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STEREOSCOPIC X-RAY EXAMINATION APPARATUS WITH LIGHT
CONDUCTIVE RODS TO TRANSMIT THE OPTICAL IMAGES

Filed Sept. 19, 1963

2 Sheets-Sheet 1

FIG. 1

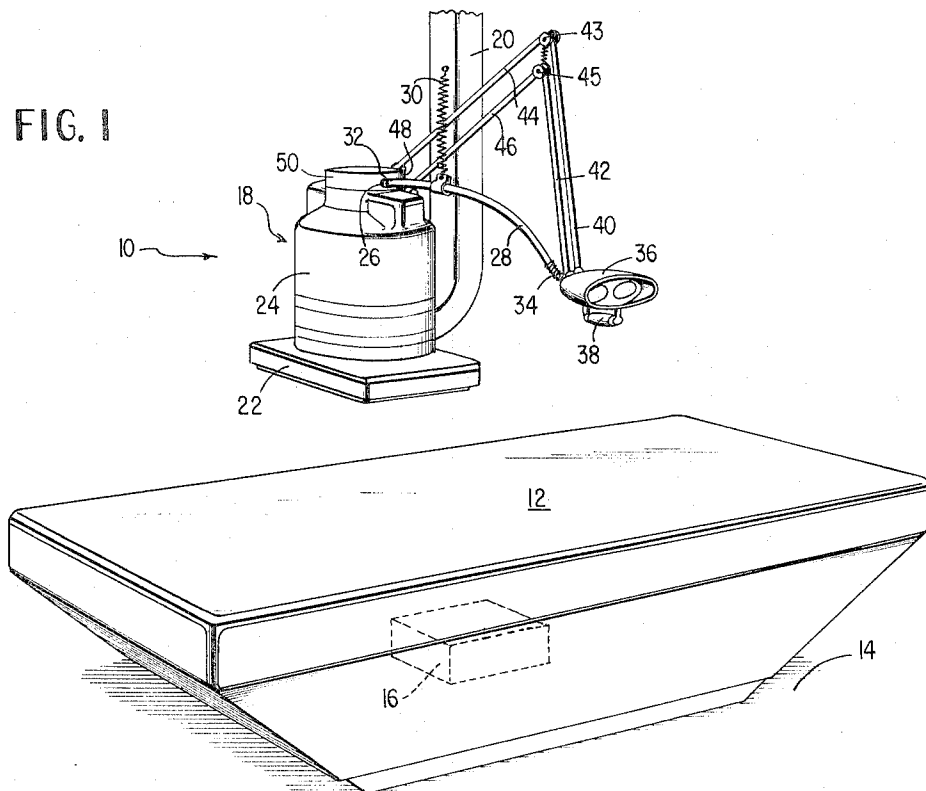
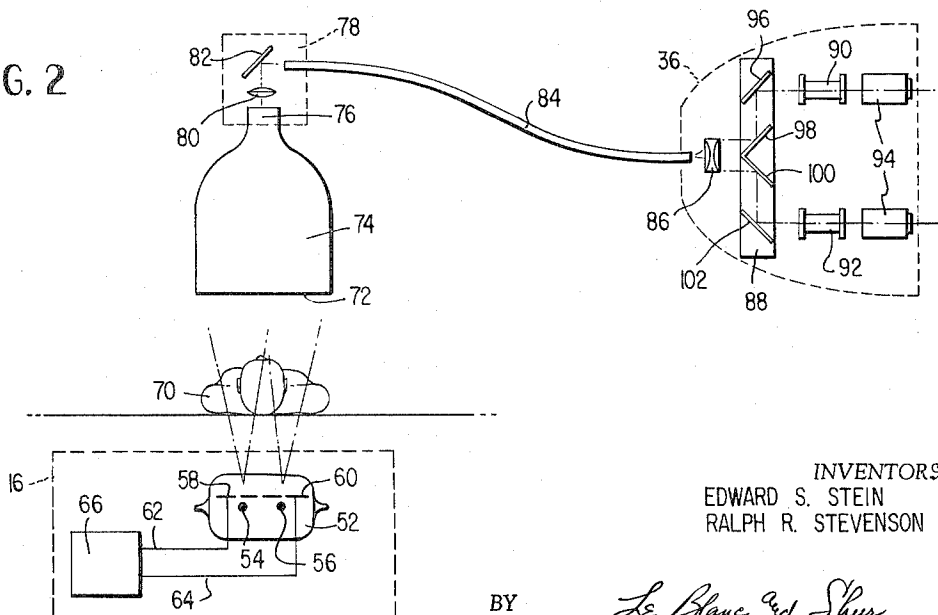


FIG. 2



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FIG. 3

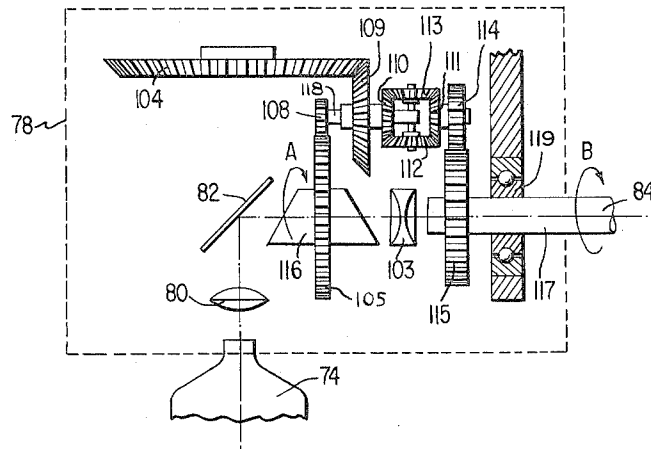


FIG. 4

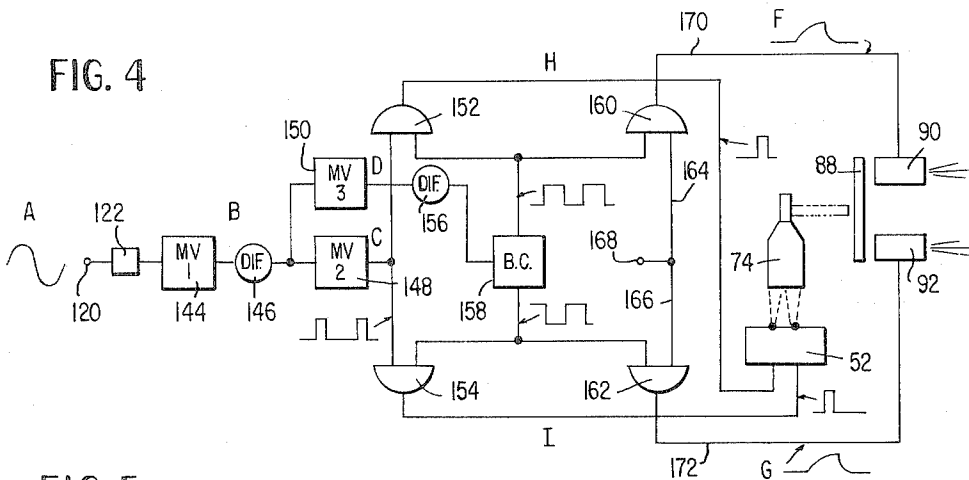
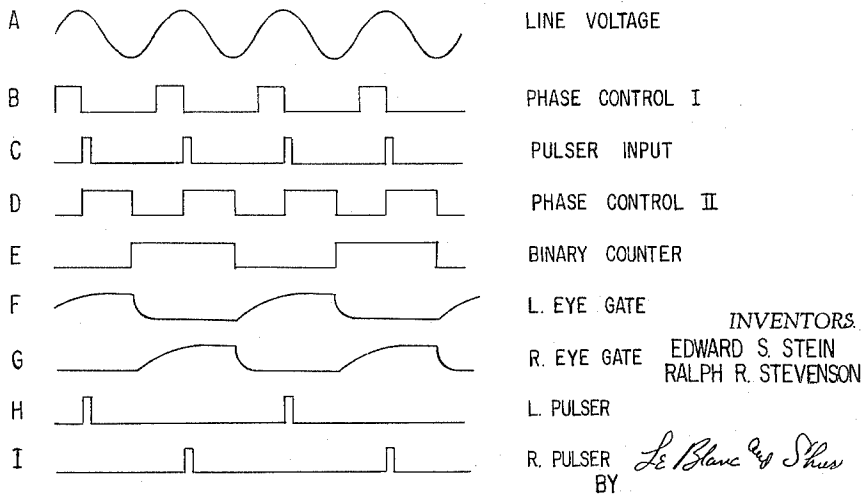


FIG. 5



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STEREOSCOPIC X-RAY EXAMINATION APPARATUS WITH LIGHT CONDUCTIVE RODS TO TRANSMIT THE OPTICAL IMAGES

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9 Claims. (Cl. 250-60)

This invention relates to an improvement of the invention disclosed in copending United States Patent application; Serial No. 257,275, filed February 8, 1963, now abandoned, said application being a continuation in part of United States Patent application Serial No. 55,608, filed September 12, 1960, now abandoned. This improvement is an invention relating to a three-dimensional or stereo X-ray and fluoroscopic device and more particularly a stereoscopic X-ray examination apparatus incorporating a stereoscopic light conductor for viewing or photographic recording of an image at a point remote from the irradiated object.

Various systems have been proposed in the past for obtaining a three-dimensional view of an X-ray image useful in medical examinations, industrial analyses, stereoradiography and scientific research. Although it is well known that a three-dimensional view of a subject or a patient is desirable and helpful to a doctor in diagnosing and treating various ailments, none of the known devices, insofar as applicants are aware, have been found to be practical, efficient, or commercially acceptable. This is probably due to the fact that in most cases they have been expensive to construct, are overly complex, have seriously limited the freedom of movement of the operator and in some instances have subjected either the patient or the doctor or both to dangerous levels of radiation.

The present invention avoids the above-mentioned difficulties by providing a relatively simple, inexpensive stereoscopic X-ray examination apparatus particularly suited for use by doctors and other medical personnel both in the hospital operating room and in the physician's office. By means of a flexible light transmitting conduit the image viewer may be freely moved about to the desired position without unduly restricting the examination of a patient while at the same time maintaining minimum radiation levels so as to not excessively expose either the patient or the operator to radiation. The unit is compact, easy to construct, uses for the most part standard proven components, is relatively inexpensive and highly reliable in operation. The unit provides a clearer three-dimensional X-ray image while at the same time allowing for the convenience and safety of the operator by permitting him to adjust the position of the viewer, yet preserving the integrity of the viewed image.

It is, therefore, one object of the present invention to provide a novel stereoscopic X-ray examination apparatus.

Another object of the present invention is to provide a novel stereoscopic X-ray examination apparatus of such greatly improved performance that not only its utility but its clinical need is apparent.

Another object of the present invention is to provide a three-dimensional X-ray apparatus permitting operation at reduced radiation levels.

Another object of the present invention is to provide a three-dimensional X-ray apparatus which may be adjusted to any desired position at the option of the user.

Another object of the present invention is to provide an X-ray apparatus having a stereo light conducting conduit for reproducing a stereo image at a point remote from the radiated object.

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These and further objects and advantages of the invention will be more apparent upon reference to the following specification, claims and appended drawings wherein:

FIGURE 1 is a perspective view showing the novel stereoscopic X-ray examination apparatus of the present invention.

FIGURE 2 is a diagrammatic view showing the overall system of the present invention.

FIGURE 3 is a diagrammatic view of the optical rotation compensator incorporated in the stereoscopic X-ray examination apparatus of FIGURE 1.

FIGURE 4 is a block diagram showing the energization circuit for the stereoscopic X-ray examination apparatus of FIGURE 1; and

FIGURE 5 is a timing diagram showing the wave forms at various locations in the circuit of FIGURE 4.

While the fluoroscope of the present invention may be used for industrial analyses, radiology and scientific research, it is particularly suited for use in clinical analysis and for use in the operating room and will be so described. During a medical analysis necessitating a view of an internal organ or obstruction or other frequent pathology the patient is most often placed recumbent on a table and irradiated by a suitable X-ray source from beneath. It is most desirable that the viewer positioned above the table be freely movable so that the physician or radiological viewer may retain an accurate view of the X-ray image as he moves about the table. During the examination the physician may use suitable lead lined gloves so that the patient's stomach, for example, may be pressed or otherwise manipulated so as to distort and move the internal organs and help in the analysis which may lead to the detection of a tumor, cancer, ulcer, or perhaps a foreign object or other abnormality in the stomach or intestinal tract. It is, however, most essential that neither the patient nor the physician be subjected to any substantial doses of radiation and particularly that the stereoscopic X-ray examination apparatus provide no path for the radiation through the instrument to the eyepiece of the viewer.

Referring to the drawings, FIGURE 1 illustrates the stereoscopic X-ray examination apparatus of the present invention generally indicated at 10 used in conjunction with an examining table 12 suitably mounted on a floor indicated at 14. An X-ray source indicated by the dashed lines at 16 within the table emits X-rays upwardly so as to be intercepted by the receiving portion of the unit 18 mounted over the table. The receiver 18 is illustrated as bolted or otherwise suitably secured to a standard 20 which may depend from the ceiling or may, if desired, be mounted upon a suitable track or floor standard so as to be adjustably positionable lengthwise and widthwise of the table 12.

The receiver comprises a suitably apertured mounting base 22 to which is secured a cylindrical casing 24 housing various components of the system as more fully explained below. Rotatably secured, as indicated at 26 to the upper end of the casing 24 is one end of a light-conducting tube 28 in the form of a long flexible coherent bundle of light fibers. The tube 28 is supported intermediate its ends by a spring 30 attached to the standard 20 and may, if desired, be provided with helical coils 32 and 34 to prevent over-flexing of the light conducting tube which might tend to cause breakage of the light fibers.

The other end of light conduit 28 is connected to a viewer 36 having a handle 38 by means of which it may be moved about to the desired position. The viewer is supported by a pair of parallel hollow rods 40 and 42. Each of the rods is pivoted to a similar pair of rods 44 and 46 having their other ends connected to a bracket

48 secured to a rotatable housing 50 slidable in a suitable circumferential groove formed in the outer surface of the casing 24. The pivots 43 and 45 permit movement of the viewer 36 in a vertical plane with respect to the table 12 while the support housing 50 permits the viewer to be moved in a horizontal plane relative to the table. Viewer 36 is preferably coupled through a single universal joint to a suitable mounting plate (not shown) on the ends of rods 40 and 42 so that it may be tilted to the desired position. Electrical connection to the viewer 36 is preferably through the hollow mounting rods.

FIGURE 2 is a diagrammatic view showing the overall system of FIGURE 1. In this figure the X-ray source indicated at 16 takes the form of a stereo X-ray tube 52. The tube consists of a single roentgen envelope containing two separately controlled cathodes indicated at 54 and 56. These cathodes are placed in close juxtaposition such that electrons as indicated in the drawing emanating from the cathodes will strike the anode in two adjacent focal spots separated by only a few inches. The resulting X-rays thus appear to originate in two adjacent spots. The tube 52 also contains two grid structures 58 and 60 which, when pulsed with voltage variations with respect to their cathodes of approximately 2% of the anode to cathode potential, can control the current to either focal spot from full cut-off to saturation. Tubes of this type are currently available from the Machlett Laboratories of Stamford Connecticut and are referred to as the "stereo dynamax" tube. Pulses are supplied to the tube grids 58 and 60 by way of leads 62 and 64 from a suitable pulse generator 66. It is, of course, apparent the in place of the single envelope tube 52 two separate X-ray tubes could be used with the advantage that the focal spot spacing can be easily changed. However, the use of two tubes has the disadvantage that the tubes must be located further apart due to their physical size.

The X-ray emanating from the tube 52 irradiate the object or subject to be viewed illustrated at 70 and pass to the input screen or phosphor 72 of an X-ray image amplifier tube 74. This amplifier tube 74 is located within the casing 24 of FIGURE 1 and is positioned so as to receive the radiation from the source 16 beneath the table. Image amplifier 74 is in the nature of an electron multiplier and includes an output phosphor or screen 76 at its other end which produces a reduced (approximately 1" diameter) luminous image which is bright in areas of low X-ray filtration and progressively darker in areas of progressively higher filtration by the subject 70. Since conversion power gains of 3,000 are common in these tubes the output luminescence is high for low levels of X-ray radiation. As a specific example, a tube such as the Machlett "Dynascope 9" may be used as the image amplifier 74.

The light then passes through an optical rotation compensator indicated generally at 78 and illustrated in detail in FIGURE 3 which compensator includes a lens 80 and a mirror 82 for directing the light onto the end of flexible light tube 84. The light then passes to viewer 36 which includes a lens 86, a beam splitter 88 and a pair of light gates 90 and 92 to a binocular type eyepiece 94. Beam splitter 88 is of more or less conventional construction and comprises a plurality of angularly oriented mirrors 96, 98, 100 and 102 for dividing the light from the lens 86 equally and transmitting each half to the respective gates 90 and 92.

The flexible light tube 84 preferably takes the form of a coherent light fiber bundle. As indicated in FIGURE 1 the bundle is preferably restrained by the helical coils 32 and 34 so as to prevent excessive bending of the light tube and breakage of the fiber bundles. This assures the prevention of breakage should the eyepiece be moved such as to bend the light tube through too small a radius. The lens 86 serves to focus the image onto the input of the two identical light gates 90 and 92. The light divider splits the image into two identical images set up side

by side at a distance roughly corresponding to the average human inter ocular separation. The two identical light gates located behind the light divider function to block light or let it pass in synchronism with the pulsing of the X-ray tube 52 such that images resulting from the left source will be passed only by the left gate and similarly for the right side. While many types of light gates may be used, in the preferred embodiment light gates 90 and 92 take the form of small image converters such as the RCA 7404 or the RCA 6914. These may be controlled by interrupting the accelerating voltage or if provided with a grid as is sometimes the case with the RCA 6914 model, they may be controlled by these grids. The use of image converters for light gates have the advantage in that it is possible to realize a substantial light gain this way. The additional light gain allows comfortable viewing again at reduced radiation levels.

The outputs of the light gates are focused onto the retinas of an observer's eyes by the eyepiece 94 which preferably takes the form of a conventional binocular type construction with a pair of simple identical high quality magnifiers. Variations in the inter ocular spacing of the observers may be accommodated in the conventional manner or if preferred may be varied by using a variable prism assembly between the observer's eyes and the magnifying lenses.

FIGURE 3 shows the image rotation compensator 78, coupling the image amplifier tube 74 to the light conducting tube 84. This unit is necessary for optimum viewing convenience to insure that the orientation of the stereo pair of images presented to the viewer will always correspond to the placement of the focal spots in the X-ray source. This is required since displacement of the fiber bundle tube 84 during manipulation of the viewer or movement of the table to an other than horizontal position causes twisting and rotation of one end of the fiber bundle relative to the other. Hence, the image must be rotated a corresponding amount so that the stereo pair is formed in the same plane.

The unit includes a dove prism 116 for accomplishing this compensation. The collimator lens 80 is situated in front of the output phosphor of the image amplifier 74 at a distance equal to its focal length for the purpose of collimating light leaving the output phosphor so that the rays leaving the lens will be almost parallel. This is done since the dove prism 116 tends to introduce undesirable astigmatism if nonparallel light enters the prism.

Rays of light leaving the lens 80 are reflected by the 45 degree mirror 82 which alters their direction by 90 degrees and directs them into the dove prism 116. The light is "reverted" by the dove prism and passes into a zoom lens 103. This lens serves a dual purpose—to focus the rays onto the end of the light bundle, and also to allow variations in the size of the image by varying magnification.

The light tube or bundle 84 is shown mounted in an antifriction bearing 119 so that its end is free to rotate about an axis through the center of the tube. The arrow B denotes this freedom of rotation. Affixed to the light bundle is a spur gear 115. This gear transmits the angular rotation of the light tube into gear 114 which is one of the end gears of a differential made up of bevel gears 110, 111, 112, 113 and the end gears 109 and 114. The rotation of gears 110 and 111 is summed by the movement of the pinion gears 112 and 113. Gears 111 and 114 are fixed to a common shaft as are gears 109 and 110.

Bevel gear 109 engages a stationary bevel gear 104 which is mounted to the same support as the image amplifier 74 and the lens 80. All of the other components of FIGURE 3 are formed into the rotatable assembly at the top of the container 24 of FIGURE 1 which is free to rotate around an axis through the optical centers of elements 74, 80, 82 and 104.

The motion of this rotary assembly is transmitted through gears 104 and 109 to the differential. Thus, the

motion of the pinion gears 112 and 113 is a function of the sum of (a) rotation of the light bundle within its mount and (b) rotation of the entire assembly around the image amplifier.

Pinion gears 112 and 113 are coupled together so as to turn the output shaft 118. This shaft is shown concentric with the shaft which supports gears 109 and 110 and is free to rotate within it. The gear 108 is affixed to the end of the output shaft and transmits this motion via gear 105 to the dove prism 116. The dove prism is located within gear 105 and is affixed to it so that both rotate together. Since it is well known that rotation of a dove prism through a given angle will result in rotation of the image passed through it of twice that angle the image will be rotated by the system of FIGURE 3 to compensate for rotation of the light bundle and/or movement of the light bundle around the image amplifier 74.

FIGURE 4 is a block diagram of the electrical components of the stereoscopic X-ray examination apparatus of FIGURE 1, and FIGURE 5 is a timing diagram showing pulse wave forms at various locations in the block diagram of FIGURE 4. Referring to this latter figure, input terminal 120 receives a 60-cycle A.C. line input which is rectified, amplified, clipped and differentiated in pulse shaper 122. The pulse shaper produces a sharp pulse which triggers a multivibrator 144 provided for the purposes of inserting a variable time delay into the system. The trailing edge of the output pulse from multivibrator 144 is differentiated in differentiator 146 and this spike triggers a second multivibrator 148. The spike is also supplied to a third multivibrator 150. The output pulses for multivibrator 148 are supplied to a pair of gates 152 and 154 in turn supplying energizing pulses to the respective grids of the stereo X-ray tube 52.

The trailing edge of the output pulse from multivibrator 150 is fed through differentiator 156 to a scale-of-one binary counter 158. The two outputs of the binary counter 158 are sent to the gates 152 and 164 and to two additional gates 160 and 162. The other terminals of gates 160 and 162 are connected by leads 164 and 166 to input terminal 168 adapted to be connected to an image converter accelerating voltage supply. The output from gates 160 and 162 is by way of leads 170 and 172 to the appropriate control electrode of the light gates or image converters 90 and 92.

Referring to FIGURE 5, curve A shows the 60-cycle 120 volt line input to terminal 120. This signal passes through a pulse shaper which may include provision for either half wave or full wave rectification at the option of the operator. In the embodiment shown, the pulse shaper provides half wave rectification so that the shaper supplies a pulse to multivibrator 144 once per cycle of the input voltage or at the rate of 60 cycles per second. The output from multivibrator 144 is illustrated at B with its leading edge coinciding with the upwardly sloping cross over point on the sinusoidal wave form A and its trailing edge, i.e. the pulse width, determined by suitable variable circuitry in multivibrator 144 so as to provide variable positioning of the trailing edge of the output pulses B.

The trailing edge of pulses B are differentiated in differentiator 146 and these spikes are supplied to multivibrator 148 which produces the narrow pulse output illustrated at C. These pulses are supplied to the X-ray tube gates 152 and 154. The spikes from differentiator 146 are also supplied to multivibrator 150 which produces the longer pulses illustrated at D in FIGURE 5. The trailing edge of these longer pulses are differentiated in differentiator 156 and supplied as trigger spikes to the scale at one binary counter 158. The output of one side of the binary counter 158 is illustrated at E in FIGURE 5 with the other output side of the binary counter of similar wave shape but 180 degrees out of phase with the wave form E. The outputs from the binary counter are supplied as gating signals to all four gates 152, 154, 160 and 162. In gates 152 and 154 the binary counters gate the narrow pulses

C so that these narrow pulses alternately appear at H and I in FIGURES 4 and 5. In gates 160 and 162 the binary counter outputs alternately couple the image converter accelerating supply voltage from terminal 168 to the opposite light gates or image converters 90 and 92. It can be seen that the gates 152, 154, 160 and 162 provide an arrangement for exciting the X-ray tube and light gates in synchronism. Because of the narrowness of the pulses C, the X-ray tube 52 is turned on for a much shorter length of time than are the light gates 90 and 92. This is done so as to minimize radiation. Furthermore, it will be noted that because of the delay incurred by multivibrator 144 the pulses H and I to the X-ray tube occur approximately coincidental with the maximum value of the line voltage A so as to provide a short period of maximum X-ray intensity from the X-ray tube.

It is apparent from the above that the present invention provides a novel stereoscopic X-ray examination apparatus of relatively simple inexpensive construction and yet one which provides not only an improved optical image to the physician or operator but incorporates the added advantages of minimum radiation exposure with complete freedom in movement of the eyepiece for optimal visualization. This latter freedom of movement permits the doctor or operator to move the eyepiece to any desired location which feature is particularly advantageous to a physician since it permits him to move about a patient as is required to provide a satisfactory clinical analysis of the interior formations of a human body.

Important features of the present invention include the provision of a light conducting tube in the form of a flexible coherent optical fiber bundle for transmitting the light away from the source of radiation to a remote point where it may be viewed by the operator. It is, of course, apparent that other types of flexible light conductors may be used such as two or more rigid or fused light fiber bundle sections suitably hinged together to provide flexibility. A further and related important feature is the provision for automatic optical rotation compensation wherein any twisting or turning of one end of the fiber bundle relatively to the other or relative to the output screen of the image amplifier during manipulation of the viewer is automatically compensated for by appropriate rotation of the optical image. Additional features include the provision of amplification both in the image amplifier and in the light gates which importantly contribute to the reduced radiation necessary to produce a satisfactory optical image in the device of this invention.

While described primarily in conjunction with medical analysis of human subjects, it is apparent that the stereoscopic X-ray examination apparatus system of the present invention finds other applications wherein objects may be viewed by X-rays. These include conventional manufacturing analysis techniques and scientific research, such as determining the location of a flaw in an opaque object which would otherwise be undetermined.

The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The present embodiment is thereof to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

What is claimed and desired to be secured by United States Letters Patent is:

1. A stereoscopic X-ray examination apparatus comprising a pair of closely spaced X-ray sources adapted to irradiate an object under study, means for alternately energizing said sources in time sequence, an image amplifier tube comprising an output screen, said image amplifier tube positioned to receive X-rays passing through said object from said sources and acting to convert said X-rays into a pair of optical images on the output screen

of said image amplifier tube, a flexible elongated light conductive means, comprising a bundle of optical fibers, said light conductive means having one end optically coupled to said output screen for receiving said optical images, said end of said light conductive means being rotatable about both its own optical axis and the optical axis of said image amplifier tube, optical rotation compensating means coupled to said image amplifier tube for compensating for movement of said end of said light conductive means, viewing means coupled to the other end of said light conductive means, said viewing means including a pair of closely spaced parallel light paths for said optical images, and means providing for alternate light transmission through said paths in synchronism with the energization of said X-ray sources.

2. A stereoscopic X-ray examination apparatus according to claim 1 wherein said compensating means comprises a dove prism optically positioned between said output screen and said end of said light conductive means, and means for rotating said prism in accordance with the movement of said end of said light conductive means about said optical axis of said image amplifier tube and said optical axis of said light conductive means.

3. A stereoscopic X-ray examination apparatus according to claim 2 wherein said rotating means comprises a gear transmission means for summing the rotation of said end of said light conductive means about each of said optical axes.

4. A stereoscopic X-ray examination apparatus comprising an X-ray tube envelope having a pair of closely spaced X-ray sources adapted to irradiate an object under study, pulse generating means for alternately energizing said sources in time sequence, an image amplifier tube having an input screen positioned to receive X-rays passing through said object from said sources and an output screen, said image amplifier producing a pair of corresponding optical images on the output screen thereof, a rotatable housing adjacent said output screen rotatable about the optical axis of said image amplifier and positioned to intercept the optical path of said image amplifier, a flexible light conductive tube, comprising a bundle of optical fibers, said light conductive tube having one end rotatably received in said housing and rotatable about its optical axis, means for rotatably mounting said light conductive tube in said housing, a lens for focusing the image on said output screen onto said end of said light conductive tube, compensating means mounted between said output screen and said end of said light conductive tube for rotating the image focused on said end of said light conductive tube in such a direction as to maintain the orientation of the image conducted to the

other end of said tube constant irrespective of rotation of said housing and said end of said light conductive tube, a pair of electrical light gates, a beam splitter between said other end of said light conductive tube and said light gates for directing the beam from said other end equally to said gates, a lens for focusing the beam from said other end of said light conductive tube onto said light gates, binocular eyepieces coupled to the output of said light gates, and means for energizing said light gates in synchronism with said X-ray sources.

5. A stereoscopic X-ray examination apparatus according to claim 4 wherein said energizing means include a plurality of electrical gates; the X-ray source on one side of said pair being gated on by the same gating pulse as the corresponding one of said light gates, the energizing pulse for said one source being of substantially less duration than said gating pulse.

6. A stereoscopic X-ray examination apparatus according to claim 5 wherein said gating pulse is produced by a binary counter supplying gating pulses on alternate half cycles to said X-ray sources.

7. A stereoscopic X-ray examination apparatus according to claim 4, said lens being a zoom lens.

8. A stereoscopic X-ray examination apparatus according to claim 4 wherein said compensating means comprises a rotatable dove prism.

9. A stereoscopic X-ray examination apparatus according to claim 4 including a 90° light bending mirror mounted for rotation with said housing and positioned between said lens and said light conductive tube.

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