; a step down transformer having a primary and a secondary connected to said cathode; a first rotatable shaft arranged axially undisplaceably; a second rotatable shaft arranged parallel to said first shaft and being axially displaceable; a third rotatable shaft arranged parallel to said first and second shafts and being axially displaceable, said first shaft being arranged centrally between said second and third shafts; a rheostat arranged along a circular arc concentric with said second shaft; a tap shiftably connected to said second shaft and connecting said primary of said stepdown transformer in

series to said rheostat so as to change the heating current flowing through said cathode by adjustment of said tap connected to said second shaft; a step-up transformer having a secondary producing a negative high voltage, said secondary of said step-up transformer being arranged along a circular arc concentric with said third shaft; a tap shiftably connected to said third shaft and cooperating with said secondary of said step-up transformer so as to be at an adjustable negative high potential; means for applying said negative high potential of said tap connected with said third shaft to said cathode, said anode being grounded; a potentiometer arranged along a circular arc concentric with said first shaft and being inserted between, said tap connected to said third shaft and ground; a tap rigidly connected to said first shaft and cooperating with said potentiometer, said tap connected with said first shaft being connected with said intermediate electrode so as to adjust the size of said focal spot on said anode and thus the drawing sharpness of said X-ray tube; and disengageable means for coupling said shafts with one another so as to obtain the maximum permissible brightness of the focal spot produced by said intermediate electrode on said anode.

5. An X-ray apparatus comprising, in combination, an X-ray tube including a cathode, an anode, and an intermediate hollow electrode arranged between said cathode and said anode so as to direct electrons emitted by said cathode to said anode and to produce a focal spot thereon; a stepdown transformer having a primary and a secondary connected to said cathode; a first rotatable shaft arranged axially undisplaceably; a second rotatable shaft arranged parallel to said first shaft and being axially displaceable; a third rotatable shaft arranged parallel to said first and second shafts and being axially displaceable, said first shaft being arranged centrally between said second and third shafts; a rheostat arranged along a circular arc concentric with said second shaft; a tap shiftably connected to said second shaft and connecting said primary of said stepdown transformer in series to said rheostat so as to change the heating current flowing through said cathode by adjustment of said tap connected to said second shaft; a step-up transformer having a secondary producing a negative high voltage, said secondary of said step-up transformer being arranged along a circular arc concentric with said third shaft; a tap shiftably connected to said third shaft and cooperating with said secondary of said step-up transformer so as to be at an adjustable negative high potential; means for applying said negative high potential of said tap connected with said third shaft to said cathode, said anode being grounded; a potentiometer arranged along a circular arc concentric with said first shaft and being inserted between, said tap connected to said third shaft and ground; a tap rigidly connected to said first shaft and cooperating with said potentiometer, said tap connected with said first shaft being connected with said intermediate electrode so as to adjust the size of said focal spot on said anode and thus the drawing sharpness of said X-ray tube; first, second, and third toothed wheels rigidly connected, respectively, to said first, second and third shafts, said second and third wheels meshing in one end position of said second and third shafts with said first toothed wheel so as to form a disengageable coupling between said shafts so as to obtain the maximum permissible brightness of the focal spot produced by said intermediate electrode on said anode.

References Cited in the file of this patent

UNITED STATES PATENTS

1,612,641	Morrison	Dec. 28, 1926
1,949,347	Bouwers	Feb. 27, 1934
2,053,792	Huppert et al.	Sept. 8, 1936

(Other references on following page)

2,842,877

9

UNITED STATES PATENTS

2,131,192	Schlesinger -----	Sept. 27, 1938	2,605,458
2,147,424	Bischoff -----	Feb. 14, 1939	2,617,046
2,270,531	Kloos -----	Jan. 20, 1942	2,683,223
2,405,477	Westendorp -----	Aug. 6, 1946	5
2,531,583	Ott -----	Nov. 28, 1950	291,941

10

Zabransky -----	July 29, 1952
Douma et al. -----	Nov. 4, 1952
Hosemann -----	July 6, 1954

FOREIGN PATENTS

Germany -----	May 15, 1916
---------------	--------------