Nov. 9, 1948. W. A. SHURCLIFF 2,453,163

X-RAY APPARATUS AND PROCEDURE

Filed Dec. 30, 1944 2 Sheets-Sheet 1

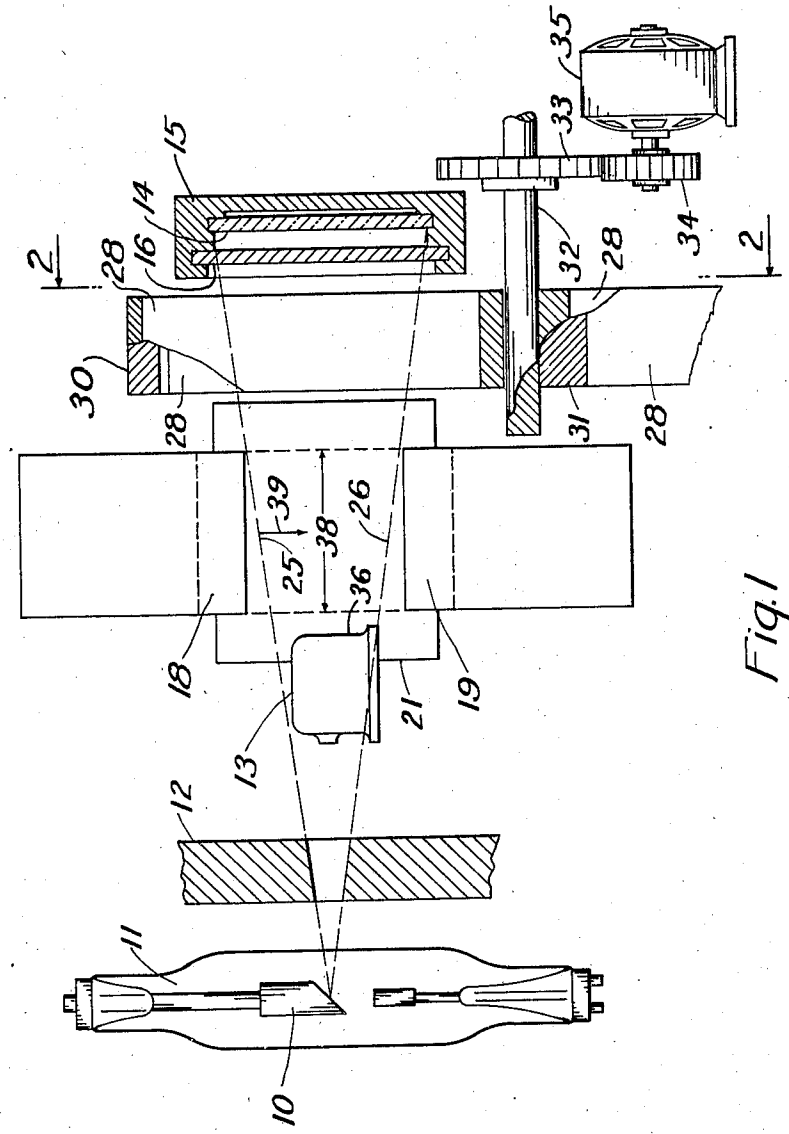


Fig. 1

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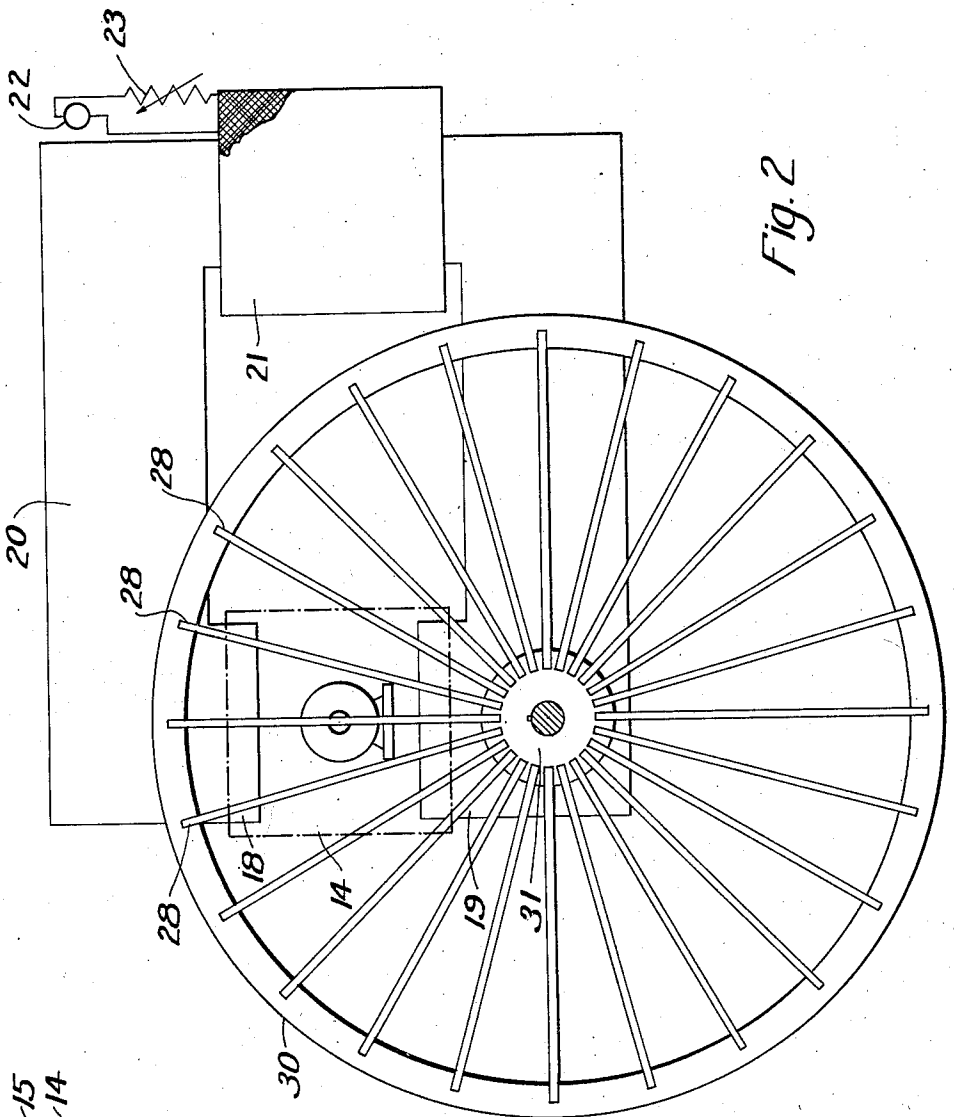


Fig. 2

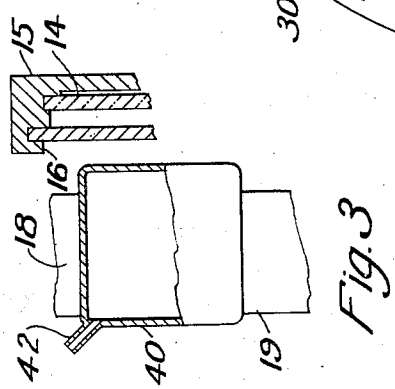


Fig. 3

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2,453,163

X-RAY APPARATUS AND PROCEDURE

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Application December 30, 1944, Serial No. 570,723

16 Claims. (Cl. 250—99)

(Granted under the act of March 3, 1883, as amended April 30, 1928; 370 O. G. 757)

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This invention relates to X-ray apparatus and procedure, and more particularly to radiography, e. g. with extremely high voltage X-rays, under conditions tending to produce appreciable quantities of energetic secondary electrons.

As the voltage on an X-ray tube is raised from low values such as 100,000 volts, the penetrating power of the radiation increases markedly, so that with the higher voltages X-ray photographs of thick and dense objects can be taken in reasonably short intervals of time. Thus by using voltages of the order of one million or more, successful X-ray photographs can be made of solid steel specimens several inches thick in less than 5 minutes; many advantages of these and especially of still higher voltage X-rays, and the increasing availability of compact and convenient equipment for such purposes have been summarized by W. D. Coolidge, in the Journal of the Franklin Institute, volume 237, pages 435 to 439 (1944). For convenience, references herein to the energy or penetrating power of X-rays will sometimes be expressed in millions of electron volts (m. e. v.), it being understood that with X-ray tube targets of tungsten, gold, platinum, or the like, and with high voltages, the energy or hardness of the radiation predominantly and approximately corresponds to the applied voltage; e. g. at an accelerating voltage of one million, the X-rays can be fairly described as having an energy of about 1.0 m. e. v.

As intimated above, on increasing the X-ray hardness to and preferably well beyond 1.5 m. e. v., further marked advantages may be theoretically realized in radiography, for example with even thicker or heavier subjects, or in reducing the required exposure time to the order of a minute or even of seconds, permitting rapid radiographic inspection of articles manufactured in large quantities. Coolidge, cited above, states that at these much higher voltages the secondary X-radiation produced in the object under examination is scattered less in direction, but unfortunately it is found that other unwanted and deleterious phenomena arise. These phenomena constitute or accompany the production of energetic secondary electrons, not only high energy photo-electrons but especially so-called pairs of negative and positive electrons. Electron-positron pair formation (See Pollard and Davidson: "Applied Nuclear Physics," page 15, N. Y. 1942) may take place when X-rays or gamma rays of energy greater than 1.02 m. e. v. impinge upon matter, it being found that approximately 1.02 m. e. v. of the energy of a given

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photon, having an original energy of, say, 1.5 m. e. v. or more, is utilized in creating the electron-positron pair, and the remaining energy of the photon is converted to kinetic energy of the positive and negative electrons. At the same time, as indicated above, extremely high energy photo-electrons may also be released by other photons of the X-ray beam.

These secondary electrons can in turn produce secondary X-rays by impinging on matter in their paths, and even though the kinetic energy of a few of the electrons might be harmlessly dissipated by ionizing collisions, a secondary radiation of considerable energy is bound to be produced by the inevitable, and usually prompt, so-called annihilation of the positrons, a process believed to involve combination of the positron with an electron, destroying both and releasing either a single 1.02 m. e. v. photon or two 0.51 m. e. v. photons, as explained by Stranathan, "The 'Particles' of Modern Physics" pages 374 to 385 (Phila., 1942).

In high voltage radiography these energetic secondary electrons have proved deleterious since they, and likewise secondary X-rays produced by them, affect the photographic plate and prevent the attainment of the desired definition, sharpness and contrast in the recorded image. Although with low voltage X-rays, electron-opaque screens in front of the plate may be useful in eliminating the low-energy secondary electrons there experienced, e. g. so-called Compton recoil electrons and relatively slow photo-electrons, it has been found that with extremely high voltage apparatus, any attempt to remove electrons and positrons by using such a screen is counterbalanced by the undesirable effect on the plate, of secondary X-rays that the incident particles produce in such a screen. Moreover, while secondary X-radiation coming directly from the subject or article under examination may in itself be less disturbing with higher voltage X-rays, or may, if desired, be reduced by a so-called Bucky grid, a device of the latter sort does not solve the problem of energetic secondary electrons, that either traverse the grid or eject secondary X-rays from it toward the plate.

All of these difficulties due to unwanted electrons become even more serious with the advent of more compact and inexpensive sources of tremendously high voltages or tremendously high velocity particles, such as the electron accelerator known as the Betatron and described by D. W. Kerst in Physical Review, volume 60, pages

47 to 53, and volume 61, page 93, improved forms of this device being capable of producing X-rays of energies corresponding to potentials greater than ten million volts.

With all of the foregoing in mind, an important object of the present invention is to provide X-ray apparatus and procedure, e. g. for radiography, wherein the effects of unwanted secondary electrons may be substantially reduced or eliminated; and further objects are to provide simple yet remarkably effective means to avoid or curtail the direct or indirect effects of energetic negative electrons and positrons, such as tend to interfere with photography or other X-ray image registration when high voltage radiation is used, for example X-rays of substantially more than 1.0 m. e. v. and particularly those of 1.5 m. e. v. and much higher energy, it being understood that unless otherwise stated, the term X-rays is used herein to include gamma rays of corresponding energy, for example such as may be emitted by intense natural or artificial radioactive sources.

Further objects are to provide improvement in the quality of X-ray photographs made under conditions conducive to the production of appreciable quantities of secondary electrons, and also to improve the quality of X-ray images made with high energy radiation and having such character that secondary electrons or effects caused by them, might otherwise impair the desired X-ray image.

To these and other ends, the present invention contemplates the provision of means, disposed in and about the path of primary X-rays between the object under examination and the photographic plate or other device for registering the image, whereby the secondary electrons are in substantial measure diverted from the paths of the primary radiation and are furthermore so diverted or diverted to such localities or in such directions that any secondary radiation produced by the electrons is not directed upon the photographic plate.

Thus, in accordance with the present invention and instead of disposing the photographic plate immediately adjacent the subject of X-ray examination, or instead of merely separating it therefrom by filters of a sort heretofore proposed, the plate or other device of similar purposes is spaced from the subject, and a magnetic field of considerable strength is caused to traverse the path of the rays in the intervening space. Taking into account the strength of the field and the anticipated maximum energy of the secondary electrons both positive and negative that are likely to be troublesome, the field preferably covers an area or distance along the path of the X-rays such that the released electrons cannot reach the plate or any screen or filter disposed in front of the plate, but will be caused by the magnetic field to follow circular paths or successive segments thereof not intersecting the screen or plate and so will tend to lose their energy harmlessly while following such paths. For maximum realization of such results, according to present understanding, the separation space between the subject or sample under observation and the screen, i. e. the space traversed by the magnetic field, should be at least approximately twice the radius of curvature of the high energy electrons in the field; thus for instance, with a magnetic field strength of about 1000 gauss, the space should extend about 10 centimeters in the direction of the X-ray travel, to take care of 1.0 m. e. v. electrons. In some cases for better elimination of undesirable effects of the secondary electrons the described region traversed by the magnetic field may be isolated and roughly evacuated; otherwise a few electrons might be fortuitously deflected from a circular path by collision with air molecules.

It is particularly desirable that the arrangement be such as to prevent secondary radiation, caused by electrons, from reaching the photographic plate, and although to a somewhat useful extent this result can be achieved by appropriate disposition of the magnetic field over a substantially large region and in such a manner that the diverted electrons are caused either to dissipate their energy or release it at positions that, for example, are far to one side of the primary X-ray paths, a further and particularly important feature of the invention includes the provision, intermediate the magnetic field and the photographic plate, of means such as a series of vanes or thin plates, arranged side by side, spaced from each other and each lying in a plane parallel to the path of the primary rays, so as to provide a set of transversely adjoining channels through which corresponding portions of the beam must travel, beyond the magnetic field.

These vanes may serve a plurality of functions, as follows: In the first place, they tend to arrest any secondary negative electrons not completely diverted by the magnetic field, and to a considerable extent tend to stop these electrons at a position sufficiently remote from the photographic plate and its screen, as to prevent any resulting radiation from reaching the plate. In the second place, the vanes tend to arrest the secondary positive electrons (positrons), at similarly remote positions and serve particularly to promote combination of the positrons at such localities with negative electrons, so that much of the annihilation radiation is so originated and directed, in effect, that it will not intercept the plate. Finally, the vanes serve to absorb all X-rays that are not parallel to the primary rays, and in this way such part of the secondary radiation produced by impact of negative or positive electrons, and of the annihilation radiation produced by the positive electrons, as might otherwise impinge upon the photographic plate, is effectively absorbed, it being understood that by reason of the other instrumentalities described, these secondary radiations are virtually all directed at a greater or less angle to the primary beam, so that even those which might progress toward the plate will be interrupted and absorbed by the thin vanes. If it is desired to prevent production of an image or shadow of the vanes on the plate, they may be given an appropriate motion across the X-ray paths, for instance as described below.

By way of illustrative example, certain embodiments of the invention are shown in the accompanying drawings, wherein:

Fig. 1 is a generally schematic elevation of an X-ray photographic system, partly in vertical section and with certain parts further cut away;

Fig. 2 is a section on line 2—2 of Fig. 1; and

Fig. 3 is a fragmentary view partly in elevation and partly in vertical section of certain modifications of a part of the system shown in Fig. 1.

Referring to Figs. 1 and 2, X-rays projected from the target 10 of an X-ray tube 11 travel through an appropriate aperture in a safety screen 12 and after traversing an object 13 under examination, such as a heavy casting or other dense article, impinge on a suitable image-registering

device such as the X-ray-sensitive photographic plate 14 mounted in a holder or cassette 15. It is to be understood that the X-ray tube 11 is operated at a suitably high voltage, e. g. somewhat in excess of 1.5 million volts, to generate extremely hard X-rays, say of 1.5 m. e. v. energy or greater, and although other types of X-ray sources, such as tubes wherein the radiation is projected from the opposite face of the target to that bombarded by electrons, or devices like the Betatron mentioned above, may be used, the drawing represents an X-ray tube of conventional design, for simplicity of illustration. If desired, photographic plate 14 may have a thin screen 16 of conventional type, for instance of aluminum, for stopping so-called soft X-rays, it being understood that this screen may be disposed in contact with the plate or spaced slightly in front of it, i. e. toward the X-ray source, as shown. Instead of the photographic plate other image-registering devices may be used, for example a simple fluorescent screen or combination of a fluorescent screen or other intensifying structure with photographic equipment, or other means for temporarily or permanently registering the image produced by the hard X-rays in traversing the object 13.

In accordance with the present invention the screen 16 and plate 14 are considerably spaced from the object 13 and at least a substantial part of the intervening region is traversed by a magnetic field extending between the pole pieces 18 and 19 of an electro-magnet that includes suitable core structure 20 (see Fig. 2) extending considerably to one side of the path of the X-rays and carrying an energizing winding 21. Current supply for the winding is diagrammatically indicated by the D. C. generator 22 connected through a rheostat 23 for adjustment of field strength if desired. The magnet poles 18 and 19 are disposed so as not to obstruct the path of primary X-rays, generally indicated by the boundary lines 25 and 26, and have sufficient transverse dimension (see Fig. 2) to extend the field through all portions of the X-ray beam. Although cylindrical or other shaped pole pieces may be used, rectangular configurations are illustrated as providing a field of desirably large cross-sectional area.

Figs. 1 and 2 also show, between the magnetic field and the screen 16, a set of thin vanes or sheets 28 of X-ray absorbing material, for example, lead, gold, or the like, arranged side by side in an essentially parallel relation with the path of the primary X-rays and with the magnetic lines of force. Although these vanes may be stationary (as where resulting shadows are of no consequence) or may be mounted to reciprocate across the beam, preferably in a motion other than simple harmonic and involving a constant velocity each way (say, 1 to 5 cm./sec.) with rest periods (e. g. 0.1 sec.) short relative to the times of movement, the vanes 28 are conveniently shown as embodied in a continuously rotating structure. Thus they are mounted as wheel spokes between a rim 30 and a hub 31 keyed to a shaft 32 parallel to but at one side of the axis of the primary X-ray beam. The shaft 32 is continuously rotated, e. g. by the gears 33 and 34 and the electric motor 35, so that the vanes sweep across the beam with a velocity sufficient, relative to the desired exposure time, to prevent shadows or blurs in the photograph. For substantial uniformity of exposure, the radial vanes can be very thin, e. g. 0.01 inch or less, or can be tapered to have decreasing thickness from rim to hub. If necessary, suitable mechanical reinforcing structure can be provided, such as supplemental spokes of relatively non-absorbing material, or even a facing disk (e. g. toward the plate 14) of material having a beneficial effect, for instance like the screen 16 or even in place of such screen. In some cases, as with a reciprocating grid of vanes, the latter may extend from the cassette into, or may lie wholly within, the magnetic field. Generally speaking, the specific devices shown in the drawing are merely illustrative, and various changes in form and dimension of the several elements may be made; for instance, the X-ray source might be placed closer to, or perhaps in many cases further from, the object under examination.

The arrangement of Figs. 1 and 2 provides a remarkably complete elimination of secondary electrons, including positrons, and effectively prevents radiation due to such particles from reaching the screen 16 or photographic plate 14. Thus a secondary particle emanating from the face 36 of the object 13 in any direction, or otherwise entering the magnetic field, is deflected to have a curved component of motion toward or away from the paper as seen in Fig. 1, i. e. to the right or left as seen in Fig. 2, depending on the polarity of its charge. Under preferred conditions as explained above, the curved electron and positron paths cover substantial arcs, most advantageously half-circles or arcs of greater angle, and usually, for best results, not less than about 90°. Many particles thus escape into regions far to the left and right of the area defined by the pole pieces 18 and 19 in Fig. 2, some continue to circle in the field, and some may obliquely strike one of the pole pieces. The deflected particles tend to dissipate their energy in ionization, and if secondary X-radiation is generated when the particles are finally stopped, they are likely to have been traveling otherwise than toward the plate 14, so that the radiation tends in effect to be similarly diverted, since high energy X-rays produced by arrest of electrons greatly predominate in the direction of electron travel, as noted by Petrauskas and others, Physical Review, volume 63, page 389 (1943). To a considerable extent the annihilation radiation of deflected positrons will be similarly directed outside of the beam 25—26.

As explained above, the system of vanes 28 co-operates peculiarly and to marked advantage with the magnet structure in affording a desirably complete elimination of the various secondary effects. The vanes tend to trap any electrons that may escape on the side of the magnetic field toward the screen and plate, and are particularly effective in promoting recombination, i. e. annihilation, of positrons, all in localities remote from the screen. Resulting secondary radiations, especially the 1.0 or 0.5 m. e. v. annihilation radiation, are almost certain to have a component of direction transverse of the primary rays and will thus be absorbed by the vane system. At the same time the vanes absorb virtually all other approaching secondary rays that are not parallel to the primary beam, including radiation resulting from the arrest or annihilation of charged particles elsewhere.

While the desired interval 38, traversed by the magnetic field between the object 13 and the screen 16, and the desired strength of such field, may vary with circumstances, the distance 38 ought preferably to be at least about twice R, the radius of curvature of the path of an electron moving at an angle to the lines of force 39. R

may be computed from the well known approximate equation:

$$HR=\frac{10^4}{3}[E(E+1.02)]^{\frac{1}{2}}$$

where H is field strength in gauss, R is expressed in centimeters, and E is the energy of the electron in m. e. v. The selected E should be the highest that will characterize any appreciable number of secondary electrons released by the incident primary beam either in the object under examination or elsewhere. For example, with primary X-rays of about 2.0 m. e. v., the total kinetic energy of each electron-positron pair will be of the order of 1.0 m. e. v., but if secondary photo-electrons are found disturbing, the space 38 and field strength H should be such as to take into account electrons of energy substantially greater than 1.0 m. e. v., because the photo-electrons may have various energies, many approaching or in fact almost equalling that of the primary beam.

Fig. 3 illustrates a modification of the invention wherein the space between the pole pieces 18 and 19 is enclosed by a thin X-ray permeable envelope 40, preferably of a material such as glass or aluminum having little susceptibility of generating hard X-radiation on impact of secondary electrons. The envelope 40 preferably encloses at least the space intermediate the pole pieces and may also extend beyond the boundaries of the pole pieces at the sides; in fact the wall of the enclosure 40 adjacent the photographic plate 14 and screen 16 may in some cases be omitted, and replaced by suitable provision for sealing the cassette 15 directly to the adjoining walls of the enclosure 40, thus avoiding the interposition of a further body of material between the field and the screen 16. The envelope 40 has a conduit 42 through which the enclosed space may be roughly evacuated, for example to a pressure of 10^{-3} mm. of mercury. As explained hereinabove this structure is of advantage in insuring that the secondary electrons deflected along curved paths by the magnetic field may complete such travel without being diverted into the path of the primary X-rays by collision with air molecules. It will be understood that the X-ray source, shield, object under investigation, and screen and photographic plate may be the same with this arrangement as with the apparatus of Fig. 1; and if desired, the vane structure may be included, although for simplicity of illustration it is omitted in Fig. 3.

It will now be seen that the described arrangements, including the wide-area magnetic field, or preferably such field in cooperation with the vane system, not only eliminate the negative electrons and their secondary rays, but are of special advantage in promoting annihilation of the positrons before they reach the photographic plate and at such localities that the resulting radiation either is absorbed or goes in other directions than toward the plate. Hence the procedure and structures of the invention are found to overcome disadvantages peculiarly characteristic of high voltage radiography, and accomplish significantly improved results, in the quality of the resulting image, that could not be attained by the use of expedients heretofore commonly practiced in X-ray photographic or like technique. Although in the use of sharply confined, i. e. very narrow beams or pencils of X-rays or gamma rays for therapeutic purposes or for mere experimental investigation of the frequency or hardness of such rays, it has been proposed to eliminate beta particles or secondary negative electrons by causing the narrow pencil of rays to traverse a single long channel or conduit of small cross section or to pass between a pair of magnet poles, such proposals have not been suggested for or applied to high voltage radiography, and indeed have failed to take into account the problems of such radiography, e. g. wherein the penetrating primary rays must be spread out through an area laterally wide enough for the desired image of the object under examination, and wherein the rays must actually traverse such an object; nor has account heretofore been taken in the practical art, so far as I know, of the problems occasioned by positive electrons with their inevitable annihilation radiation.

Thus representing a practical solution, not heretofore apparent, of difficulties peculiar to the art of radiography, the invention contemplates a variety of uses, and among them, special utility in obtaining improved high voltage radiographs of thick and dense objects, either for the analysis of such objects in the laboratory or for their routine examination in industrial production, or for their inspection in situ as parts of ships, guns, machines, and the like.

It is to be understood that the invention is not limited to the specific apparatus or procedure herein set forth by way of example but may be carried out in other ways without departure from its spirit.

The invention herein described and claimed may be used and manufactured by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

I claim:

1. In X-ray apparatus, in combination, a source of X-rays of energy greater than 1.0 m. e. v. and conducive to generation of secondary negative and positive electrons, means for registering an X-ray image of a subject exposed to radiation from said source, means for establishing an electron-deflecting magnetic field across the path of X-rays between said subject and said image registering means, said field establishing means providing said magnetic field crossing the said path throughout a distance at least about twice the radius of curvature of an energetic secondary electron ejected into said field transversely thereof, electron and radiation impeding structure disposed intermediate the center of said magnetic field and said image-registering means and channeled in the direction of travel of said image-forming X-rays, and means for moving said structure transversely of the X-ray path to prevent undesired shadows in the image-registering means.

2. In X-ray apparatus, in combination, a source of X-rays of energy greater than 1.0 m. e. v., means for registering an image of a subject, produced by X-rays from said source traversing the subject, means for producing a magnetic field across the path of X-rays between said subject and said image-registering means, and a plurality of vanes of X-ray absorbing material disposed substantially parallel with the direction of said X-rays and in spaced relation to each other transversely of said path intermediate the center of said magnetic field and the image-registering means.

3. In X-ray apparatus, in combination, a source of X-rays of energy greater than 1.0 m. e. v., means for registering an image of a subject traversed by said X-rays, means for producing a

magnetic field across the path of X-rays between said subject and said image-registering means, electron-arresting and secondary-radiation-absorbing structure disposed intermediate the center of said magnetic field and said image-registering means and comprising a plurality of thin vanes of absorbing material spaced laterally from each other and each disposed in a direction essentially parallel to the X-rays, and means for moving said structure to prevent creation of observable shadows thereby in the image-registering means.

4. In X-ray apparatus, in combination, a source of X-rays of energy of at least about 1.5 m. e. v., means for registering an image of a subject traversed by X-rays from said source, and means for establishing a magnetic field across the path of X-rays between said subject and said image-registering means, said field establishing means providing a magnetic field extending along the path of the X-rays for a distance at least about twice the radius of curvature of the path of a secondary electron ejected by the X-rays at an angle to said field.

5. In X-ray apparatus, in combination, a source of X-rays of energy greater than 1.0 m. e. v., and sufficiently hard to form appreciable quantities of electron-positron pairs on traversing a subject under examination, X-ray image-registering means disposed to register an image of a subject traversed by X-rays from said source, and means including structure establishing a magnetic field transverse of the path of X-rays between the subject and the image-registering means, for inhibiting secondary charged particles and radiation produced by said particles from affecting the image-registering means.

6. In X-ray apparatus, in combination, means including a source of X-rays of energy greater than 1.0 m. e. v. to be received by a subject, for projecting an image-forming beam of X-rays from the subject and for registering an image of the subject in response to said beam, and means including electron deflecting structure associated with said first mentioned means, for preventing secondary electrons from impairing the image-forming property of said beam.

7. In X-ray apparatus, in combination, a source of X-rays of energy greater than 1.0 m. e. v., photographic means for registering an image of a subject traversed by said X-rays, and means including structure establishing a magnetic field across the X-rays that have traversed the subject, for inhibiting secondary charged particles from impairing image registration by said photographic means.

8. In X-ray apparatus, in combination, a source of X-rays of energy greater than 1.0 m. e. v., means for registering an X-ray image of a subject exposed to radiation from said source, and means establishing a magnetic field transverse of the path of X-rays from the subject to the image-registering means and having an extent along said path sufficient to deflect energetic electrons in an arc of at least about 90°.

9. In X-ray apparatus, in combination, a source of X-rays, means for registering an X-ray image of a subject exposed to radiation from said source, means for establishing an electron-deflecting magnetic field transverse of the path of image-forming X-rays from the subject to the image-registering means, absorbing structure disposed adjacent the image-registering means in the path of the image-forming X-rays and channeled in the direction of travel of said image forming X-rays, and means for rotating said structure to sweep across the X-ray path.

10. In X-ray apparatus, in combination, a source of X-rays of energy greater than 1.0 m. e. v., means for registering an X-ray image of a subject exposed to radiation from said source, means for establishing an electron-deflecting magnetic field transverse of the path of image-forming X-rays from the subject to the image-registering means, and absorbing structure disposed adjacent the image-registering means in the path of the image-forming X-rays and channeled in the direction of travel of said image-forming X-rays.

11. In X-ray apparatus, the combination, with means for producing X-rays having energies corresponding to an X-ray tube voltage of at least about 1.5 m. e. v. and means for registering an image of said X-rays that have traversed a subject under examination, of means comprising structure establishing a magnetic field transverse of the path of said X-rays between the subject and the image-registering means, for deflecting secondary charged particles from the image-producing rays and for inhibiting secondary radiation excited by said charged particles from appreciably affecting the image-producing means.

12. In X-ray apparatus, in combination, means including an X-ray source adapted to project X-rays of energy greater than 1.0 m. e. v. toward a subject, for establishing and registering a beam of X-rays having a transverse distribution providing an image of said subject, and means including electron deflecting structure adjacent the path of said beam in the first mentioned means, for removing energetic secondary electrons from said beam.

13. In X-ray apparatus, in combination, a source of X-rays of energy greater than 1.0 m. e. v., means for registering an image of a subject traversed by said X-rays, means for producing a magnetic field across the path of X-rays between said subject and said image-registering means, to deflect secondary electrons into directions other than toward said image-registering means, and means for maintaining the space traversed by said field in the path of the X-rays, at a pressure substantially less than atmospheric.

14. In X-ray apparatus, in combination, a source of X-rays of energy greater than 1.0 m. e. v., means for registering an image of a subject produced by X-rays from said source traversing said subject, means for producing a magnetic field across the path of X-rays between said subject and said image-registering means, and ray-channeling means intermediate the center of said field and said image-registering means for inhibiting passage of radiation in other directions than that of the X-rays from the source.

15. In a method of radiography, the steps of establishing an X-ray image of a subject by directing through the subject X-rays of hardness corresponding to generation by electrons of at least 1.5 m. e. v. energy, and registering said image at a predetermined locality while inhibiting degradation of the same due to secondary charged particles and radiation produced by such particles, by magnetically deflecting said particles, so as to cause secondary radiation thereafter produced by them to be projected in directions different from that of the X-rays traversing the subject, and interrupting travel of said secondary

radiation in directions toward the aforesaid locality of image registration.

16. In a method of radiography, the steps of establishing an X-ray image of a subject by directing to said subject, X-rays of energy greater than 1.0 m. e. v. and conducive to generation of secondary negative and positive electrons, and registering said image while inhibiting degradation of the same due to such electrons and to radiation produced thereby, by subjecting the image-forming X-rays from said subject to a transverse magnetic field sufficient to deflect secondary electrons through at least a semi-circle, and by interposing electron-stopping and secondary-radiation-absorbing material in regions along the path of said image-forming X-rays beyond the center of said field, to remove electrons

and radiation traveling at an angle to said path, but in a disposition to absorb no more than a fraction of said image-forming X-rays.

WILLIAM A. SHURCLIFF.

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