PATENT SPECIFICATION

(11) 1 579 265

(21) Application No. 21123/77 (22) Filed 19 May 1977
(31) Convention Application No. 7605687
(32) Filed 26 May 1976 in
(33) Netherlands (NL)
(44) Complete Specification published 19 Nov. 1980
(51) INT CL[3] G01N 23/06
(52) Index at acceptance
H4F D18X D25L D27L D27V D56X D61 D83B L

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(19)

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(54) IMPROVEMENTS IN OR RELATING TO TOMOGRAPHY

(71) We, N.V. OPTISCHE INDUSTRIE "DE OUDE DELFT", a Dutch body corporate of Van Miereveltlaan 9, Delft, the Netherlands, 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 an apparatus for tomography.

Such an apparatus comprises, conventionally, an X-ray source, a detector surface, and means optically and/or electronically coupled to said detector surface for providing and processing signals which are a measure for the X-ray absorption, in various directions, in a slice-shaped transaxial section of an object to be disposed between the X-ray source and the detector surface, which signals are producible owing to the provision of means for effecting relative rotation of the object relative to the apparatus about an axis perpendicular to the plane of the slice-shaped section.

It is of essential importance that each element of the section can contribute to the absorption of the X-rays. If this is not the case, the information is incomplete, and no accurate image reconstruction is possible.

To realise this object, it is conventional to use a large number of detectors, which may be arranged to perform a translatory movement in addition to a possible rotary movement. It will be clear that such a combined movement is time-consuming, and moreover tends to complicate the construction of the apparatus.

A disadvantage of a construction with a stationary array of discrete detectors is that the compromise between resolution and computer time required for image reconstruction is optimal for one magnification of the section only. For when the distance between the object and the array of detectors is varied, the computer time does not vary, but the resolving power does vary as a consequence of varying geometrical magnification in a divergent beam of X-rays.

According to the present invention, there is provided apparatus for use in the tomographic examination of an object, comprising a detector, an X-ray source for projecting a fan-shaped beam towards the object, when disposed between the source and the detector, to irradiate a transaxial section of the object, the detector having a detector surface which extends so as to intercept the whole of the beam, means optically and/or electronically coupled to the detector to produce an electrical signal carrying information concerning the absorption by said section of radiation from said source as derived from the X-ray image incident on the detector surface, and to process said signal to produce a tomogram of said section, and means for effecting rotation of said object relative to the source and detector about an axis which extends perpendicular to the plane of the beam and the transaxial section and which intersects the beam at a point at or adjacent one of the divergent lateral edges thereof, whereby upon rotation about the axis through a complete revolution of an object which never extends beyond the other lateral edge of the beam but of which only a part of the transaxial section is irradiated at any instant, the complete transaxial section of the object becomes irradiated, the thickness of said section, parallel to said axis being determined by the thickness of the beam.

The X-ray source may have a linear focus parallel to said axis of rotation.

The detector surface may comprise a two-dimensional matrix of discrete X-ray detecto-elements, with which matrix electronic means are coupled for successfully scanning the detector elements to produce signals for further processing. Alternatively the detector surface may be continuous, two dimensional X-ray screen. In this form of invention, lens means, mirror means of fibre-optics means may be provided for focusing the X-ray absorption image at the detector surface onto the cathode of an image intensifier tube. Furthermore the detector surface may be provided within the envelope of an X-ray image intensifier tube.

The detector surface may have the shape of a part of the surface of a cylinder whose axis preferably coincides with the linear focus of the X-ray source.

Means may be provided for rotating the object relatively to a stationary combination of an X-ray source and a detector surface about said axis of rotation. Additionally or alternatively, there may be provided means for rotating the combination of the X-ray source and the detector surface around a stationary object.

The axis of rotation may be located within the object.

Finally, means may be provided for adjusting the position of the transaxial object section relative to the combination of the X-ray source and the detector surface.

Some embodiments of the invention will now be described by way of example, with reference to the accompanying diagrammatic drawings.

In said drawings:

Figure 1 shows one embodiment of apparatus according to the present invention;

Figure 2 shows a part of the apparatus shown in Figure 1 with an X-ray source having a linear focus;

Figure 3 shows an embodiment of a mirror-optical system for depicting the detector surface on the photo-cathode of an image intensifier tube;

Figure 4 shows an embodiment of a fibre-optics system for depicting the detector surface on the photocathode of an image intensifier tube;

Figure 5 shows an embodiment in which the detector surface is provided within the envelope of a conventional X-ray image intensifier tube;

Figure 6 shows an embodiment of a detector surface curved according to a part of the surface of a cylinder, for use with an X-ray source having a linear focus; and

Figure 7 shows the use of a detector surface according to Figure 6 in an apparatus of the type illustrated in Figure 1.

The apparatus shown in Figure 1 comprises an X-ray source 1 and a fluorescent X-ray screen 2. When the apparatus is in operation an object 3 is placed between these two parts. In the situation depicted in the figure, the centre of this object is contained in the imaginary perpendicular from source 1 to screen 2. With such an arrangement, only a portion, and in particular substantially half of the section of this object is irradiated by the fan-shaped beam projected from the source 1 and intercepted by the screen 1 and when the object is rotated through 360° a transmission image of a slice-shaped section of the object is formed on screen 2.

On the side of screen 2 away from source 1, there is further provided an optical system 4 of very high light-gathering power for depicting the image appearing on screen 2 on the photocathode of an image intensifier 5.

In the embodiment of the invention illustrated in Figure 1, image intensifier 5 is directly coupled by fibre-optics means to a subsequent television pick-up tube 6. Pick-up tube 6 serves for scanning the image appearing on the anode screen of image intensifier 5, in the manner conventional in television technique, to provide a video signal, which is supplied to a monitor 9 and a logarithmic video amplifier 7, the latter being in turn coupled to an image reconstruction apparatus 8, which forms a tomogram of the object section from the video signals received.

It is clear that this requires rotating the object 3 about an axis relatively to the combination of X-ray source 1 and screen 2, or rotating the combination of source 1 and screen 2 around object 3. This is indicated in the figure with an arrow.

One advantage of the invention, as is apparent from the figure, is that a relatively small detector surface is needed to produce all information required for the eventual reconstruction of a complete sectional image, without it being necessary to perform any translatory movement. Because of the fact that, with the arrangement of object 3 as shown in Figure 1, only part of object 3 is depicted on screen 2 at a time, the production of a complete sectional image of object 3 requires the latter to be rotated about its axis through an angle of 360°. The drawback of a complete revolution is outweighed by the advantages achieved using a detector surface of relatively small extent, in particular if the arrangement is such that the axis of rotation is vertical.

The use of a relatively small detector surface further renders it possible for the further components of the apparatus, such as the optical system 4, image intensifier tube 5, etc., to be of relatively small dimensions, and hence relatively inexpensive. In addition these smaller dimensions make for lighter constructions having a lower moment of inertia, by virtue of which considerably faster rotation can be achieved with less power. As a result, blurring, as an effect, for example, of the patient's breathing, can be substantially minimized.

Another advantage of the relatively small extent of detector surface 2 is that a good resolution is obtained with the apparatus. As a matter of fact, one television image, the resolution of which is determined by the number of television lines and the bandwidth used, is used for processing the information respecting approximately half the object at any instant. Consequently, in the reconstruction of the whole object, the contribution of the television image to unsharpness is proportionally less, while at the same time the resolving power in a horizontal sense is approximately doubled as compared with the case in which the detector surface is larger and one television image is used for the whole object.

It will further be clear that, although Figure 1 illustrates the case in which the axis of rotation of the object 3 coincides with the perpendicular from source 1 to screen 2, this is not strictly necessary, and that, provided the axis is adjacent one of the edges of the beam, said axis may be located within the confines of the fan-shaped beam.

The disposition of object 3 as shown in Figure 1 has both an advantage and a disadvantage. The disadvantage is that a so-called "central pip" is formed at the left-hand edge of the screen as viewed in the drawing, which gives rise to a point in the reconstructed image. It is, however, possible for this "central pip" to be used as a reference, which is of interest, for example, in therapy-planning for irradiation of the object. This is an advantage, which proves to outweigh the visual objection to the formation of the point in the reconstructed image, partly in view of the liberty one has to choose the place of the "central pip" in a less interesting portion of the section.

In an apparatus according to the invention for tomography, it is preferable for the X-ray source to have a line focus parallel to the axis of rotation of the object or the combination of the X-ray source and the screen, as shown in Figure 2 of the accompanying drawings. In that case it is also possible, and preferred, that the detector surface, if located outside the envelope of an image intensifier, is given the shape of part of a cylinder surface, the axis of which coincides with the linear focus of the X-ray source, as shown in Figure 6. This obviates the necessity of applying corrections for variation in linear magnification along the detector surface.

Figure 7 shows the use of a concavely curved detector surface in apparatus of the type illustrated in Figure 1. The apparatus comprises an X-ray source 1 and an X-ray screen 2, which is concave in this case. Between these parts an object 3 is disposed in the manner described hereinbefore.

Disposed on the side of screen 2 away from source 1 is an optical system, shown here as a lens 4, for focusing the image appearing on screen 2 onto the photocathode 14 of an image intensifier 5.

In connection with the concave shape of screen 2, in this embodiment the input surface of the image intensifier is also made concave. Between this input surface and photocathode 14, there is provided a fibre-optics system 13, similar to the embodiment of Figure 4.

Where reference is made herein to a screen or detector surface, there is meant a construction that is built up from a two-dimensional matrix of discrete X-ray detector elements, or a continuous, two-dimensional X-ray screen.

In the embodiment of Figure 1, the image appearing on the detector surface is depicted on the photocathode of image intensifier tube 5 by means of a lens system 4. This may also be effected using a mirror system, as shown in Figure 3. In that embodiment, a ray emanating from detector screen 2 is directed via a curved lens 10 to a mirror 11 having a central aperture, which mirror reflects the ray to a curved-mirror assembly 12, which in turn reflects the ray to the photocathode of image intensifier 5.

Figure 4 shows an embodiment in which the image appearing on the detector surface is depicted on the intensifier cathode by fibre-optical means 13 provided between screen 2 and the cathode. Also, in that embodiment, the detector surface 2 is deposited within the envelope of a direct X-ray image intensifier tube 5, unlike the embodiment of Figure 1, in which the detector surface is arranged outside the envelope of image intensifier tube 5. As appears from Figure 5, screen 2 is disposed in the immediate vicinity of the photocathode 14 of image intensifier 5 within the envelope thereof.

As stated above, during operation of the apparatus, the object 3 may be rotated relatively to a stationary combination of X-ray source 1 and screen 2, or said combination may be rotated relatively to a stationary object 3. For simplicity, the means for effecting such rotation are not shown in the drawings. In either of these embodiments the axis of rotation may be located within the object 3.

Furthermore the apparatus may be provided with means for adjusting the place of the slice-shaped object section relative to the combination of X-ray source 1 and detector surface 2. These means, too, are not explicitly shown in the accompanying diagrammatic drawings.

WHAT WE CLAIM IS:

1. Apparatus for use in the tomographic examination of an object, comprising a detector, an X-ray source for projecting a fan-shaped beam toward the object, when disposed between the source and the detector, to irradiate a transaxial section of the object, the detector having a detector surface which extends so as to intercept the whole of the beam, means optically and/or electronically coupled to the detector to produce an electrical signal carrying information concerning the absorption by said section of radiation from said source as derived from the X-ray image incident on the detector

surface, and to process said signal to produce a tomogram of said section, and means for effecting rotation of said object relative to the source and detector about an axis which extends perpendicular to the plane of the beam and the transaxial section and which intersects the beam at a point at or adjacent one of the divergent lateral edges thereof, whereby upon rotation about the axis through a complete revolution of an object which never extends beyond the other lateral edge of the beam but of which only a part of the transaxial section is irradiated at any instant, the complete transaxial section of the object becomes irradiated, the thickness of said section, parallel to said axis being determined by the thickness of the beam.

2. Apparatus according to claim 1, wherein said X-ray source has a linear focus parallel to said axis of rotation.

3. Apparatus according to claim 1 or claim 2, wherein the detector surface is provided by a two-dimensional matrix of discrete X-ray detector elements.

4. Apparatus according to claim 1 or 2, wherein said detector surface is a continuous two-dimensional fluorescent X-ray screen.

5. Apparatus according to claim 4, wherein lens means, mirror means or fibre-optics means are provided for focusing the X-ray absorption image at the detector surface onto the photocathode of an image intensifier tube.

6. Apparatus according to claim 4, wherein said detector surface is deposited within the envelope of an X-ray image intensifier tube.

7. Apparatus according to claim 2 or any one of claims 3 to 6 when dependent on claim 2, wherein the detector surface has the shape of a part of the surface of a cylinder whose axis coincides with the linear focus of the X-ray source.

8. Apparatus according to any one of the preceding claims, wherein the combination of the X-ray source and the detector surface is stationary, and means are provided for rotating the object about the axis of rotation relatively to said combination.

9. Apparatus according to any one of claims 1 to 7, wherein means are provided for rotating the combination of the X-ray source and the detector surface around the object.

10. Apparatus according to any of the preceding claims, wherein means are provided for adjusting the position of the transaxial object section relative to the combination of the X-ray source and the detector surface.

11. A method of making a tomogram, which comprises: placing an object to be examined between an X-ray source and a detector surface, producing an X-ray absorption image of a section of said object on said detector surface while causing a complete relative rotation between said object and the combination of said X-ray source and said detector surface about an axis perpendicular to the X-ray beam emanating from said source, converting the successive images appearing on said detector surface to signals representative of the X-ray absorption pattern of said section in various directions, and processing said signals to form a tomogram of said section, wherein the X-ray beam is fan-shaped, said axis about which said complete relative rotation is effected intersects the X-ray beam at a point at or adjacent one of the divergent edges thereof, and the object never extends beyond the other of the said divergent edges such that at any instant only a part of said section is irradiated, the thickness of said section, parallel to said axis being determined by the thickness of the beam.

12. Apparatus constructed, arranged, and adapted to operate substantially as described herein with reference to the accompanying drawings.

13. A method of making a tomogram substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

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Printed in England by Her Majesty's Stationery Office, 1980. Published by the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

1579265 COMPLETE SPECIFICATION

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

Sheet 1

FIG. 1

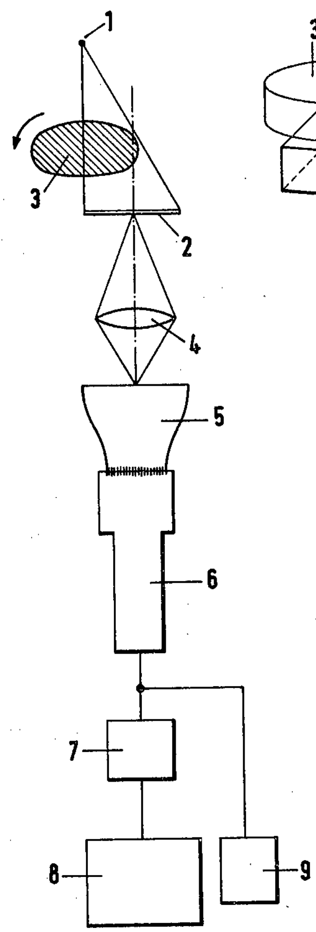


FIG. 2

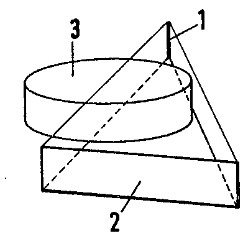


FIG. 3

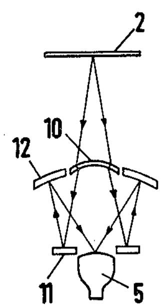


FIG. 4

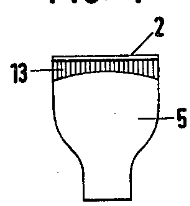


FIG. 5

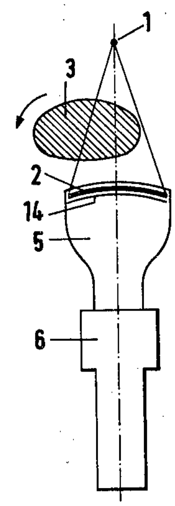
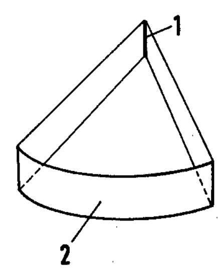


FIG. 6



1579265 COMPLETE SPECIFICATION
2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheet 2

FIG. 7