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(54) X-RAY EXAMINATION APPARATUS

(71) We, GENERAL ELECTRIC COMPANY, a corporation organized and existing under the laws of the State of New York, United States of America, of 1 River Road, Schenectady 12305, State of New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to x-ray examination apparatus, such as x-ray cardiosvascular examination apparatus which can be used for general purpose x-ray examinations also.

An established procedure for examining the vascular system of organs such as the heart involves injecting a radiopaque dye into the blood vessels and fluoroscoping the organ of interest with a suitable x-ray image to optical image converting device such as an x-ray image intensifier. The dye outlines the heart and the associated vascular system which can then be observed while it is functioning for circulatory obstructions, aneurisms and other defects. As is well known, in an intensifier, the x-ray image impinges on a fluorescent screen which is the image input plane of the intensifier. The fluorescent image is converted into an electron image and then into a miniaturized bright optical image which may be viewed with a video camera or recorded with a cine camera or a spot film camera. The fluoroscopic image from the intensifier as viewed by the video camera is displayed on a video monitor. One of the problems with this procedure is that certain important blood vessels are often disposed with their axes perpendicular to the viewing plane, thus making defects difficult to observe. In other instances, blood vessels in the heart are superimposed or concealed by other vessels so it is difficult to distinguish them and to observe the defects in them.

Turning the image intensifier and x-ray source jointly is one approach to viewing blood vessels in the heart perpendicular to the viewing plane rather than axially. Turning also permits viewing between vessels that would otherwise be superimposed or obscured if they were other than parallel to the viewing plane.

Some prior apparatus for performing the specialised vascular procedures have an x-ray source arranged on one side of the patient and an image intensifier system on the other side with the source and system on a common mounting which causes the central x-ray beam to remain directed at the image plane for various angles at which viewing of the heart or blood vessels is desired. In some prior apparatus, the patient is supported for limited lengthwise turning and longitudinal turning relative to the x-ray beam to provide for viewing the heart at various angles. In other designs, the x-ray source can be turned longitudinally while the patient is supported for limited lengthwise rotation or no rotation at all.

Typically, in x-ray apparatus used heretofore for the purposes indicated, the x-ray source and imaging devices are supported on the ends of a U-shaped or a C-shaped arm which can approach the patient endwise or laterally. Turning is achieved by rotating the C-arm about a laterally extending axis or the U-arm about a longitudinal axis and turning the source and intensifier longitudinally. The problem with either of these designs is that the patient is supported on a table and the source and intensifier are in free space. A major disadvantage of this open construction is that shielding the operator from stray and secondary x-radiation is difficult, if not impossible.

According to the invention, here is provided an x-ray examination apparatus comprising:

An X-ray source and first mounting means carrying said source for turning about a first axis; a source turning drive motor coupled with said source and operative to effect turning of said source in either angular direction about said first axis; a second mounting means constructed and arranged for enabling longitudinal translatory movements and translatory movements perpendicular thereto and to the first axis relative to said X-ray source; an X-ray image receiver having an image input plane desired to be maintained in perpendicular relationship with the X-ray beam from said X-ray source; third mounting means carrying said image receiver and mounted on said second mounting means for turning said image receiver about a second axis parallel to but not coincident with said first axis; a first turning sensor connected with said X-ray source for delivering signals controlled by the turning of said X-ray source; a first translation sensor for delivering signals controlled by translation of said second mounting means in a first direction; a second translation sensor dor delivering signals controlled by translation of said second mounting means in a second direction; a second turning sensor for delivering signals controlled by the turning of said X-ray image receiver; a source comparator responsive to signals from said first turning sensor and said first and second translation sensors for delivering a source comparator output signal; means for applying said source comparator output signal to said source turning drive motor; and a receiver comparator for delivering reeciver comparator output signals in response to an input from said second turning sensor and an input controlled by turning of said source.

In a preferred embodiment of the invention, an X-ray source is mounted on one side of a patient supporting table for being motor driven angularly and an X-ray image intensifier system is mounted on the other side of the table for being shifted longitudinally and vertically to the position where turning is desired. Motor means are provided for driving the intensifier angularly, synchronously and coordinately with the x-ray source such that the central x-ray beam from the source is maintained in perpendicularity at all times with the x-ray image input plane of the image intensifier. The x-ray source is preferably within a table structure or enclosure. A servo motor is coupled with the source for driving it angularly about a transverse or laterally extending axis. The x-ray image intensifier is mounted on a vertically movable and horizontally translatable means above the table. The intensifier also has a servo motor for driving it angularly about a laterally extending axis synchronously with the x-ray source. In a preferred embodiment, means are also provided for driving the x-ray source and patient supporting table up and down selectively to improve angular viewing even more.

Coordination of angles and positions of the apparatus components may be made automatic by providing means for developing electric error signals which are functionally related to the position or angle of the various components of the apparatus. The signal developing means are typified by potentiometers which are connected in a bridge circuit such that if any component position or angle changes, all the others will change coordinately. This keeps the central x-ray beam from the source always perpendicular to the image input plane of the image intensifier.

An advantage of the preferred embodiment is that there is no mechanical connection between the image intensifier system on one side of the x-ray table and the x-ray source on the other side of the table. In a practical sense, this means that there is no link arm between the image receiving intensifier and the x-ray source which would interfere with the examiner working on the patient supported on the table. The absence of interfering objects is important when emergency procedures involving several assistants must be resorted to during an examination.

Preferred embodiments of the invention which will now be described with reference to the accompanying drawings, in which:—

FIGURE 1 shows a front elevation view of an x-ray apparatus in which the new motor turned x-ray source and x-ray image intensifier and the new control system therefor may be employed;

FIGURE 2 is a more schematic view of the type of apparatus shown in FIGURE 1 except that in this FIGURE the mechanical components are shown schematically to better illustrate the relationship with associated analog voltage developing potentiometers which are used in the illustrative control system;

FIGURE 3 is a circuit diagram of the control system;

FIGURE 4 is a diagram which is useful in explaining results obtainable with the control system;

FIGURE 5 is a circuit diagram of an alternative embodiment of the invention; and

FIGURE 6 is a circuit diagram of another alterantive embodiment of the invention.

The apparatus in FIGURE 1 comprises an x-ray table assembly which is generally designated by the reference numeral 10. The table has a flat base 11 with upstanding ends 12 and 13. A cradle in which the patient is supported during an examination is marked 14. The cradle is mounted on power driven shafts 15 and 16 so that the cradle and patient thereon may be rotated through a substantial angle in either direction about a longitudinal axis. Table base 11 is supported on an enclosed structure 17 which has the necessary internal clearances for permitting an x-ray beam to be projected upwardly through a patient on cradle 14. Within enclosure 17 are suitable components, not visible, for enabling table base 11 to be shifted laterally, that is, in either direction perpendicular to the plane of the drawing. There are also components, not shown, for permitting the table base 11 to be shifted in opposite longitudinal directions, that is, in parallelism with the plane of the drawing. The mechanism for shifting the table longitudinally and laterally is known and need not be described.

Enclosure 17 is supported on housing 20, which except for a part of its top, is x-ray impermeable. Within housing 20 is an x-ray tube casing 21 in which there is a conventional x-ray tube, or source as it is referred to herein, not visible. Casing 21 is mounted for being turned about a horizontal laterally extending axis 22 that is preferably substantially coincident with the focal spot on the x-ray tube target. X-ray tube casing 21 is supported for turning on a stand 23 which has a base 24. The stand and base are schematically represented. The base is movable vertically with respect to schematically represented stationary members 25. In one embodiment of the invention, as will be discussed later, the x-ray tube casing 21 and the table assembly 10 are adapted for being elevated and lowered jointly. X-ray tube casing 21 is subject to longitudinal turning about lateral axis 22 by operation of a reversible servo motor 26. The mechanical drive between motor 26 and casing 21 is symbolized by the dashed line 27.

Located above table assembly 10 is an image receiving means such as the x-ray image intensifier assembly which is indicated generally by the reference number 30. Intensifier assembly 30 comprises a lower housing portion 31 in which there is a conventional x-ray image intensifier tube, not visible. The upper part of assembly 30 has another housing portion 32 in which a video camera, not visible, is located. Although spot film and cine cameras are not illustrated as being mounted on upper housing 32, it will be understood by those skilled in the art that these components are usually present in x-ray image intensifier or fluoroscopic systems for vascular examinations. For the sake of illustration, one may consider that the input plane of the intensifier on which the x-ray image impinges is at the level of a line 33 which is coincident with the plane. The central ray from x-ray source 21 is suggested by the dash-dot line 34. Effective use of the apparatus requires that central x-ray remain perpendicular to image plane 33 at all times. The arrangements to be described in detail hereinafter facilitate maintaining perpendicularity between the central ray 34 of the x-ray beam and image plane 33.

Image intensifier assembly 30 is on longitudinally and vertically movable mounting means. Thus, the intensifier assembly is mounted on an arm 35 for pivoting about a laterally directed axis 36 through limited opposite longitudinal angles. Typically, intensifier 30 can be turned longitudinally 35° caudally and 15° cranially. The caudal and cranial terms are based upon the assumption that the patient's head will be at the end of the table that has shaft 15 and the feet will be at the end that has shaft 16.

Image intensifier assembly 30 is subject to being turned on arm 35 about lateral axis 36 under the influence of a servo motor, not visible in FIGURE 1, which motor is within a housing 37.

Arm 35 is attached to one of a group of vertically extensible and contractible telescoping members 38 which are counterpoised in any of several known ways and are movable within themselves and in respect to a vertically immovable base 39. The base is suspended from a carriage 40 which has wheels such as 41 that permit the carriage to translate longitudinally and parallel with the x-ray table 11 on a rail system 42. Thus, it will be evident that image intensifier assembly 30 is vertically movable on telescoping members 38 and that it is subject to longitudinal translation on carriage 40 and subject to turning about axis 36. Due to the new automatic control system which will be described in detail hereafter, when carriage 40 is shifted longitudinally, the x-ray image intensifier assembly 30 is turned and the x-ray tube casing 21 is turned synchronously so that the central x-ray 34 of the x-ray beam will maintain perpendicularity with the image plane 33 of the intensifier. This means that the image plane can be maintained in parallelism with the plane of interest in the patient's anatomy. Caudal translation and turning of the image intensifier is suggested by the phantom view of the image intensifier which is marked 30'. It will be understood that, in respect to FIGURE 1, when the image intensifier 30 is shifted longitudinally and automatically turned, the x-ray source 21 will turn synchronously and the central beam 34' will remain perpendicular to the image plane.

The arrangements which enable synchronous and coordinated control of the x-ray image intensifier 30 and x-ray tube casing 21 will now be described in detail in reference to FIGURES 2-4. In FIGURE 2, several position sensors consisting of resistance potentiometers are mounted to sense longitudinal position of carriage 40, intensifier height 39, intensifier angle and x-ray tube casing 21 angle. There are also potentiometers for sensing longitudinal position of the x-ray table assembly 10 and the height of the table.

In FIGURE 2, longitudinal position of carriage 40 is sensed by a schematically represented potentiometer 45. Potentiometer 45 produces an analog voltage signal which corresponds with or is a function of distance (XI) through which carriage 40 and, hence, image intensifier 30 is moved in the X direction. Another potentiometer 46 produces a signal which is a function of the height of the lateraly directed axis 36 and hence the height (YI) of intensifier 30. A potentiometer 47, mounted on image intensifier 30 produces a signal which is a function of Θ, the intensifier angle, or tan Θ the tangent function thereof. X-ray tube casing 21 has a potentiometer 48 which produces a signal which is a function of the angle (ΘS) or its tan Θ, of the x-ray tube casing 21. A potentiometer 49 produces a voltage that is a function of the table longitudinal position (XT). Two potentiometers 50 and 57 produce a voltage or voltages which are a function of the height (Y2) of x-ray table 10 in conjunction with x-ray tube casing 21. The table height is sometimes adjusted to facilitate transferring a patient from a hospital cart or stretcher. It is also adjusted to provide a convenient work height for the examiner.

In FIGURE 2, the x-ray table 10 is shown mounted on a schematically represented frame 58 which is on stationary members 25. In the actual embodiment the frame would be in an x-ray shielding enclosure as in FIGURE 1. X-ray tube casing 21 and the stand 23 on which it turns are mounted on a base, symbolized by a platform 59 that is fastened to frame 58. A motor 60, also marked MST for indicating that it moves the source and table, has laterally extending shafts such as 61 which drive one or more lead screws 62. The lead screws are threaded into plate 59 in this symbolic representation so that their rotation in one direction will raise table 10 and in the other direction will lower table 10. This function permits controlling the distance between the focal spot of the x-ray tube and the input image plane of the intensifier.

First motor means comprising a servo motor for driving x-ray tube casing 21 angularly is marked 66 and MS to imply that it turns the source on its axis. Second motor means comprising a servo motor for driving image intensifier 30 angularly is marked 65 and MI in FIGURE 2. The third motor means comprising the servo motor for translating the x-ray table longitudinally is marked 68 and MT. The fourth motor means comprising the motor for adjusting the elevation of the x-ray source and table jointly is marked 60 and MST.

The various potentiometers and motors shown in FIGURE 2 are connected in a bridge circuit which is shown in FIGURE 3. Besides the interconnecting wires shown in this FIGURE, the only elements which have not as yet been mentioned are a dc power source 70 and servo amplifiers 71, 72 and 73. These are conventional null comparator amplifiers. When there is a difference or error signal between their inputs, they drive their associated motors 68, 65 and 66, respectively, until the error signal is nullified.

The structure and function of the FIGURE 3 circuit will now be described concurrently. Assume that the image intensifier 30 is positioned initially with its axis 36 vertically above the x-ray source axis 22 and that the intensifier is then shifted by the operator or examiner longitudinally from its solid line position in FIGURE 1 through the distance XI in FIGURE 4 at which the intensifier will be turned to obtain the desired view. In the initial centered position, of course, the central ray 34 from the x-ray tube is vertical and perpendicular to the image input plane 33 of intensifier 30. The intensifier would usually be shifted longitudinally to take a view perpendicular to the plane in the patient's anatomy that is not perpendicular when the intensifier is vertical. To achieve this result, the intensifier must be shifted and turned so the central x-ray 34 will be perpendicular to the new angular plane in the anatomy and to the input image plane 33 of the intensifier.

In reference to FIGURE 4, if the rotational axis 36 of the intensifier has been shifted through the distance XI the central x-ray 34 will then describe the angle ΘS in respect to the rotational axis 22 of the x-ray tube. The center point 74 of image input plane 33 of the intensifier will shift to the positions shown and it will be necessary to incline plane 33 such that the angle ΘI is obtained. ΘI, the angle of the intensifier, will then equal Θ6, the angle of the source.

In FIGURE 3, the error signal produced by shifting the intensifier through a distance XI changes the signal level to one input 76 of comparator servo amplifier means 73 because the slide arm on potentiometer 45 moves in corerspondence with longitudinal movements of the intensifier. This signal unbalance causes motor 66 or MS to be driven such as to turn the x-ray tube casing or source 21 through the angle ΘS. Motor MS will simultaneously drive the arm having a potential corresponding with tan ΘS on potentiometer 48, thus changing its output potential. This new potential is applied to input 77 of comparator servo amplifier means 72 which causes motor MI to drive the intensifier 30 through the angle ΘI. At the same time, motor MI drives the arm having a potential corresponding with tan ΘI on potentiometer 47. When ΘI is attained, the input to amplifier 72 is nulled and motor MI stops and the intensifier stops turning. Now angles ΘS and ΘI and their tangents are equal. Central x-ray beam 34 will be perpendicular to image plane 33 of the intensifier.

Note that the resistance of potentiometer 48 is connected directly across regulated voltage source 70. The potential on the arm or sliding contact of potentiometer 48 corresponds with tan ΘS, where ΘS is the angle of the x-ray source. When the arm is at the lowermost end of the resistance, the tan ΘS potential is zero. Zero condition exists when the x-ray source and intensifier rotational axes are vertically aligned and if the intensifier is not shifted yet, its potential would also be zero and the potentiometer arm XI which is connected to amplifier input 76 and has the signal which is a function of the displacement of the carriage 40 would be at the lowermost end of the resistance of potentiometer 45.

The arm of potentiometer 46 has a pontential on it which is a function of the height (YI) of the intensifier axis 36 relative to the x-ray source axis 22. This potential is multiplied by the potential on the arm of potentiometer 48 which corresponds with tan ΘS since the potential on the arm of potentiometer 48 is applied to the top of the resistance of potentiometer 46. By way of example, if the source 70 voltage were one volt and the arm or sliding contact were at the top of potentiometer resistance 48, one volt would appear on the arm as representing a particular angle Θ or its tangent. If, at the same time, the arm of potentiometer 46 which is connected to amplifier input 75 were at its midpoint of the resistance, 1/2 volt would appear on this arm. Now if Θ and, hence, tan ΘS changed so that the arm of potentiometer 48 were at the midpoint of potentiometer 48, 1/2 volt would appear on the arm and 1/2 × 1/2 or 1/4 volt would appear on the arm of potentiometer 46, that is, if YI or the height of the intensifier remained the same. Thus, the potential on the arm of potentiometer 46 is always equal to the product of the signal corresponding with the hight YI and the signal corresponding with tan Θ. Balance of the two input signals is thus obtained when, expressed mathematically, $XI = YI \tan \Theta S$. Thus, when the potential which is a function of the longitudinal position (XI) of the intensifier, is changed by moving the intensifier, the new potential is applied to one input 76 of comparator servo control 73. This causes motor MS or 66 to drive the arm on which the potential representing tan ΘS is developed and drive continues until the potential corresponding with YI tan ΘS is developed on the arm of potentiometer 46. Then null is reached and the x-ray source 21 is turned properly.

If the intensifier height (YI) function potential is changed simultaneously or sequentially with a change in the longitudinal position, of the intensifier, the potential on the arm on potentiometer 46 connected to amplifier input 75 will change. This potential change on input 75 of comparator servo control 73 causes motor 66 or MS to again change the potential on the arm of potentiometer 48 representing tan ΘS until null is reached.

It should be noted that whenever the potential on the arm of potentiometer 48 corresponding with tan ΘS changes, due to turning the x-ray source or to raising or lowering the intensifier, the potential to input 77 of the intensifier comparator servo control 72 will change. This results in the intensifier turning motor 65 or MI running until the potential representing tan ΘS is nulled by the potential representing tan ΘI in which case the angular displacements of the x-ray source and intensifier become equal.

It may be desirable to move the x-ray table top automatically to keep the same region of the anatomy in the center of the x-ray beam during the turning as before turning of the intensifier. In FIGURE 4, assume that a point in the region of interest was initially somewhere around the point marked 81 in FIGURE 4. When the intensifier shifted through the distance XI, it would be necessary to shift the point 81 in the anatomy through the distance XT in FIGURE 4 so that the x-ray beam 34 would pass through the shifted position of the point 81′ in FIGURE 4. Referring to FIGURE 3 again, it will be noted that when x-ray source turning motor 66 or MS was being driven, the potential representing tan ΘS on the arm of potentiometer 48 was also applied to an input 79 of servo amplifier 71 as well as to input 77 of amplifier 72 as discussed above. This results in table top motor MT driving the table-top to locate 81′ in the x-ray beam. Motor MT drives until the arm on potentiometer 49 which has the potential corresponding with XT on it and is connected to input 80 reaches null. At null, the potential representing tan ΘS is proportional to the potential representing XT, which satisfies the geometry of FIGURE 4. Now point 81 has been moved proportionately to the change in tan ΘS that was initiated by the operator shifting the image intensifier longitudinally. Of course, the system functions in substantially the same way if the intensifier 30 is moved to the right or left as those skilled in the art will realize.

To continue the functional example,

assume now that the image intensifier has been shifted longitudinally as described above and it has turned automatically with the x-ray source 21 so that the central x-ray beam 34 is perpendicular to intensifier's input image plane 33 and centered thereon. Now assume further that the plane of interest in the patient's anatomy still cannot be viewed fluoroscopically to the operator's satisfaction. Under such circumstances lowering or raising image intensifier 30 may be required. If the intensifier 30 is lowered, for example, it will turn counterclockwise as viewed in FIGURE 2 and the source 21 will also turn similarly to maintain x-ray beam perpendicularity as described heretofore. When the intensifier is lowered, usually manually, meaning that YI has changed an error signal is produced on the arm of potentiometer 46. This signal is applied to input 75 of servo amplifier 73, thus causing motor 66 or MS to operate. This drives the x-ray source 21 through a new angle ΘS and the intensifier assumes a corrected angle ΘI as described above. Motor MS stops when the error signal due to a change in YI is nulled. When motor MS is running and changing the x-ray source angle ΘS, a signal is developed on the arm of potentiometer 48 which results in a change in the signal corresponding with tan ΘS. This signal is applied to input 79 of servo amplifier 71 and causes longitudinal table shifting motor MT to operate and shift the patient longitudinally over the distance XT.

To summarize the functional description thus far given, if the operator shifts carriage 40 and the intensifier 30 supported thereon longitudinally along the x-ray table, XI is caused to change, producing an error signal which operates the x-ray tube turning motor MS, turning the tube to follow the intensifier. This in turn changes tan ΘS, rebalancing that portion of the bridge. However, an error signal is now produced in another portion, causing intensifier turning motor MI to operate and change the signal corresponding with tan ΘI until that error signal vanishes, thus aligning the intensifier and the x-ray tube. If the intensifier is moved vertically, the signal for YI changes, causing the x-ray tube turning motor to drive the x-ray tube to following the intensifier and rebalance that portion of the bridge. As described above, this unbalances the other portion causing the intensifier to rotate to the same angle as the x-ray tube. In the described embodiment wherein the table top shifts automatically to keep the desired portion of the anatomy in the x-ray beam during turning, motor 68 or MT is operated concurrently with the intensifier and x-ray source turning. In other words, whenever the tube angle ΘS changes, a third error signal drives the table motor MT or 68 until the error vanishes.

Another feature alluded to above, is the height adjustment of the x-ray tube casing 21 and the table top 10 which must move vertically together. The table and source are raised and lowered jointly with motor 60 which is also marked MST. The motor may be operated with manually responsive control circuitry, not shown.

In reference to FIGURE 3, when motor MST 60 is operated, to change the table and source height, it drives the arms marked Y2 of potentiometers or voltage dividers 50 and 57 such as to effectively produce an error signal corresponding with YI relative to the height of the intensifier. The error signal is applied to input 75 of amplifier 73 which causes x-ray source turning motor MS to operate and produce the coordinate operation ofthe intensifier turning motor MI so that the x-ray source and intensifier change their angles ΘS and ΘI, respectively, synchronously. In FIGURE 4, the height of the intensifier relative to a ground plane 85 is marked Y1. The amount by which the x-ray tube focal spot or rotational axis is raised or lowered is marked Y2. The actual height of the intensifier relative to focal spot axis 22 is represented by YI. It will be seen that YI is equal to Y1−Y2. The height of a plane or point which it is desired to maintain at a constant distance from focal spot 22 is marked K. The correct amount of longitudinal table shift is marked XT. XT is always equal to K tan ΘS hence, the correction in XT required by changing the elevation of focal spot 22 by the distance Y2 is reflected in YI, the vertical distance between the center point 74 of the image plane and the focal spot 22. Accordingly, dimension YI changes when the distance Y2 is developed and, as can be seen in FIGURE 3, source turning motor MS responds to the error signal so generated by turning the x-ray source through the proper angle ΘS. The intensifier 30 turns concurrently to the desired angle for beam perpendicularly as described above.

In mathematical terms, the following equations are solved in the bridge circuit of FIGURES 3, 5 and 6; ΘI = ΘS; tan ΘI = tan ΘS; XI = YI tan ΘS; XT = K tan ΘS; and, YI = Y1 − Y2 where the terms of the equations are the electric signal counterparts of distance and angles.

The intensifier 30 turning cannot change inadvertently nor can it be changed manually. Any attempt to turn it by hand would tend to change the potential representing tan ΘI on input 78 of comparator servo control 72 but the established tan ΘS potential on the input 77 would permit an error signal to remain and the motor 65 or MI would drive the intensifier back to its original position.

Those skilled in the art will appreciate that some users might consider it desirable to automate other motions, such as the motion of the intensifier carrying carriage 40. If this is done, the basic bridge circuit of FIGURE 3 will remain the same, the only changes being in the connections of the error amplifiers and coupling of the sensors to the drives. In any case, the bridge must compare the product of the height sensors and the tangent of the angle with the carriage position sensor, and the resulting motions, whether automated or manual, required to obtain a null also result in generation of the product. The bridge circuit may also be arranged with tan ΘI interchanged with tan ΘS, but the arrangement shown and described above is preferred since an analysis of tracking error during turning reveals that the arrangement shown produces a lesser error.

An alterantive circuit, which accomplishes essentially the same objectives as the FIGURE 3 circuit, is shown in FIGURE 5. In the previously described FIGURE 3 circuit potentiometer 48 was used to produce a signal corresponding with tan ΘS and potentiometer 47 was used to produce a signal corresponding with tan ΘI. Any non-linear potentiometer such as one which produces a voltage proportional to a trigonometric function is much more expensive than a linear device. The FIGURE 4 circuit reduces the number of non-linear devices which are required.

In FIGURE 5, a linear potentiometer 90 has been inserted for producing a signal proportional to ΘS (instead of tan ΘS). Potentiometer 90 is mounted on the x-ray source 21 and, although it is not shown in FIGURE 2, it may be mounted in that figure to produce a signal proportional to ΘS similar to the manner in which potentiometer 48 is mounted for producing a signal proportional to tan ΘS as the x-ray source 21 turns. Potentiometer 90 has an arm 91 which is electrically connected to one input 75 of servo amplifier 73 which controls the x-ray source turning motor 66 (MS). Potentiometer 47 is converted to a linear potentiometer which will now produce a signal proportional to the angle, ΘI, of the image intensifier (instead of a signal proportional to the tan of ΘI as in the FIGURE 3 circuit).

Having potentiometer 90 in the circuit, the image intensifier turning indicating device, potentiometer 47, may now be a linear device for producing a signal proportional to ΘI (instead of tan ΘI as in FIGURE 3). Since non-linear potentiometer 48 for producing a signal proportional to tan ΘS and linear potentiometer 90 for producing a signal proportional to ΘS have their arms driven jointly when motor 66 or MS turns x-ray source 21, tan ΘS and ΘS change simultaneously. This is suggested in FIGURE 5 by the dashed line 92.

When the image intensifier 30 is shifted longitudinally over the distance XI in reference to the FIGURE 5 circuit, the signal from potentiometer 45 will unbalance the inputs to servo amplifier 73, thus causing x-ray source turning motor 66 to drive. This changes the signal from potentiometer 48 which is proportional to tan ΘS as in the FIGURE 3 circuit. But turning of the source 21 also changes the signal on linear potentiometer arm 91 which signal is proportional to ΘS and is supplied to one input 77 of servo amplifier 72 which controls the image intensifier turning motor 65 or MI. The unbalance signal from arm 81 causes motor 65 to turn the image intensifier 30 and also to change the signal from linear device 47 which appears on input 78 of servo amplifier 72. When the signal from potentiometer 47, corresponding with ΘI, balances the signal from potentiometer 90, corresponding with ΘS, the ΘS equals ΘI and the x-ray source 21 and image intensifier 30 are similarly turned.

Those skilled in the art will appreciate that the control system herein described for an x-ray cardiovascular examination table can be made with less sophisticated and with the elimination of some features, depending on the needs and desires of the user. For example, the height adjustment of the table and source could be eliminated with sacrifice of operator's comfort. This could eleminate use of motor MST 60 and voltage dividers or potentiometers 50 and 57. In the most rudimentary models all motions may be subject to manual control in place of using motors in which case the error signals may be detected on meters instead of with null amplifiers. The operator may then position the parts manually until the meters indicate no error signal.

FIGURE 6 is a circuit diagram for another alternative embodiment of the invention wherein parts which are similar to those used in previously described embodiments are given the same reference numerals.

In this embodiment the motors are eliminated which were used to translate the x-ray table top 10 longitudinally and to turn the image intensifier 30. Elimination of these motor drives assures that a patient on the table top cannot be driven into collision with a part of the apparatus such as the image intensifier and that the patient will not be struck by an intensifier which is turned under power. In this case, however, the image intensifier 30 is raised and lowered, turned and shifted longitudinally by manual force but the x-ray source 21 is turned with a motor 66. The angular error is detected on a null meter 94 and the intensifier is adjusted angularly until the error with the angle of the x-ray source is zero.

The FIGURE 6 system is based on the assumption that the operating radiologist knows the angle which intensifier 30 should make to afford the view of the patient's anatomy which is desired. So the radiologist shifts the intensifier 30 longitudinally to the desired position over the patient and later turns the intensifier as required.

In FIGURE 6 the x-ray source turning motor 66 is controlled by servo amplifier 73 which has inputs 75 and 76. The signal on input 76 is obtained from the arm of potentiometer 45. This signal is proportional to XI, the longitudinal distance of the intensifier rotational axis from being vertically over the axis of the x-ray source. A signal on input 75 is obtained from the arm of potetniometer 46. This signal is proportional to YI, the height of the image intensifier axis or to YI tan Θ if the intensifier is turned and raised or lowered from its normal position. As in the previously described embodiments, non-linear potentiometer 48 changes its signal corresponding with tan ΘS as the x-ray source turning motor runs. Thus, if the signal corresponding with XI on linear potentiometer 45 changes due to longitudinal shifting of the intensifier and whether the signal on the arm of potentiometer 46 corresponding with YI, the hight of the intensifier, changes or not, the source turning motor 66 will run until the two input signals to servo amplifier 73 are nulled. This occurs when manual shifting of the intensifier has been stopped. At this time, the intensifier 30 may not yet be manually turned by the radiologist but the x-ray source is approximately correctly turned.

The FIGURE 6 circuit also has a linear potentiometer 90 whose arm 91 is driven when the x-ray source turns as described above. Concurrent driving of potentiometer 90 and potentiometer 48 is indicated by the dashed line 92. The signal on arm 91 of potentiometer 90 is proportional to the angle, ΘS, of the x-ray source. This signal constitutes one input 77 to a servo amplifier 93 which drives meter 94. Also connected to an input 78 of amplifier 93 is the arm of potentiometer 47. The signal on this arm is proportional to the angle, ΘI, of the image intensifier since potentiometer 47 is driven by turning the intensifier manually.

Thus, when the image intensifier 30 is shifted longitudinally the distance XI and the x-ray source turns an error signal corresponding to ΘS is applied to amplifier 93 and the error is manifested on meter 94 which no longer reads zero but reads plus or minus zero on its angularly calibrated scale. Now the radiologist turns the intensifier and changes the signal on the arm of linear potentiometer 47 which signal is proportional to ΘI, the angle of the intensifier. This signal is another input to meter amplifier 93. Hence, when the intensifier angle, ΘI, is manually induced to equal the source angle, ΘS, their corresponding signals will be nulled and meter 94 will be zero again. Now the x-ray source 21 and intensifier 30 are at the same angle and aligned.

Raising or lowering the intensifier will change the signal from potentiometer 46 to unbalance the inputs to amplifier 73 and source turning motor 66 will run until a new null point is reached. The new angle of the x-ray source results in a meter 94 error which calls for turning the intensifier manually until the error disappears and ΘS and ΘI become equal again.

Those skilled in the art will recognize that the table top translation motor 68 or MT may be eliminated and that the top may be moved manually and its position could be indicated with a meter, not shown. In such case, if the intensifier is turned the meter will indicate an error and the table top may be shifted so the x-ray beam will be aimed generally through the same portion of the patient's anatomy.

Although in the above described embodiment potentiometers were used to develop turning and position error signals, those skilled in the art will appreciate that other more complex means may be used when economically feasible such as digital logic circuitry or other analog circuits. The potentiometer bridge circuit herein described, however, is simple, flexible and reliable.

WHAT WE CLAIM IS:—

1. X-ray examination apparatus comprising:

an X-ray source and first mounting means carrying said source for turning about a first axis; a source turning drive motor coupled with said source and operative to effect turning of said source in either angular direction about said first axis; a second mounting means constructed and arranged for enabling longitudinal translatory movements and translatory movements perpendicular thereto and to the first axis relative to said X-ray source; an X-ray image receiver having an image input plane desired to be maintained in perpendicular relationship with the X-ray beam from said X-ray source; third mounting means carrying said image receiver and mounted on said second mounting means for turning said image receiver about a second axis parallel to but not coincident with said first axis; a first turning sensor connected with said X-ray source for delivering signals controlled by the turning of said X-ray source; a first translation sensor for delivering signals controlled by translation of said second mounting means in a first direction; a second translation sensor for delivering signals controlled by translation of said second mounting means in a second direction; a second turning sensor for delivering signals controlled by the turning of said X-ray image receiver; a source comparator responsive to signals from said first turning sensor and said first and second translation sensors for delivering a source comparator output signal; means for applying said source comparator output signal to said source turning drive motor; and a receiver comparator for delivering receiver comparator output signals in response to an input from said second turning sensor and an input controlled by turning of said source.

2. X-ray examination apparatus as claimed in claim 1, in which said first turning sensor is arranged to produce a signal corersponding to the tangent of the angle of displacement of said source from a reference position.

3. X-ray examination apparatus as claimed in claim 2, in which a patient table is disposed between said source and said image receiver, said first translation sensor is responsive to movements of the image receiver in a direction perpendicular to the flat surface of said table, said second translation sensor is responsive to movement of said image receiver parallel to said table, and the output from said first turning sensor serves also as an input to said first translation sensor.

4. X-ray examination apparatus as claimed in claim 1, in which there is provided a receiver turning drive motor coupled with said image receiver, and means connecting the receiver comparator output signal with said receiver turning drive motor.

5. X-ray examination apparatus as claimed in claim 4, in which there is provided a patient table disposed between said source and said image receiver.

6. X-ray examination apparatus as claimed in claim 5, in which said patient table is movable in the lengthwise direction thereof, there being provided a third translation sensor connected with said table for delivering signals controlled by the movement of said table, a table comparator having a first input connected with the output of said third translation sensor and a second input connected to the output of said first turning sensor for delivering an output signal responsive to comparison of the inputs thereto, a table drive motor connected with said table, and means connecting said table drive motor with the output of said table comparator.

7. X-ray examination apparatus as claimed in claim 6, in which said first translation sensor is responsive to movements of the image receiver in a direction perpendicular to the patient receiving surface of said table and said second translation sensor is responsive to movement of said image receiver parallel to the line of movement of said table.

8. X-ray examination apparatus as claimed in claim 7, in which the output signal of said first turning sensor corresponds to the tangent of the angle by which said source departs from a predetermined reference position.

9. X-ray examination apparatus as claimed in claim 8, in which the output signal from said first turning sensor serves as an input to said first translation sensor.

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1575077 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

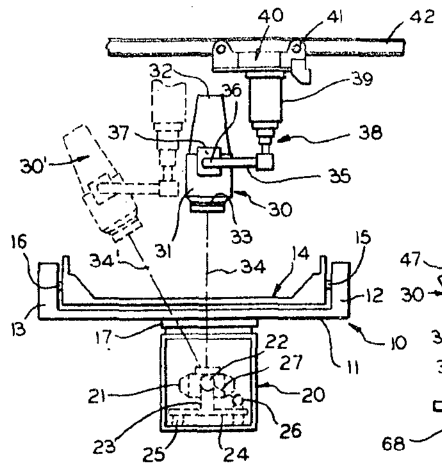


FIG. 1

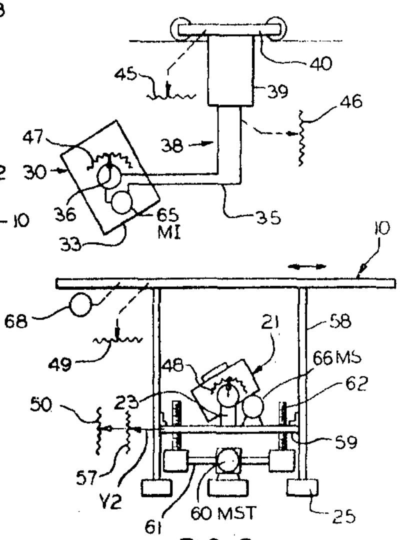


FIG. 2

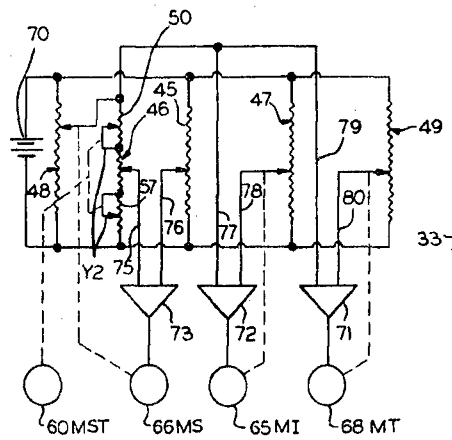


FIG. 3

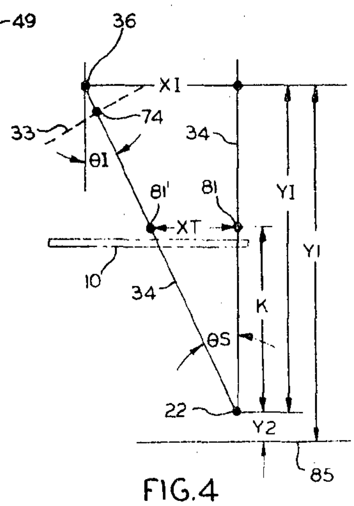
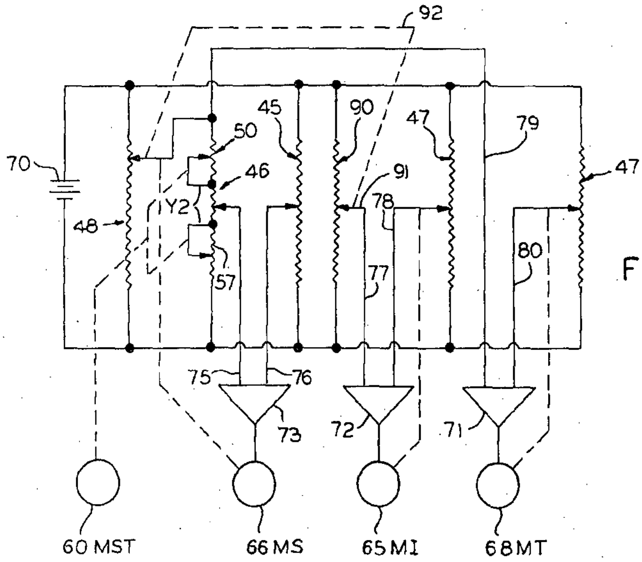


FIG. 4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Y2
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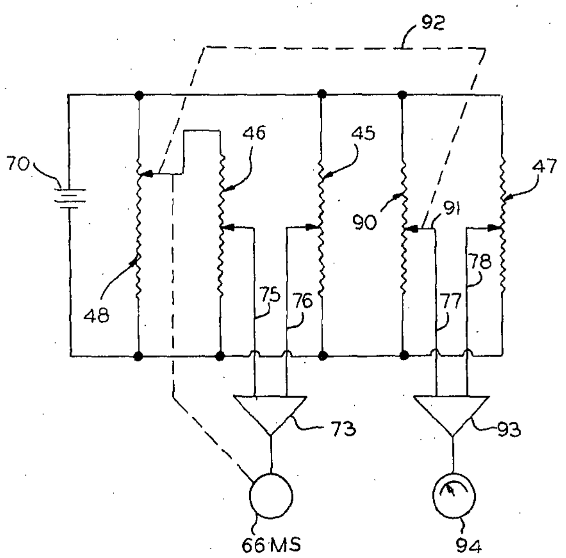
60 MST
66 MS
65 MI
68 MT

FIG. 5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66 MS
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FIG. 6