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X-RAY MOTION-PICTURE PHOTOGRAPHY

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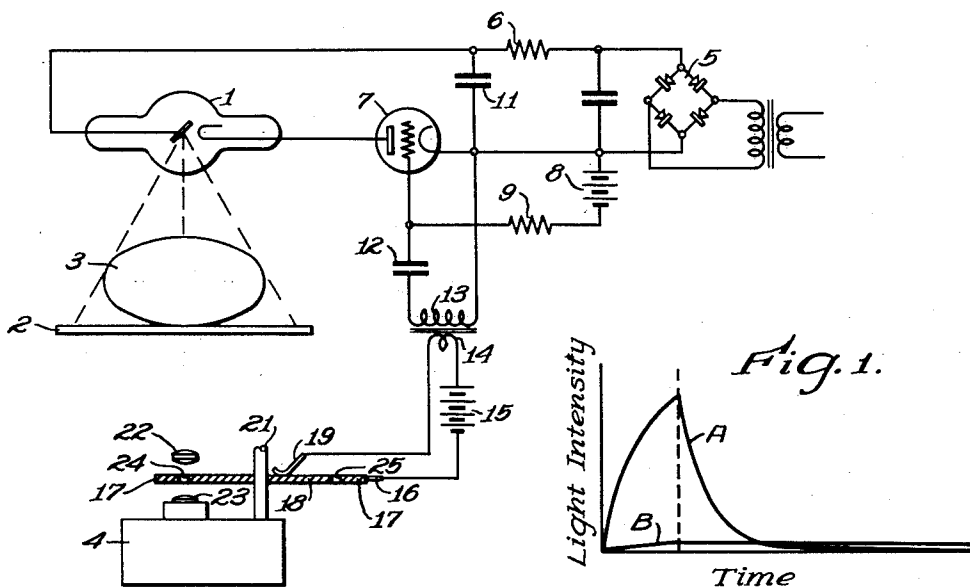


Fig. 1.

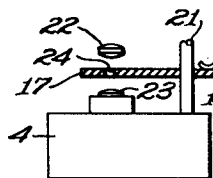


Fig. 2.

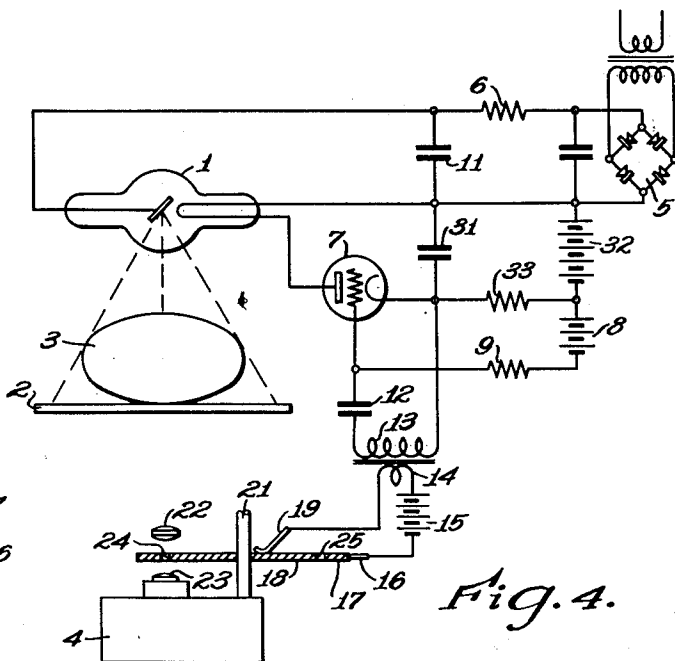
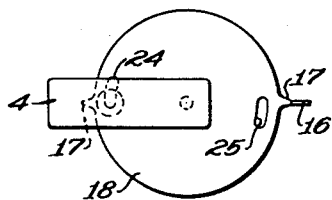


Fig. 3.



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X-RAY MOTION-PICTURE PHOTOGRAPHY

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My invention relates to X-ray apparatus and, in particular, to X-ray apparatus in which permanent records of the X-ray patterns are made by photography or similar means. It is particularly applicable to making motion pictures of X-ray patterns.

For many purposes it is desirable to make motion pictures by X-ray of the human body, for example, to observe the movement of various organs, such as the heart. The method most commonly used for this purpose is to produce images of the desired portion of the body on a fluorescent screen, and to take motion pictures of the views thereon. Because a patient can tolerate only a limited dosage of X-rays, it is important that the quantity of X-rays required to produce the necessary exposure on the photographic plate for each frame shall be held to a minimum. Among several factors affecting the X-ray quantity needed is the brightness of fluorescence of the screen as registered by the photographic emulsion. For most observations, difficulty is found in obtaining the necessary brightness on the fluorescent screen without subjecting the patient to over-exposure to X-rays. Of the screens now commercially available, those showing the greatest brightness for photographic purposes are of the zinc sulphide type, but these are found to be subject to a long persistence of fluorescence after the exciting X-rays are cut off, which causes an objectionable blurring and multiple exposure effects when the organ being observed is in motion. By an analytical study of the luminescence of fluorescent materials, I have discovered methods by which images due to these long persistence effects can be substantially avoided, with a resulting clear definition of the various images of a moving organ being subject to radiography.

One object of my invention is accordingly to provide an arrangement in which blurring and multiple exposure effects may be avoided in radiography of moving objects.

Another object of my invention is to provide an arrangement in which long persistence luminosity effects in a fluorescent screen may be prevented from affecting photographic recordings thereof.

Another object of my invention is to provide an arrangement for effectively utilizing the photographic effects of extremely short-persistence luminosity in fluorescent screens.

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Still another object of my invention is to separate the effects of luminosities of different time constants in fluorescent screens.

Still another object of my invention is to provide an arrangement in which luminosity excited on the fluorescent screen of an X-ray apparatus, by X-ray pulses of extremely short duration is efficiently utilized to produce clear light-images for observation.

Other objects of my invention will become apparent upon reading the following description taken in connection with the drawing, in which:

Figure 1 is an idealized graphical representation of the variation of luminosity with time of a typical fluorescent material;

Fig. 2 is a schematic diagram of one form of apparatus capable of embodying the principles of my invention;

Fig. 3 is a view in elevation of a rotating shutter shown in plan in Fig. 2; and

Fig. 4 is a schematic diagram similar to Fig. 2 but showing another embodiment of the principles of my invention.

While the mechanism and precise nature of phosphorescent response of a fluorescent screen to stimulation by X-rays is still by no means completely understood, it has been found in practice that many fluorescent materials behave as if their response to such stimulation followed an exponential relationship with time. A relationship of this type would be one in which, with an X-ray stimulation of constant intensity, the luminous intensity would grow in accordance with the equation of the form;

$$I_s = C \left(1 - e^{-\frac{t_1}{T}} \right)$$

Similarly the decay of the luminous intensity after termination of the excitation would follow an exponential form given by the following equation:

$$I_d = C \left(1 - e^{-\frac{t_1}{T}} \right) \left(e^{-\frac{t_2}{T}} \right)$$

where T is the phosphorescent period (i.e., the time for the luminosity to decay to 1/e of its original intensity); t_1 is time measured during excitation; t_2 is the total time of excitation; e is the base of Napierian logarithms; t_2 is the time since X-ray excitation was cut off; and C is a constant.

In the case of materials used in many commercial fluorescent X-ray screens including the zinc sulphide mentioned above, the response is found not to be so simple as the foregoing exponential equation would indicate. If the constants of the second equation are adjusted to the observed curve during the initial decay, it is found that the phosphorescence does not fall as rapidly during its later period as would correspond to the equation. It is, however, possible to attain for analytical or descriptive purposes a reasonable approximation to observed effects by considering the luminosity to be made up of two or more superposed exponential curves of rather widely different phosphorescent periods T .

In Fig. 1, I have shown two such exponential curves A and B of different phosphorescent periods which, by their superposed ordinates, would serve to illustrate the behavior of a fluorescent material insofar as is required for the present explanation. The curve A obviously has a relatively short-time period, both for growth of intensity during stimulation and decay of the luminous intensity after stimulation ceases. The curve B is of considerably longer time period in both respects. The relative phosphorescent periods of curves A and B are however chosen rather to make their representation clear than because they are typical of values found in nature. In actual practice I have found phosphorescent periods for a single screen which differ from each other by a factor as great as a million.

By producing X-ray pulses enduring for only $\frac{1}{1,000,000}$ of a second (i. e., for only one microsecond), and measuring the luminous intensity as a function of time for the above-mentioned sulphide screens, I have found that the greater part of the total luminous response, including the rise of intensity to a maximum during excitation and the greater part of the decay is complete in from 10 to 100 microseconds. Considering the observed response for simplicity as being made up of two components, A and B, the response during this 10 to 100 microseconds is largely due to the component A of shorter phosphorescent period. The response due to component B is spread over a considerably longer time interval, because of the much longer associated period of phosphorescence. Thus the effect of stimulating the screen for such an extraordinarily short time of excitation as 1 microsecond is to concentrate nearly all of the response due to the A component into a very short time interval, thereby separating it from most of the response due to the B component, the latter being little affected by this shortening of the time of excitation. By making use of X-ray pulses of such extremely short duration and employing a rapid shutter to expose the photographic plate of the camera taking pictures of the screen only for short periods of the order of that required for the short-time component of luminosity to largely disappear, I have found it possible to obtain photographic records of the short-time component of luminosity A, and to practically exclude the long period phosphorescent effects represented by the curve B in Fig. 1.

Since the deleterious effects of X-rays on the human body are mainly proportional to the product of intensity of radiation by time, it is possible with such short pulses, as I have described to employ instantaneous intensities which are very much higher than those possible with conventional types of X-ray equipment. It is evi-

dent that by utilizing only the short-time luminous component to produce the photographic effect, and excluding the long-time component from action on the film I attain a very high definition in pictures of moving bodies and avoid blurring and multi-exposure effects resulting from the long-time components of luminosity.

While I have employed exponential curves of luminosity in illustrating the above described phenomena, the conclusions drawn, and the results of such extremely short term exposure as I have described, are not limited to luminosities obeying the exponential equations, but the principles are applicable to response following hyperbolic or other curves.

It is possible to show that where the luminous response can be represented by exponential curves, such as A and B in Fig. 1, the maximum segregation of the photographic effects due to the short-time component A is attained by using an X-ray pulse duration which is short compared with the value T for this component and by using a period of opening for the shutter which is still shorter than the pulse and is confined to the latter portion thereof. However, the improvement is only slightly less marked where the pulse lasts for a period approximating the value T for the short-period component and where the shutter is held open during approximately the same period or a little longer. Where maximum strength of photographic image for a given exposure of the body to X-rays is imperative, it may be desirable to hold the shutter open for a period around thrice as long as that of the X-ray pulse.

It is, of course, unnecessary to shorten the X-ray pulse and the time during which the camera shutter is open so far as a microsecond to accomplish worthwhile improvement in clarity of photographic image. While the theoretical and practical limits of improvement which can be expected have been suggested in the last paragraph, it is apparent that for practical purposes it is unnecessary to decrease these times further than is required to accomplish the degree of sharpening of the image requisite for a given motion picture application. Thus, the improvement obtained by reducing these times only to the order of a thousandth or a ten-thousandth of a second may be sufficient for satisfactory results, allowing greater economy through technical simplicity in the apparatus involved.

The foregoing being the fundamental principles of my invention, they may be practically applied in such an arrangement as is shown diagrammatically in Fig. 2 of the drawing, in which an X-ray tube 1 is positioned to irradiate a fluorescent screen 2 by rays passing through a body 3, which is the subject of observation. Fluorescent screens, such as 2, are well known in the X-ray art, one suitable for making use of the principles of my invention being known as the Patterson D creen. The luminous image produced on the fluorescent screen 2 is arranged to be photographed by a camera 4, which is arranged to take successive photographs at intervals sufficiently short to show properly the movement of any organ undergoing observation. For many purposes typical motion picture practice of sixteen or twenty-four images per second will suffice for the camera 4, though a frame frequency of sixty-four or higher may be desired at times for "slow-motion" photography.

The X-ray tube 1 is arranged to be energized in intermittent short pulses of suitably small duration. The X-ray tube 1 is caused to emit such

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short pulses of X-rays by energizing it from a direct current source 5 of a suitable type well known in the art through a resistor 6 and a trigger tube 7. The trigger tube 7 may be a three-electrode tube having an anode and cathode, and a control electrode which is connected to the negative terminal of a bias source 8 through a resistor 9. A capacitor 11 preferably is placed across the primary voltage source 5 through a resistor 6, being charged up to a voltage nearly equal to the source 5 between successive pulses of the X-ray tube 1. A capacitor 12 in series with a secondary winding 13 is connected between the control electrode and cathode of the tube 7. Cooperating with the secondary winding 13 is a primary winding 14 in series with a direct current source 15 and a make-and-break switch comprising a bunch 16 positioned to intermittently make contact with a projection 17 on the periphery of a conducting disc 18 which acts as a shutter for the camera 4. A second brush 19 making contact with the disc 18 is connected to the free terminal of the winding 14.

The disc 18 is continuously rotated by a suitable motor (not shown) through a shaft 21, and as disc 18 rotates, the projection 17 makes and breaks contact with the brush 16 to send pulses from source 15 through the primary winding 14. These pulses of current induce voltages in the secondary winding 13 which produce positive pulses of voltage on the normally negative control electrode of tube 7, thereby rendering the latter conductive twice during each rotation of the disc 18. The trigger tube 7 is normally maintained non-conductive by the negative voltage impressed on it relative to the cathode of tube 7 by bias battery 8. When, however, the above-mentioned positive pulses are impressed on the control electrode of trigger tube 7, it is rendered conductive, current flows from the capacitor 11 and between the anode and cathode of X-ray tube 1. This produces a brief pulse of X-rays from tube 1 which irradiate the body 3 and fluorescent screen 2.

The disc 18 lies in the shutter plane of a lens system 22, 23 of a camera 4, and is provided with a pair of properly shaped slots 24, 25. During the major portion of its period of rotation, the disc 18 constitutes an opaque shutter in the optical system of the camera 4 so that the film of this camera is exposed to light from the fluorescent screen 2 only during the short periods when the slots 24 and 25 align with the axis of the optical system 22, 23. By properly proportioning the length of slots 24, 25, the length of exposure of the film in the camera 4 can, of course, be made of any desired duration.

The film in the camera 4 is preferably moved by an intermittent mechanism (not shown), such as are well known in the photographic art. Since the details of this intermittent mechanism are not a feature of my invention, they will not be described in detail; but for the purpose of illustration such an intermittent motion is shown and described in U. S. Patent No. 2,331,225 of F. T. Powers.

It will be obvious that the short pulses of X-rays are produced through the tube 1 when the positive voltage pulse is impressed on the control electrode of tube 7 by the action of brush 16 and projection 17. It is preferable to arrange the circuit so that this positive pulse is made as sharp as possible, and I find this to be attained when the brush 16 breaks contact with the projection 17. When it is desired that the film in the cam-

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era 4 be exposed at the very beginning of the emission of the pulse by tube 1, the leading edges of the slots 24 and 25 are made to align with the optical axis of lens system 22, 23 when the brush 16 breaks contact with the projection 17. When it is desired that the exposure of the film shall not begin until near the latter part due to the short-time component of luminosity of screen 2, the position of the leading edge of the slots 24 and 25 in disc 18 is appropriately retarded for a sufficient time after brush 16 breaks contact with projection 17. The proportioning of the circuits and mechanism to produce these results will be readily evident to those skilled in the art.

The intermittent mechanism driven by shaft 21 to impart an intermittent movement to the film of camera 4 is likewise adjusted in ways well known to those skilled in the art, so that all motion of this film takes place during the period when the disc 18 acts as a closed shutter for the camera 4.

While I have described an intermittent movement as imparted to the film in camera 4, it will be evident to those skilled in the art that the film may be given a continuous motion by providing suitable tilting mirrors or lenses to move the image of fluorescent screen 2 on film 4 at the same speed as the latter while the shutter in optical system 22, 23 is open. Likewise, while I have described a rotating disc 18 as providing the shutter for optical system 22, 23, it will be obvious to those skilled in the art that a reciprocating shutter of the type shown in Jones U. S. Patent 2,166,440, Fig. 2, may be employed, the electromagnet 14 therein being suitably energized by a time switch and thereby synchronized with the current pulses which produce conductivity in the trigger tube 7.

Fig. 3 merely shows a view of the disc 18 at right angles to the view thereof shown in Fig. 2 and requires no separate description from that already given.

The system for energizing the X-ray tube 1 to produce short pulses, which is shown in Fig. 2, is one known in the X-ray art. In Fig. 4 I have shown an alternative system of intermittently energizing the X-ray tube 1. The circuit in Fig. 4 differs from that in Fig. 3 in arranging the trigger tube 7 to control the discharge through the cathode filament of X-ray tube 1 of a capacitor 31 which is charged, in intervening periods between the pulses, from a voltage source 32 through a resistor 33. The trigger tube 7 is, like the corresponding tube in Fig. 2, normally non-conductive when no pulses of the X-rays are being produced from tube 1. Tube 7 is rendered conductive by the mechanism embodying disc 18 already described in connection with Fig. 1 to send such pulses of current through the cathode filament of X-ray tube 1. When these pulses raise the temperature of the latter to incandescence, a pulse of X-rays is produced from tube 1 which lasts only for the short-time interval during which the discharge of capacitor 31 raises the cathode of tube 1 beyond the electron emitting temperature.

In certain instances, it may be suitable to take the successive motion pictures with camera 4 at a frequency equal to that of an alternating current power line, or at some simple multiple thereof. In such instances it will be evident to those skilled in the art that by employing a synchronous motor to drive the shaft 21, and by employing the alternating voltage of the power line to trigger the tube 7, the tying-in circuit between the trig-

ger tube 7 and the disc 18, comprising the elements 14, 15, 16 and 19, may be dispensed with.

While I have described the light image produced by lens-system 22, 23 as registered by photography, it is possible to employ the principles of my invention to attain sharp images of a moving object for visual observation by arranging a suitable eyepiece to directly observe the light image produced by the optical system.

I claim as my invention:

1. In combination an X-ray source a fluorescent screen positioned in the path of said X-rays, means for supporting an object to be irradiated by X-rays from said source, means for causing said source to irradiate said object for a time short compared with the phosphorescent period of said screen, an optical system traversed by light from said fluorescent screen, and a shutter for said optical system adapted to interrupt light passage therethrough except during a period synchronized with said X-ray pulses and which is confined to the said short-time portion of said phosphorescent period.

2. In combination an X-ray source of extremely short duration, means for supporting an object to be irradiated by X-rays from said source for the time of the order of a microsecond, a zinc sulphide screen positioned for incidence of said X-rays, an optical system traversed by light from said fluorescent screen, and a shutter for said optical system adapted to interrupted light passage therethrough except during periods synchronized with said X-ray pulses and having a duration of the order of three times that of said pulses.

3. In combination with a fluorescent screen exhibiting luminosity components of which one is substantially of short duration compared with others, a source of X-ray pulses having a length of the order of the phosphorescent period of said short-time component, means for irradiating said screen by said X-ray pulses, and optical means traversed by light from said fluorescent screen and arranged to permit passage of said light only during time periods of the order of duration of said phosphorescent periods.

4. In combination with a fluorescent screen exhibiting luminosity components of which one is substantially of short duration compared with any others, a source of X-ray pulses having a length of the order of the phosphorescent period of said short-time component, means for irradiating said screen by said X-ray pulses, and optical means traversed by light from said fluorescent screen and arranged to permit passage of said light only during time periods of the order of duration of said phosphorescent periods and synchronized with said X-ray pulses.

5. In combination with a fluorescent screen exhibiting luminosity components of which one is substantially of short duration compared with others, a source of X-ray pulses having a length of the order of the phosphorescent period of said short-time component, means for irradiating said screen by said X-ray pulses, optical means traversed by light from said fluorescent screen and arranged to permit passage of said light only during time periods of the order of duration of said phosphorescent periods, and photographic means for recording the light images produced by said optical system.

6. In combination with a fluorescent screen having a component of luminosity which is of short-time period compared with other components of its luminosity, means for exciting luminosity of said screen for periods having a

duration of the order of the phosphorescent period of the first-mentioned component of luminosity, an optical system traversed by radiation from said fluorescent screen, and means for interrupting the passage of light through said optical system except during periods of the order of said phosphorescent period.

7. In combination with a fluorescent screen having a component of luminosity which is of short-time period compared with other components of its luminosity, means for exciting luminosity of said screen for periods having a duration of the order of the phosphorescent period of the first-mentioned component of luminosity, an optical system traversed by radiation from said fluorescent screen, and means for interrupting the passage of light through said optical system except during periods of the order of said phosphorescent period and synchronized with said periods of excitation.

8. In combination with a fluorescent screen exhibiting luminosity components of which one is substantially of short duration compared with any others, a source of X-ray pulses having a length of the order of one microsecond, means for irradiating said screen by said X-ray pulses, optical means traversed by light from said fluorescent screen and arranged to permit passage of said light only during time periods of the order of duration of said phosphorescent periods, and photographic means for recording the light images produced by said optical system.

9. The method of registering the luminosity of the short-time luminosity component of a fluorescent screen which comprises impressing an exciting stimulus for luminosity on said material for a period of the order of the phosphorescent period of said short-time component, and registering the light flux from said fluorescent material for a period of the order of said phosphorescent period.

10. The method of registering the luminosity of the short-time luminosity component of a fluorescent screen which comprises impressing an exciting stimulus for luminosity on said material for a period of the order of the phosphorescent period of said short-time component, and registering the light flux from said fluorescent material for a period of the order of said phosphorescent period and synchronized with said exciting stimulus.

11. In combination with a fluorescent screen exhibiting luminosity components of which one is substantially of short duration compared with any others, a source of X-ray pulses having a length of the order of one microsecond, means for irradiating said screen by said X-ray pulses, optical means traversed by light from said fluorescent screen and arranged to permit passage of said light only during time periods of the order of 10 to 100 microseconds, and photographic means for recording the light images produced by said optical system.

12. In combination with a fluorescent screen comprising zinc sulphide, a source of X-ray pulses having a length of the order of one microsecond, means for irradiating said screen by said X-ray pulses, optical means traversed by light from said fluorescent screen and arranged to permit passage of said light only during time periods of the order of 10 to 100 microseconds and photographic means for recording the light images produced by said optical system.

FITZ-HUGH B. MARSHALL.

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