

Dec. 14, 1954

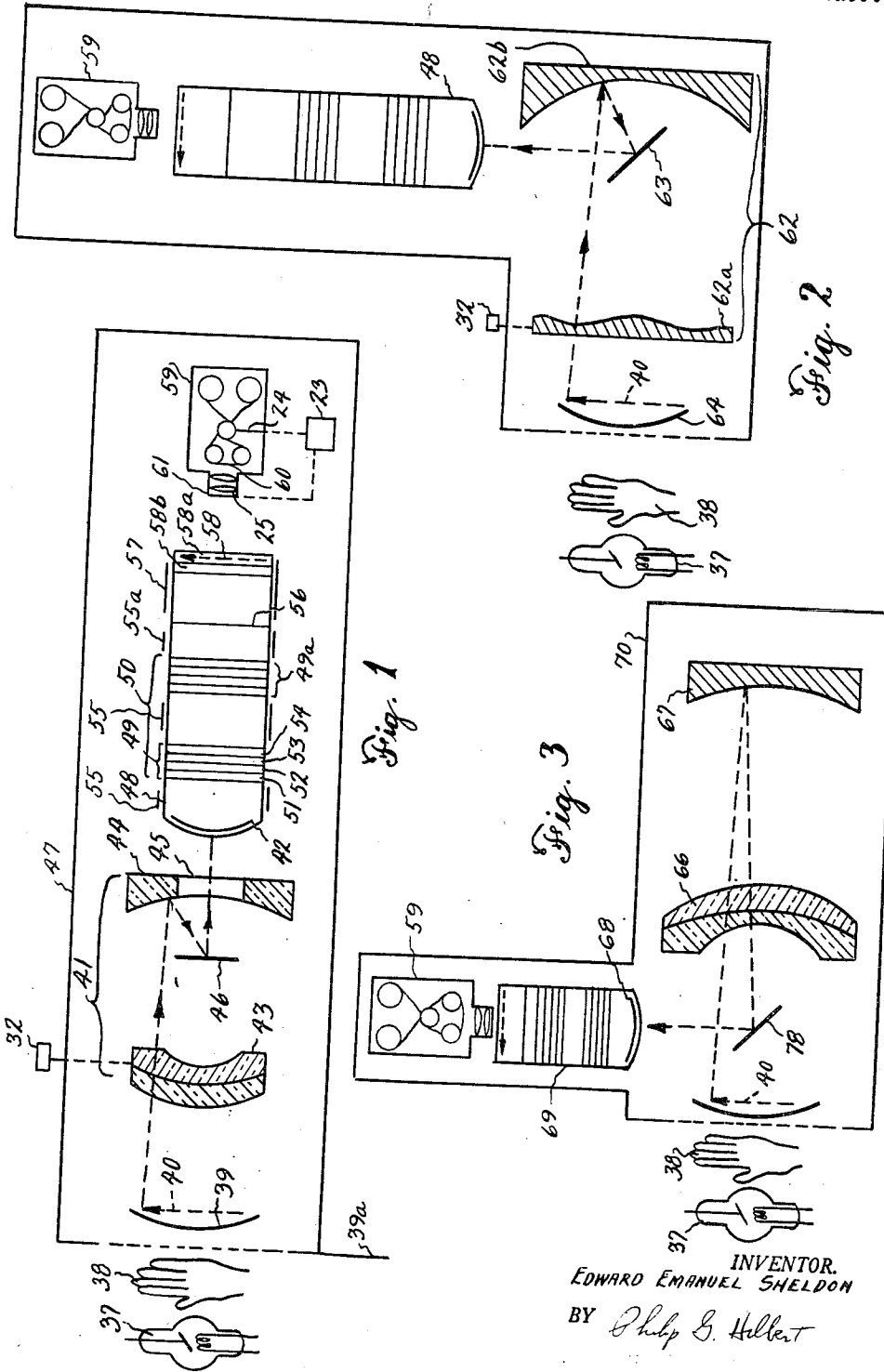
E. E. SHELDON

2,697,182

TUBE FOR INTENSIFICATION OF IMAGES

Original Filed Dec. 9, 1948

2 Sheets-Sheet 1



INVENTOR.
EDWARD EMANUEL SHELDON

BY Philip B. Hilbert

ATTORNEY

Dec. 14, 1954

E. E. SHELDON

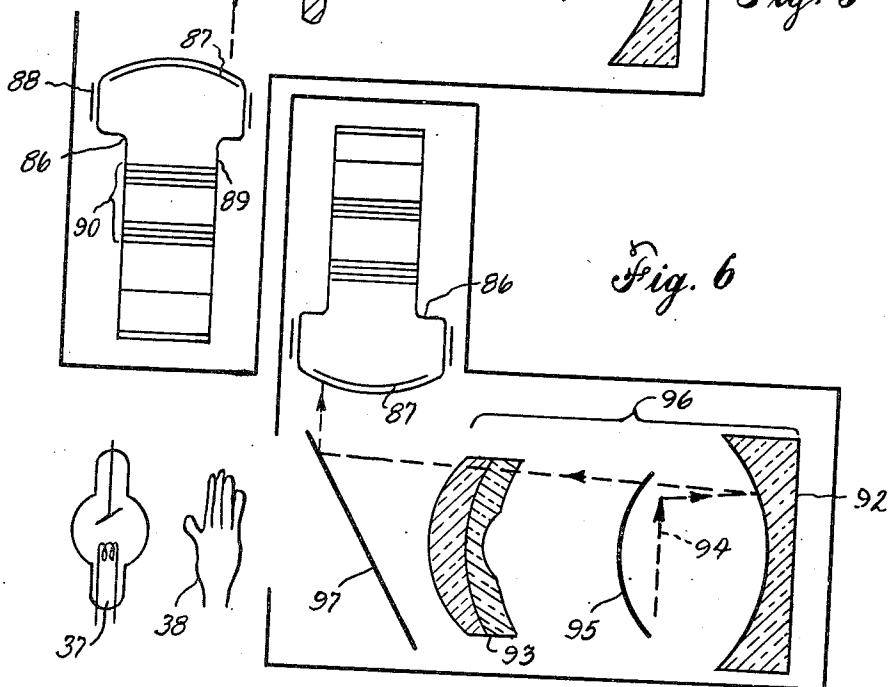
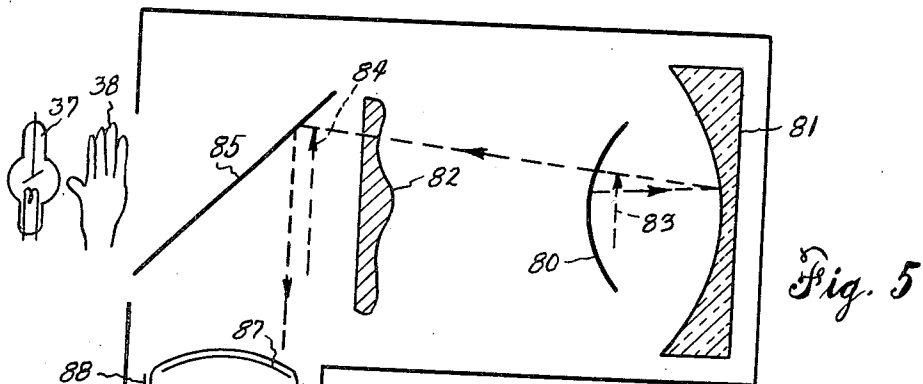
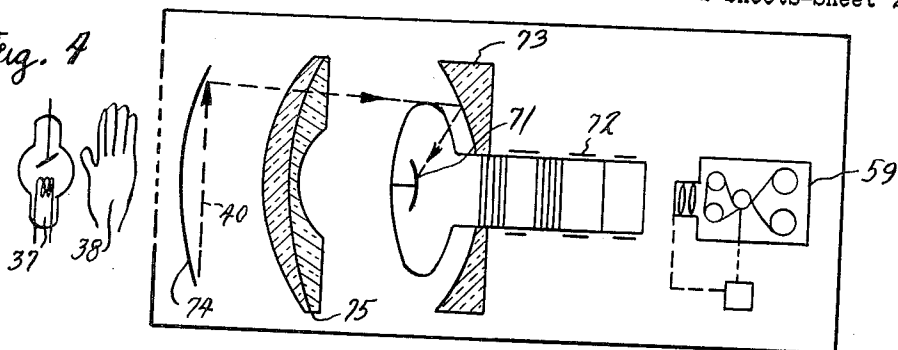
2,697,182

TUBE FOR INTENSIFICATION OF IMAGES

Original Filed Dec. 9, 1948

2 Sheets-Sheet 2

Fig. 4



INVENTOR.
EDWARD EMANUEL SHELDON

BY *Philip S. Hilbert*

ATTORNEY

TUBE FOR INTENSIFICATION OF IMAGES

Edward Emanuel Sheldon, New York, N. Y.

Original application December 9, 1948, Serial No. 64,329, now Patent No. 2,586,392, dated February 19, 1952. Divided and this application January 8, 1952, Serial No. 265,466

4 Claims. (Cl. 313—65)

My invention relates to the method and device for producing X-ray moving pictures and represents a division of my co-pending patent application, Serial No. 64,329 filed on December 9, 1948, now U. S. Pat. No. 2,586,392, issued February 19, 1952 and is a continuation in part of my U. S. Pat. No. 2,555,423.

The importance of cinematographic X-ray pictures to study the organs in health and disease was recognized long ago. Lately, the value of 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 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 the 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 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-ray 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, is the limit of safe X-ray application.

It is, therefore, the purpose of my invention to overcome these drawbacks and to shorten the time of the exposure to such a degree that X-ray moving pictures should be no hazard to the patient.

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 multimillion 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 greater contrast than it was possible until now.

The purposes of my invention were accomplished by the use in combination of an X-ray source, an X-ray image intensifying tube, an optical system and a moving picture camera. The invisible X-ray images of the examined body are projected onto a screen in which they are converted into fluorescent images. The fluorescent X-ray images are projected on an intensifying tube, in which they are converted into photoelectron images having the pattern corresponding to X-ray images. The photoelectron images after intensification by cascade amplification, by electronic diminution and by secondary emission, 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 by the optical system onto moving pictures recording camera.

The invention will be better understood when taken in connection with the accompanying drawings.

In the drawings:

Figure 1 represents a device for recording X-ray moving pictures.

Figure 2 represents another form of this invention in which a more compact reflective optical system is shown.

Figure 3 represents a variety of this invention, in which a faster reflective optical system is shown.

Figure 4 represents a modification of the image pick-up tube having a solid photocathode.

Figure 5 represents a modification of this invention, in which the image tube is responsive to an enlarged fluorescent image.

Figure 6 represents a modification of the optical system used in combination with the image tube responsive to an enlarged fluorescent image.

Reference will now be made to Fig. 1, in which is shown the X-ray source 37, the examined body 38, the fluoroscopic screen 39, the fluorescent X-ray image 40, the optical system 41 and the image intensifying tube 48. The X-rays after the passage through the examined body form an invisible X-ray image, which is converted in the fluoroscopic screen 39 into fluorescent X-ray image 40. The fluorescent image is projected by the reflective optical system 41 on the photocathode 42 of the image intensifying tube 48. 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 Schmidt may be used for this purpose, but 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. Therefore, I am making the use, in this invention, of the optical system belonging to the family of so-called "wide field fast cameras" described by L. G. Henyey and Jesse L. Greenstein in OSRD Report No. 4505 which optical system can be manufactured in quantity with necessary precision. This optical system does not require aspherical correction plate and consists essentially of meniscus lens and of the concave spherical mirror. All optical surfaces have a common center of curvature located at diaphragm which limits the entering light rays. 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 focus. The operation of this optical system is shown in Fig. 1. The fluorescent X-ray image is produced by invisible X-ray image on the fluoroscopic screen 39, which has curved surface in order to eliminate spherical aberration. The fluorescent light rays pass through the meniscus lens 43 and are reflected by aluminized concave spherical mirror 44 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 42 of the image intensifying tube 48, which is disposed opposite the reflecting surface of the concave mirror and in the axis of its aperture. The fluoroscopic screen 39, the optical system 41 and image intensifying tube 48 are enclosed in light-proof box 47 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 lock-screw mechanism and micrometer adjustment screw 32, which shifts the lens 43 along the optical axis. For proper positioning of the box 47 in relation to the examined part of the body serves separate fluoroscopic screen 39a attached outside of the box 47. The fluorescent X-ray image produces in the photoemissive photocathode 42a a photoelectron image. The photoelectron image obtained from the photoemissive layer 42 which may be of materials such as caesium silver oxide, caesium with antimony or bismuth or antimony in combination with lithium or potassium, is projected on the first composite screen 49 of the amplifying section 50 having one or a few successively arranged amplifying screens 49 and 49a, by means of focusing magnetic or electro-magnetic fields 55, which are not indicated in detail, since they are well known in the art and would serve only to complicate the illustrations. The amplifying composite screens 49 and 49a consist of an electron pervious, light opaque, light reflecting layer 51, an electron fluorescent layer 52, a light transparent barrier layer 53 and a photoemissive layer 54. Fluorescent substances, which may be used for the layer 52 of amplifying screens 49 and 49a are zinc silicates; zinc sulphide, barium sulphate, calcium tungstate with or without activators, NaI.

3
or KI. Another group of fluorescent substances, which may be used for this purpose comprises organic phosphors, such as anthracene, phenanthrene or the like. The satisfactory photoemissive materials for the layer 54 will be caesium oxide activated by silver, caesium with antimony or with bismuth, or antimony with lithium or potassium. The barrier layer 53 between the fluorescent and photoemissive surfaces can be an exceedingly thin transparent film of mica, ZnF_2 , silicon or of a suitable plastic. The electrons emerging from the amplifying screen 49 are electron-optically diminished and focused by means of magnetic or electro-magnetic fields 55 on the next amplifying screen 49a. The electron images from the amplifying section 50 are focused by magnetic or electro-magnetic fields 55a and are projected on the target 56 where they are intensified by secondary emission. The secondary electron image is diminished electron-optically by magnetic or electro-magnetic lenses 57 and is focused on the electron reactive fluorescent screen 58a producing intensified fluorescent image having the pattern of the original X-ray image. The screen 58a has backing of a thin layer of aluminum 58b, which is transparent to electrons, but not transparent to the light. In this way, back-scattering of light from the fluorescent screen 58a is prevented.

The intensified fluorescent images 58 appearing on the screen 58a of the X-ray intensifying tube 48 can be filmed by the movie camera 59 as their luminosity is now strong enough to expose the film 60 in a frame time, despite the use of the very small amount of X-ray energy. The movie camera is driven with the synchronous motor 23 at 15 to 30 frames/second according to the speed of motion of examined organs. The shutter 61 in the camera has opening giving exposure time from $\frac{1}{15}$ to $\frac{1}{30}$ of a second.

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.

A more compact arrangement of this invention is shown in the Fig. 2. The optical system 62 consists here of aspherical correction plate 62a, concave spherical mirror 62b and of plane mirror 63. The plane mirror 63 is placed at an angle between the reflective surface of the concave mirror 62b and its nearest conjugate focus. The intensifying tube 48 is positioned outside of the axis of the optical system 62b, so that it does not obstruct the path of the fluorescent rays from the fluoroscopic screen 64 through the optical system.

Another reflective optical system having still greater speed for producing X-ray image pictures is shown in Fig. 3. The fluorescent light rays from the curved fluoroscopic screen 65 pass through doublet lens 66 and are reflected back by the concave spherical mirror 67. The reflected rays pass again through the doublet lens 66 and are focused on the plane mirror 78, positioned at an angle to the optical axis of the system. The plane mirror 78 reflects fluorescent light rays on the photocathode 68 of the image intensifying tube 69 placed outside of the optical system in order not to obstruct the path of light through the optical system. The photocathode 68 must have a curved surface corresponding to the curvature of the focal plane of the concave spherical mirror 67. This optical system has an exceptional speed and contributes considerably to improvement of sensitivity of X-ray motion picture camera. The fluoroscopic screen, the optical system and the image intensifying tube are enclosed in a light-proof box 70 in fixed position to each other to avoid need for focusing at each examination. The remaining components of X-ray moving picture recording device, such as motion picture camera, intermittent mechanism shutter and synchronous motor are the same as described above, and shown in Fig. 1.

Further improvements in sensitivity of the X-ray movie camera is shown in Fig. 4. In this variety of invention, the photocathode 71 of the intensifying tube 72 is positioned in the focal plane of the concave spherical mirror 73 while the remaining part of said image intensifying tube is on the opposite side of the reflecting surface of said concave spherical mirror. The fluorescent rays from the fluoroscopic screen 74 pass through meniscus lens 75 and are focused by the concave spherical mirror 73 on the photocathode 71. This optical arrangement allows the use of solid photocathode instead of translucent photocathode and results in gain of photoelectron 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 X-ray moving picture cameras. The remaining components of X-ray moving picture camera are the same as described above and illustrated in Fig. 1.

In some instances, it is advantageous to produce an enlarged X-ray fluorescent image in the photocathode of the image tube. In such a case, see Fig. 5, the fluoroscopic screen 80 is disposed between the reflecting surface of the concave mirror 81 and the aberration correcting element 82. The reflective optical system produces enlarged image 84 of the fluorescent image 83 in the fluoroscopic screen 80. This enlarged image is reflected by the X-ray transparent plane mirror 85 on the image tube 86. The optical system used for the enlargement of the X-ray image may have many forms and modification, only some of which have been illustrated and it is to be understood that many changes may be made without departing from the spirit and scope of the invention. The image tube 86 used in this modification of my invention has a very large photocathode 87, which is of size sufficient to respond to the enlarged X-ray image 84. The photoelectron image produced by the projection of the X-ray fluorescent image on the photocathode 87 is electron-optically diminished by magnetic, electrostatic or electro-magnetic fields 88, which are not indicated in detail, as they are well known in the art, and is projected on the first composite screen 89 of the amplifying section 90. By electron-optical demagnification of the previously enlarged X-ray image, I obtained much better intensification of said X-ray image than with previously described methods, because electronic intensification is proportional to the square of linear diminution. The remaining parts of the image tube 86, as well as the motion picture camera are the same as described above.

Another optical system for projection of an enlarged X-ray image is illustrated in Fig. 6. The optical system 96 in this case consists of reflecting concave mirror 92 and of meniscus lens 93. The fluorescent X-ray image 94 is produced in the fluorescent screen 95, which is positioned between the concave mirror and the meniscus lens 93. The fluorescent X-ray image 94 is projected by the optical system 96 in enlarged form on the X-ray transparent plane mirror 97 and is reflected therefrom on the image tube 86 described above.

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

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 by those skilled in the art without departing from the true scope and spirit of the foregoing disclosure.

I claim:

1. An image sensitive tube comprising in combination a photocathode of a photo-emissive material for receiving an image and converting said image into a first electron beam having the pattern of said image, a composite screen consisting of a light opaque layer transmitting said electron beam from said photocathode, a fluorescent layer adjacent said light opaque layer for converting said electron beam into a fluorescent light image, a light transparent separating layer discontinuous from walls of said tube and of a photoemissive layer receiving light from said fluorescent layer through said separating layer and emitting in response to said light the second electron beam having the pattern of said first electron beam and an electron reactive screen for receiving said second electron beam and converting said electron beam into an image.

2. In a vacuum tube in combination a photocathode for receiving an image and converting said image into a beam of atomic particles having the pattern of said image, electron-optical means for demagnifying said beam to intensify said beam, and a composite screen for receiving said demagnified beam, said screen comprising a fluorescent layer on the side facing said demagnified beam, a light transparent layer and a photoelectric layer.

3. In a vacuum tube in combination a photocathode for receiving an image and converting said image into a beam of atomic particles having the pattern of said image, electron-optical means for demagnifying said beam to intensify said beam, and a screen for receiving said de-

magnified beam, said screen comprising an electron transparent light opaque layer, a fluorescent layer, a light transparent layer and a photoelectric layer.

4. A device, as defined in claim 1, wherein said photocathode is light-sensitive.

References Cited in the file of this patent

UNITED STATES PATENTS

Number	Name	Date	
2,177,259	Keck	Oct. 24, 1939	10

Number
2,189,321
2,214,973
2,344,043
2,555,423
2,555,545
2,586,392

5

Name	Date
Morton	Feb. 6, 1940
Rose	Sept. 17, 1940
Kallmann	Mar. 14, 1944
Sheldon	June 5, 1951
Hunter et al.	June 5, 1951
Sheldon	Feb. 19, 1952