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DEVICE FOR X-RAY MOTION PICTURES

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FIG. 1

FIG. 2

FIG. 4

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FIG. 3

FIG. 5

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My invention relates to the method and device for producing X-ray moving pictures and contains subject matter common with my U. S. Patent No. 2,525,424 and represents a continuation in part of my co-pending patent application Serial No. 648,991, now U. S. Patent No. 2,525,832. The importance of cinematographic X-ray pictures to study the organs in health and disease was recognized long ago. Latently the value of the X-ray moving pictures gained understanding in industry in examination of moving parts of machinery. In spite of obvious advantages of this method no progress was made because the X-ray energy available after the passage through the examined body was not sufficient to expose the moving film. To use a source of X-rays of greater energy was not compatible with the patient’s safety. The dose of X-rays which would be sufficient for filming purposes would produce burns of skin and severe injury to the blood-forming system of the patient. This was the reason why all X-ray motion picture apparatuses known at present such as e. g. of J. Jany, U. S. Patent No. 2,205,853, or described by R. J. Reynolds in British Journal of Radiology, 1934, pages 415–424, or by Stewart W. H. in American Journal of Roentgenology and Radium Therapy, 1937, vol. 38, pages 465–469, failed in their application. The development of more sensitive film emulsion could not remedy this situation as, filming requires 15–24 frames second which is equivalent to taking 15–24 X-rays pictures in one second. On the other hand it is well known in the art that 30–40 X-ray pictures of the same region, which would represent only 2 seconds of cinematographic exposure, represents the limit of safe X-ray application.

Another purpose of this invention is to reduce X-ray energy necessary for producing X-ray moving pictures in order to eliminate the need for expensive and bulky multi-million volt X-ray equipment necessary for industrial cinematographic studies.

Another objective of my invention is to provide X-ray motion pictures of better detail and of the greater contrast than it was possible until now.

The purposes of my invention were accomplished by the use in combination of X-ray source, of X-ray image intensifying tube, described in my co-pending application No. 13,916, now U. S. Patent No. 2,555,424, issued on June 5, 1951, of optical system, of shutter system and of moving pictures camera. The invisible X-ray images of the examined body are projected onto X-ray intensifying pick-up tube in which they are converted into photo-electron image having the pattern corresponding to X-ray images. The photo-electron images after intensification by cascade amplification, by electronic diminution, by storage and by secondary emission are sent in the form of video signals to the receiver where they are reconverted into fluorescent images having the pattern of original X-ray images but of a few thousand times greater intensity. The intensified fluorescent X-ray images are projected through the shutter, by the optical system onto moving pictures camera for recording.

The invention would be better understood when taken in connection with the accompanying drawings. In the drawings:

Fig. 1 represents device for recording X-ray moving pictures.

Fig. 2 represents variety of this invention in which reflective optical system is used to project intensified fluorescent image onto moving film.

Fig. 3 represents an alternate form of this invention in which reflective optical system consisting of meniscus lens, concave spherical mirror and of plane mirror is shown.

Fig. 4 represents variety of this invention in which faster and more compact reflective optical system is shown.

Fig. 5 represents variety of this invention in which more efficient X-ray image intensifying tube is shown.

Referring to the Fig. 1 there is shown the X-ray source 26, the examined body 27 and the X-ray image intensifying tube 28. The face 1 of X-ray intensifying tube 28 must be of a material transparent to the type of radiation to be used. Inside of the face of the tube there is a very thin light reflecting aluminum layer 2 which prevents the loss of light from the X-ray source. The face is made up of a few thousand times greater sensitivity to the X-rays to be used, and the photoemissive material likewise should have its maximum sensitivity to the wave length emitted by the fluorescent screen. Fluorescent substances that may be used are zinc silicates, zinc selenides, zinc sulphide, barium sulphate or calcium tungstate with or without activators. The satisfactory photoemissive materials will be cadmium oxide, cadmium oxide activated by silver, cadmium with antimony or with bismuth or antimony with lithium or potassium. The barrier layer 4 between the fluorescent and photoemissive surfaces can be an exceedingly thin transparent film of mica, ZnF₂, silicon or of a suitable plastic.

The photo-electron image obtained and stored in the photo-emissive layer 5 is now projected on the first screen 6 of the amplifying section 7 having one 6a or a few successively arranged amplifying screens 6a by means of focusing magnetic and/or electromagnetic fields 25 which are not indicated in detail since they are well known in the art and would only serve to complicate the illustrations.

The amplifying screen 6 consists of electron pervious light reflecting layer 8, of electron fluorescent layer 9, of light transparent barrier layer 10 and of photo-emissive layer 11. Fluorescent substances that may be used for amplifying screen 6 and 6a are zinc silicates, zinc sulphide, barium sulphate or calcium tungstate with or without activators. The satisfactory photoemissive materials will be cadmium oxide activated by silver, cadmium with antimony, or antimony with lithium or potassium. The barrier layer 10 between the fluorescent and photoemissive surfaces can be exceedingly thin transparent film of mica, ZnF₂ or ZnS, silicon or of a suitable plastic. ZnF₂ is transparent to ultraviolet radiation. The electron images emitted from the amplifying screen 6 are electron-optically diminished and are focused by means of magnetic or electromagnetic fields 25a on the next amplifying screen 6a producing image intensification proportional to the square power of the linear diminution. The electron images from the amplifying section 7 are focused by mag-
getic or electromagnetic fields 25b and are projected on the target, which means a screen 12, where they are intensities or frequencies by an error. The output is then scanned by electron beam 13. The latter is modulated by the electron pattern on the target so that returning electron beam 14 brings the charge corresponding to the electron image on the target to the multiplier section 15. There they are intensified by second or third elements and are stored. The output 16 to the amplifiers 17 and then led to a coaxial cable 18 or by high frequency waves to immediate or remote receivers 19 where they are converted into fluorescent images. The X-ray intensifying pick-up tube used in this invention can be of intensity modulation type, of detection modulation type, of velocity modulation type or of photo-conductive type and it is obvious that various types of pick-up tubes can be used without affecting the basic idea of this invention. The synchronizing and deflection circuits 25c are not indicated in detail as they are well known in the art and will only complicate the drawings.

The intensified fluorescent images appearing on the screen 20 of the kinescope 19 can be filmed by the movie camera 21 as their luminosity is now strong enough to expose the film 22 in a frame time, in spite of the use of a very small amount of X-ray intensifying device operates at 30 frames/second or at submultiple of this figure. In many instances it will be preferable to use 15 frames/second which will be sufficient to avoid the flicker and will allow for a longer storage time improving sensitivity of the system. The movie camera is driven with the synchronous motor 23 also at 15 frames/second. The shutter 23c in the camera is open for 170 degrees giving exposure close to $\frac{1}{10}$ of a second. The motor drive is phased so that the shutter opens and closes during the vertical blanking period of the television image. In this way anding is completely eliminated.

The 15 frames/second recording can be projected by a standard movie projector at 16 frames/second without impairment of the quality of motion picture. On the other hand if X-ray motion pictures have to be projected by 24 frames/second movie projector, special arrangements have to be made in order to prevent the appearance of a black or white bar across the film image during projection. This complication called shutter-bar or banding occurs whenever the rate of frequency of the television system and the frame rate of the motion picture camera are not equal or are not submultiple of each other. In such a case the unwanted shutter in the motion picture camera which can be driven by 60 cycles/second synchronous motor at 24 cycles/second. This shutter has opening angle of 288 degrees which means opening time of $\frac{1}{10}$ second, equal to the time of one television frame. The shutter is closed for $\frac{1}{125}$ second during which time pull-down of the film must occur. By this arrangement banding effect can be completely eliminated.

The kinescope 19 and motion picture camera 21 are enclosed in a light-proof box 24 in a fixed position, so that no adjustment of focus is necessary at each examination. The lens system 25b of motion picture camera in this form of invention is of conventional type and does not have to be described in detail as it is well known in the art. In order to have visual control over part of the examined body being filmed, another receiver tube 19a is provided on which the examiner can watch recording. The receiver tube could be composed of the photo-cathode of the X-ray image intensifying tube in order to be able to correlate image on it with the examined part of the body.

In this way X-ray motion pictures can be produced without the use of the excessive amount of X-ray energy and the intensifying effect of the system is such that multi-million volt expensive X-ray equipment will not be necessary any more in industrial X-ray moving pictures which was another purpose for my invention. Furthermore the contrast of the original X-ray image can be markedly increased by the use of the X-ray image intensifying output 16 having variable mu tube, with the circuit so designed that grid bias of the variable mu tube is smaller at high signal level than at low signal level, which results in amplification of the contrast and represents another important objective of this invention. Furthermore, the grain of photographic film emulsion can be reduced without necessity of prolongation of the time of the exposure which will result in pictures of much better detail and which is another purpose of my invention.

An alternate form of this invention is represented in Fig. 2. In some cases it is preferable not to use the full intensification possible with the X-ray intensifying pick-up tube. It is important then to utilize fully the light of the fluorescent X-ray image on the receiver 19. It is well known that the conventional lens system causes 95% loss of the light. In order to prevent this loss I am using reflective optical system 29 which in this embodiment consists of correcting lens in form of meniscus 30 and of concave spherical mirror 31. It is obvious, however, that reflective optical system may have many forms and varieties which can be used in my invention. It is understood therefore that my invention is not limited to any particular form of X-ray intensifying system, as solid system or Schmitt system are also applicable.

The fluorescent X-ray moving images 32 are reflected by the concave aluminum mirror 31 on the intermittently moving film 33. The moving film must have curved surface in order to avoid optical distortion. The shutter disc 34 controls the number of frames of the motion picture so that banding is prevented. The shutter is driven by synchronous motor 35 in a fixed time relation with the intermittent mechanism 36. The intermittent mechanism is also driven by the synchronous motor 35 through the gear drive 37. This optical system allows utilization of 15—20% of available light and represents considerable improvement in operation of the device.

Another variety of this invention is shown in Fig. 3. In this embodiment of my invention the invisible X-ray picture is converted into fluorescent X-ray image in the fluorescent screen 40 before its transmission. This transmission is projected by the reflective optical system onto X-ray image intensifying pick-up tube for intensification necessary for filming.

Referring now to Fig. 3 there is shown X-ray source 26, the examined body 27, the fluorescent screen 39, the fluorescent X-ray image intensifying tube 41 and the X-ray image intensifying tube 42. The X-rays after the passage through the examined body form invisible X-ray moving image which is converted in the fluorescent screen 39 into fluorescent X-ray image 40. The fluorescent X-ray image is projected by the reflective optical system 41 on the photocathode 47 of the X-ray image intensifying tube 42. The optical system 41 in this form of invention must have the greatest possible speed as the fluorescent X-ray image 40 is of a very weak luminosity. The reflective optical system of Schmitt used for this purpose as explained in my co-pending application No. 744,103, now abandoned requires precise workmanship, as the aspheric correcting plate is of a shape which is described mathematically as a curve of the fourth degree. Such a plate cannot be produced by machine with precision necessary for high speed and good resolution. Producing the modification of the optical system belonging to the family of so-called "wide field fast cameras" described by L. G. Heney and Jesse L. Greenstein in OSD Report No. 4504, which optical system can be manufactured in quantity with necessary precision. This optical system does not require apochromatic correction plate and consists essentially of meniscus lens and of concave spherical mirror. All optical surfaces have a common center of curvature located at diaphragm which limits
I modified this optical system for purposes of my invention by using in addition a plane or convex spherical mirror located between the reflecting surface of the concave spherical mirror and its nearest conjugate for the entering light rays. The operation of this optical system is shown in Fig. 3. The fluorescent X-ray image is produced by invisible X-ray image on the fluorescent screen 39 which has curved surface in order to eliminate spherical aberration. The fluorescent light rays pass through the correction meniscus lens 43 and are reflected by aluminized concave spherical mirror 45 having an aperture 45 in the center thereof on the plane mirror 46 placed in the focal plane of the concave mirror. They are reflected from the plane mirror on the photocathode 47 of the X-ray image intensifying tube 42 which is disposed opposite the reflecting surface of the concave mirror and in the axis its aperture. In case a more compact optical system is preferable the plane mirror 46 is placed at angle, the concave spherical mirror has no aperture in its center, and the X-ray image intensifying tube is positioned outside the path of the optical system and does not obstruct the path of the fluorescent rays from the fluorescent screen through the optical system. The fluorescent screen 39, the optical system 41 and X-ray image intensifying tube 42 are enclosed in light-proof box 37 in fixed position to each other in order to avoid need for focusing at each examination. In case of maladjustment focusing can be accomplished by means of locking mechanism and micrometer adjustment screw 38 which shifts the lens along the optical axis. For proper positioning of the box 37 in relation to the examined part of the body, serves separate fluorescent screen 97a attached outside of the box 37 and monitor receiver tube 56a. The fluorescent image produced in the photomultiplier photocathode 47 photocathode image. The photodetector image obtained from the photoemissive layer 47 is projected on the first composite screen 44 of the amplifying section by means of focusing magnetic or electromagnetic fields which are not indicated since they are well known in the art and would serve only to complicate the illustrations. The amplifying composite screen 44 and 44a consist of electron pervious light reflecting layer 8, of electron fluorescent layer 9, of light transparent barrier layer 10 and of photo-emissive layer 11. Fluorescent substances which may be used for amplifying screens 44 and 44a are zinc sulphide or cadmium sulphide or cadmium oxide with or without activators. The satisfactory photo-emissive materials will be calcium oxide activated by silver, calcium with antimony or with bismuth, or antimony with lithium or potassium. The barrier layer 10 between the fluorescent and photo-emissive surfaces can be an exceedingly thin transparent film of mica, ZnF2 or ZnS, silicon or of a suitable plastic. The electrons emitted from the amplifying screen 44 are electron-optically diminished and focused by means of magnetic or electron-magnetic fields 46 on the next amplifying screen 44a, producing image intensification proportional to the square power of the linear diminution. The electron images from the amplifying screen 44a are focused by magnetic or electromagnetic fields 48a, and are projected on the target 49 where they are intensified by secondary emission and are stored. The target 49 is scanned by the latter is modulated by electron pattern on the target so that returning electron beam 51 brings the charges corresponding to the electron images on the target to the multiplier section 52. There they are intensified by secondary emission and then sent in form of video signals 53 to the amplifier 54 and therefrom by coaxial cable 55 to immediate or remote receivers 56 where they are reconverted into fluorescent images.

The intensified fluorescent images appearing on the screen 57 of the kinescope 56 now can be filmed by the movie camera 59 as their luminosity is strong enough to expose the film 58 in a frame time, in spite of the use of the very small amount of X-ray energy. The X-ray image intensifying device operates at 30 frames/second or at submultiple of this figure. In many instances it will be preferable to use 15/second which will be sufficient to avoid the flicker and will allow a longer storage time improving sensitivity of the system. The movie camera is driven with the synchronous motor 60 at 15 frames/second. The shutter 61 in the camera is open for 170 degrees giving exposure close to 5/6 of a second. The motor drive is phased so that the film is advanced twice during the vertical blanking period of the television image. In this way X-ray motion pictures can be produced without the use of excessive amount of X-ray energy and with complete safety for the patient which was the main objective of my invention.

Another reflective optical system having still greater speed for producing X-ray moving pictures is shown in the Fig. 4. The fluorescent light rays from the curved fluoroscopic screen 62 pass through doublet meniscus lens 63 and are reflected back by the concave spherical mirror 64. The reflected rays pass again through the doublet lens 63 and are focused on the plane mirror 68, positioned at an angle to the optical axis of the system. The plane mirror 68 reflects fluorescent light rays on the photocathode 65 of the X-ray image intensifying tube 66 placed outside of the optical system in order not to obstruct the path of light through the optical system. The photocathode 65 must be made reflective not conforming to the curvature of the focal plane of the concave spherical mirror 64. This optical system has an exceptional speed and contributes considerably to improvement of sensitivity of X-ray motion picture camera. The fluoroscopic screen and the optical system and the X-ray image intensifying tube are enclosed in light-proof box 67 in fixed position to each other to avoid need for focusing at each examination. For proper positioning of box 67 in relation to the examined part, serves separate fluorescent screen 62a attached outside of the box and monitor receiver tube 56a. The remaining components of X-ray moving picture recording device such as amplifier system, kinescope, motion picture camera, intermittent mechanism and synchronous motor are the same as described above. Further, improvement in sensitivity of the X-ray movie camera is shown in Fig. 5. In this variety of invention the photocathode 70 of the X-ray intensifying tube 71 is positioned in the focal plane of the concave spherical mirror 72 while the remaining parts of said X-ray image intensifying tube are on the opposite side of the reflecting surface of the concave spherical mirror 72. The fluorescent rays from the fluoroscopic screen 73 pass through meniscus lens 74 and are focused by the concave spherical mirror 72 on the photocathode 70. This arrangement allows the use of solid photocathode instead of translucent photo-cathode and results in gain of photo-electron output by factor of 2. This is equivalent to the same gain in sensitivity of X-ray motion picture camera and represents considerable improvement over other systems. Besides the solid photocathode the rest of the construction of the X-ray image intensifying tube is the same as the tube 28, illustrated in Fig. 1.

Although the preferred embodiments of the invention have been described it will be obvious to those skilled in the art that various changes and modifications may be made without departing from the true spirit and scope of this invention.

One such modification may consist in using a scanning X-ray beam for producing X-ray images in my invention. One method of effectuating this modification of my invention may consist, referring to Fig. 1, in converting the X-ray point images in the composite photocathode, there shown, into photocathode electron images, then intensifying said photocathode electron images, as shown in the amplifying section 7 of Fig. 1, and transmitting these images to receivers (19 or 19a) to be reconstructed into visible images for observation and recording.
Another method of using a scanning X-ray beam in my invention, may consist (referring to Fig. 4) in converting the X-ray point images, into fluorescent point images (screen 62), projecting them by the optical system of Fig. 4, into a photocathode 65, then proceeding with the photoelectron point images so produced in a similar manner as just described hereinafore.

It will be understood that still X-ray pictures may be produced by my invention in a similar manner as described hereinafore for taking motion pictures. The motion picture camera will be in such a case replaced by a still picture camera.

What is claimed is:

1. A vacuum tube comprising in combination luminescent means, light transparent means of electrically conducting material and a photoelectric layer having an exposed surface, said light transparent means being disposed between said luminescent means and said photoelectric layer.

2. A vacuum tube comprising in combination luminescent means, light transparent means of electrically conducting material and a photoelectric layer having an exposed surface emitting a beam of electrons when excited by light from said luminescent means, said light transparent means being disposed between said luminescent means and said photoelectric layer, and a screen for receiving said beam of electrons of material emitting secondary electrons when impinged by said beam of electrons.

3. A vacuum tube comprising in combination a light reflecting layer, luminescent means receiving radiation through said light reflecting layer, light transparent means of electrically conducting material and a photoelectric layer receiving light from said luminescent means through said light transparent layer, having an exposed surface and emitting a beam of electrons when excited by said light from said luminescent means, said light transparent means being disposed between said luminescent means and said photoelectric layer, and a screen of material emitting secondary electrons when impinged by said beam of electrons.

4. A device as defined in claim 1, in which said photoelectric layer comprises an element of the group consisting of antimony and bismuth.

5. A device as defined in claim 1, in which said photoelectric layer is continuous and comprises an element of the group consisting of potassium and lithium.

6. A claim as defined in claim 1, in which a light reflecting layer is mounted adjacent to said luminescent means and said luminescent means receive radiation through said light reflecting layer.

7. A device as defined in claim 4, which comprises in addition means for converting said electron beam into electrical signals.

8. A vacuum tube comprising in combination luminescent means, light transparent means also transparent to ultraviolet radiation, and a photoemissive layer supported by the end wall of said tube, having an exposed surface and emitting a beam of electrons when excited by light from said luminescent means, said light transparent means being disposed between said luminescent means and said photoemissive layer, and a screen for receiving said beam of electrons of material emitting secondary electrons when impinged by said beam of electrons.

9. A vacuum tube comprising in combination a light reflecting layer, luminescent means receiving radiation through said light reflecting layer, light transparent means also transparent to ultraviolet radiation and a photoemissive layer in contact with said light transparent means, having an exposed surface and emitting a beam of electrons when excited by light from said luminescent means, said light transparent means being disposed between said luminescent means and said photoemissive layer comprises an element of the group consisting of antimony and bismuth.

11. A device as defined in claim 8, in which the surface of said photoemissive layer presented to said screen is continuous and said photoemissive layer comprises an element of the group consisting of antimony and bismuth.

12. A device as defined in claim 9, in which said photoemissive layer comprises an element of the group consisting of potassium and lithium.

13. A device as defined in claim 8, which comprises in addition means for converting said electron beam into electrical signals.

14. A vacuum tube comprising in combination a light reflecting layer, X-ray reactive luminescent means, light transparent means of electrically conducting material and a photoelectric layer having an exposed surface and producing a photoelectric image when excited by light from said luminescent means, said light transparent means being disposed between said luminescent means and said photoelectric layer, and means for converting said photoelectric image into electrical signals.

15. A vacuum tube comprising in combination X-ray reactive luminescent means, light transparent means of electrically conducting material and a photoelectric layer comprising an element of the group consisting of antimony and bismuth, and having an exposed surface producing a photoelectric image when excited by light from said luminescent means, said light transparent means being disposed between said luminescent means and said photoelectric layer, and means for converting said photoelectric image into electrical signals.

16. A device as defined in claim 9, in which surface of said photoemissive layer is continuous and said photoemissive layer comprises an element of the group consisting of antimony and bismuth.

17. A device as defined in claim 8, in which a light reflecting layer is mounted adjacent to said luminescent means, and said luminescent means receive radiation through said light reflecting layer.

References Cited in the file of this patent

UNITED STATES PATENTS

1,985,715 Bucky Dec. 25, 1934
1,998,317 Harper Jan. 29, 1935
2,158,853 Coolidge May 16, 1939
2,189,319 Morton Feb. 6, 1940
2,198,479 Langmuir Apr. 23, 1940
2,219,120 Somers Oct. 22, 1940
2,234,808 Ploke Mar. 11, 1941
2,297,478 Feldmann Sept. 29, 1941
2,307,661 Bateleur Jan. 15, 1944
2,319,712 Williams May 18, 1943
2,321,611 Maynham June 15, 1943
2,344,043 Kallmann Mar. 14, 1944
2,370,165 Hare Feb. 27, 1944
2,401,736 Janes June 11, 1946
2,420,198 Rosenthal May 6, 1944
2,433,941 Weimer Jan. 6, 1944
2,442,287 Edwards May 25, 1948
2,555,423 Sheldon June 5, 1951
2,555,424 Sheldon June 5, 1951
2,690,516 Sheldon Sept. 28, 1954

FOREIGN PATENTS

326,603 Great Britain Mar. 20, 1930