(12) UK Patent Application (19) GB (11) 2 044 985 A

(21) Application No **7909077**
(22) Date of filing **15 Mar 1979**
(43) Application published **22 Oct 1980**
(51) **INT CL³** **H01J 35/30**
(52) Domestic classification **H1D** 2A 2F 2X 32 9C1X 9C1Y 9CY 9G 9Y
(56) Documents cited **GB 640694**
(58) Field of search **H1D**
(71) Applicants **EMI Limited, Blyth Road, Hayes, Middlesex.**
(72) Inventors **Bernard Joseph Mayo**
(74) Agents **I.A. Fleming**

(54) **X-ray tube**

(57) An x-ray tube in which the x-ray origin is scanned on a circle around the patient, comprises a ring-shaped anode (8), an electron beam (4) travelling along a circular path being deflected onto the anode at the desired positions. The electron beam path may be in a plane parallel to the anode and perhaps at the same radius. It may be in the same plane as a transmission target/ anode and at a greater radius. The anode should extend over at least 180° although it may extend to 360°. Electrostatic means (6,7) may be provided to constrain the beam to the circular path and further electrostatic means (9) (of also Figure 3, not shown) deflect it to the anode of the beam and ensure it is focussed at the point of incidence. Collimators (12, 13) provide a planar fan-shaped beam and the anode may be shaped to attenuate side lobes of the radiation. Electrode (15) collects electrons not deflected. The focal regions may be adjacent or otherwise. Coils may provide periodic focusing to overcome space charge dispersion and dynamic adjustment of the focusing before deflection ensures focusing at target incidence. Focusing may be absent near the deflection region, and current in the coil section near the focal region should be zero.

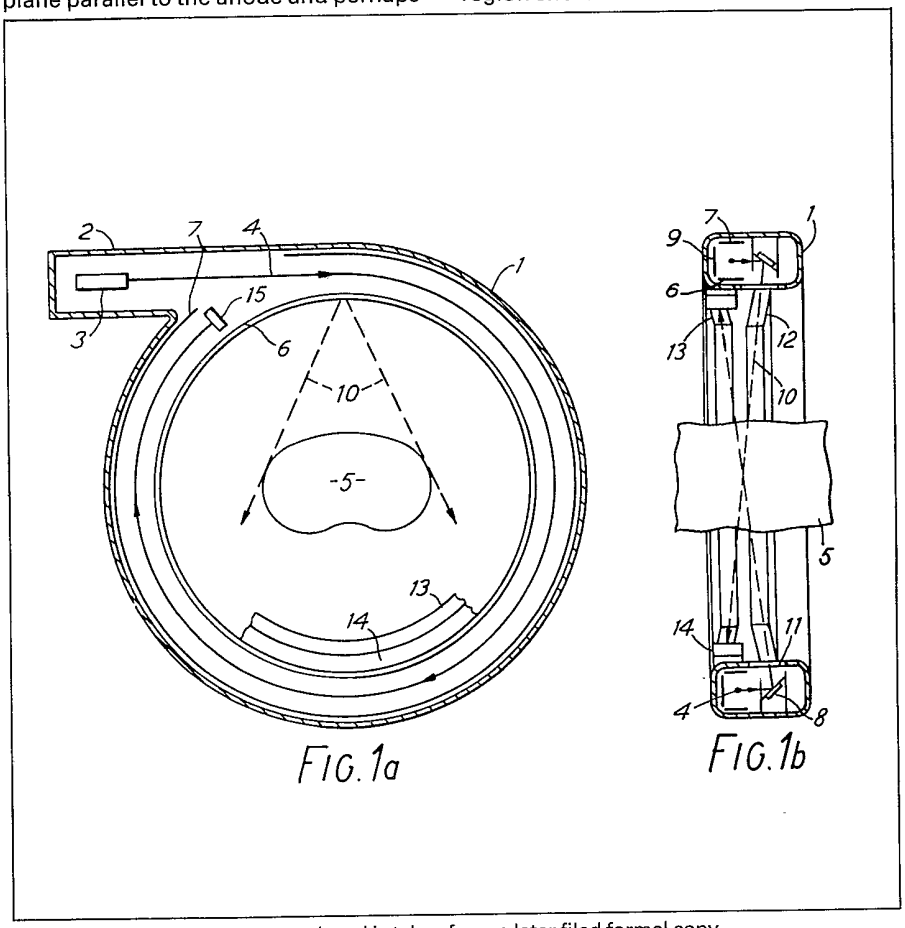

FIG. 1a FIG. 1b

GB 2 044 985 A

The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

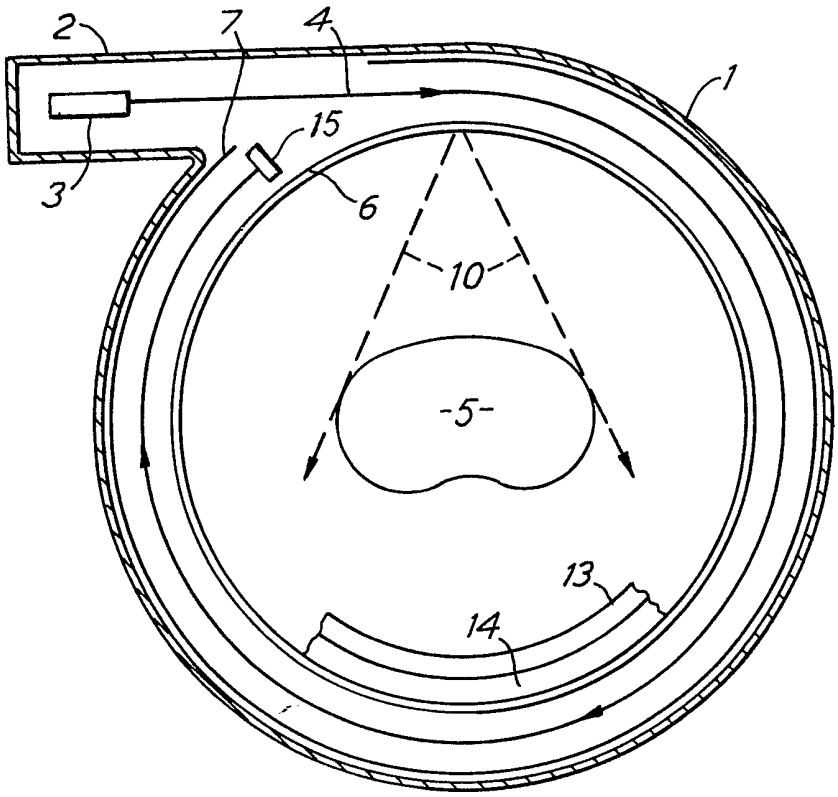

FIG. 1a

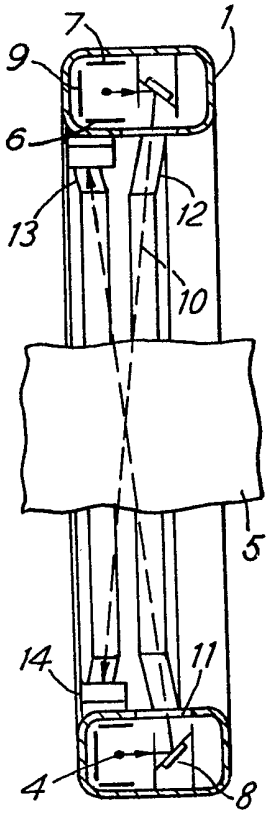

FIG. 1b

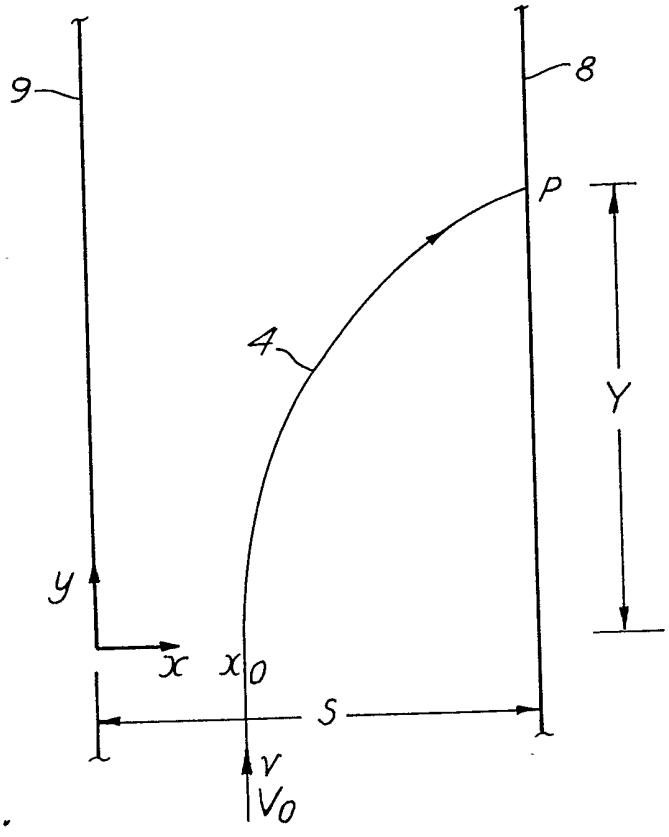

FIG. 2

2044585

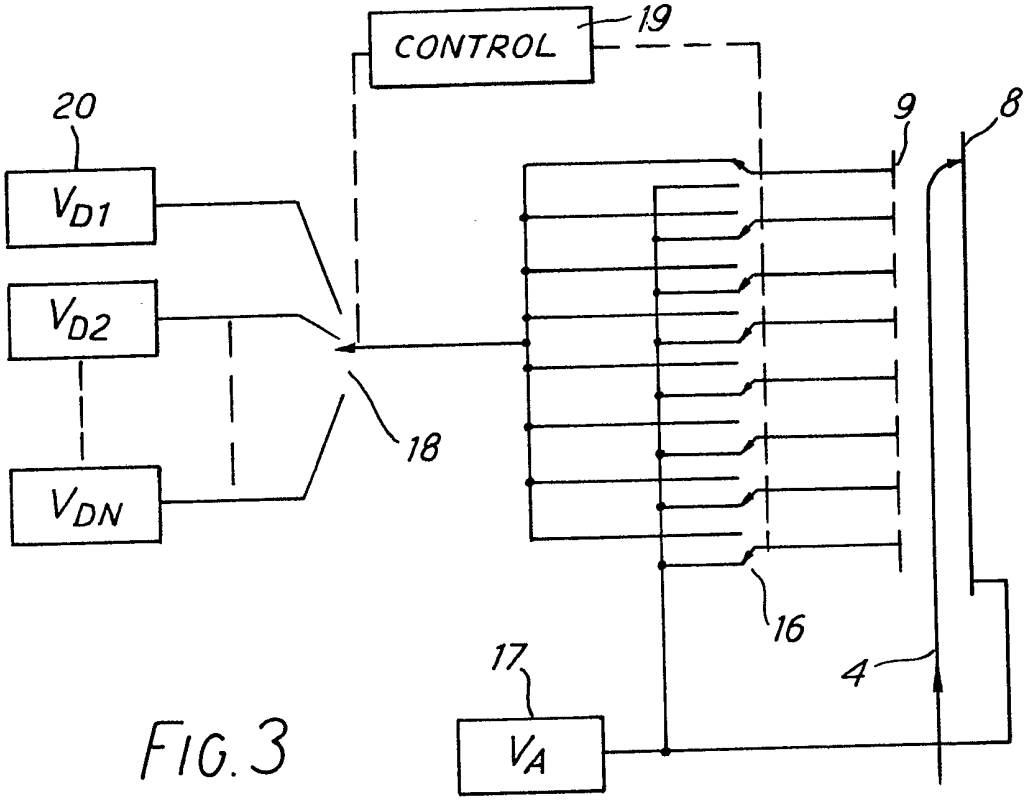

FIG. 3

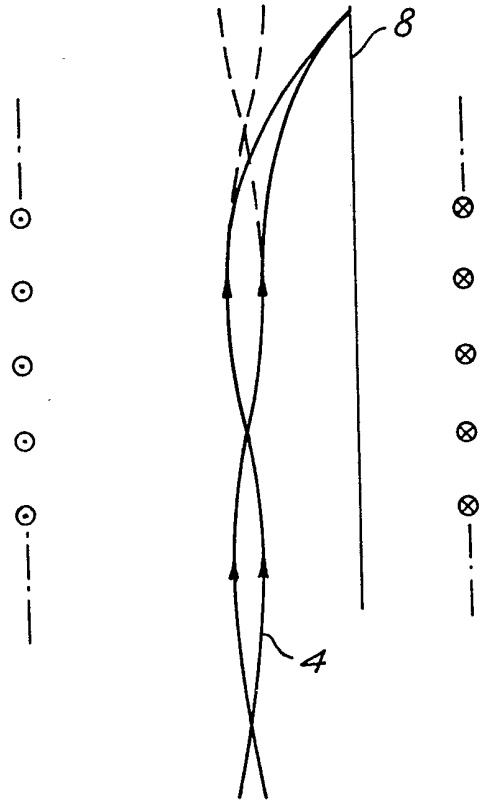

FIG. 4

SPECIFICATION

Improvements in or relating to radiography

The present invention relates to x-ray tubes and is particularly related to x-ray tubes suitable for rapid operation of radiographic apparatus known as computerised tomographic (CT) apparatus.

In British Patent No. 1283915 there is described such apparatus. To achieve an examination, one or more beams of radiation are directed into the body of a patient and the intensity of radiation transmitted through the body is measured by suitable detectors. The proportion absorbed by each beam is then determined and can be processed to provide a distribution of absorption coefficients for an examined slice of the body. The processing may be as described in the said Patent or further developments of the technique, such as that described in British Patent No. 1471531. To allow suitably accurate processing, beams of radiation should be directed through the body from many different directions. It has been the practice to achieve this by scanning a radiation source around the body.

It has also been proposed to achieve at least part of the scan by scanning an electron beam over a fixed x-ray target so that the origin of the x-rays is moved in relation to the target and therefore in relation to the body being examined. By this means the entire examination may be completed in a much reduced time. This technique may be extended to achieve a complete examination by extending the x-ray target on an arc extending for at least 180° around the patient. Thus a fan of x-rays originating at the target may be directed through the patient's body from positions disposed over at least 180° and the transmitted intensity measured by suitable detectors. X-ray tubes including such a target have been proposed in conical form with the electron gun disposed on the cone axis and suitable deflection provided to direct the electron beam to the target and to scan the beam along the target.

Such tubes suffer from several practical problems. For example the tube is cumbersome and the cone structure almost completely encloses the patient, which is psychologically undesirable. It would be more suitable to construct the equipment in the form of a ring, as moving x-ray tube CT machines have been constructed. However it has proved difficult to achieve a scanned anode arrangement in ring form.

It is an object of this invention to provide a ring anode x-ray tube of more practical form.

According to the invention there is provided an x-ray tube including a substantially circular or part circular x-ray target means for providing an electron beam constrained to a circular path about the same axis as an adjacent said target and means for deflecting electrons from said circular path to be incident on said target at predetermined positions.

In order that the invention may be clearly understood and readily carried into effect it will now be described by way of example with reference to the accompanying drawings, of which:-

Figure 1a and *1b* are respectively front- and side-elevational cross-sections of a tube in accordance with this invention,

Figure 2 is used to explain the relevant considerations for deflection of the electron beam,

Figure 3 shows how the deflection is controlled and

Figure 4 is used to explain the use of refocussing of the electron beam.

In this invention it is proposed to constrain an electron beam to move in a substantially circular ring path around the patient and to deflect it out of this path onto an adjacent ring anode so that, in effect, the beam is caused to scan one face of the ring anode.

Figure 1a and 1b are respectively side-elevational and end-elevational cross-sections of the tube. The tube envelope 1 is substantially a torus, of a suitable material such as non-magnetic stainless steel, with a tangential section 2 having an electron gun 3. The gun 3 is of conventional design and provides an electron beam 4. The tube in practice is associated with suitable arrangements (not shown) to place the body of a patient 5 axially thereof. Also provided are two circular electrodes 6 and 7 for controlling the electron beam. Suitable potentials are placed on these electrodes, relative to the electron gun cathode, by means not shown to cause the beam, after entry into the ring portion of the tube, to follow a circular path as shown. Electrodes (not shown) are also provided for introducing the beam from the straight path into the circular region. Suitable techniques are known, for example for extracting particle beams from circular paths in synchrotrons and the like.

At substantially the radius of the electron beam and displaced axially therefrom is an x-ray anode/target 8 also of ring form. The target is made of appropriate material for emitting x-radiation. A ring of electrodes 9 disposed on the other side of the electron beam 4 from target 8 is effective, with suitable potentials thereon, to deflect the beam axially of the tube to be incident on the target 8. For clarity target 8 and electrode 9 are not shown in Figure 1a.

When the electron beam is incident on the target 8, x-rays 10 are emitted therefrom. These leave the x-ray tube by a window 11 and are constrained by collimators 12 and 13 into a planar fan shaped spread, to be incident on detectors 14. This is substantially the same as the arrangement known for conical x-ray tubes and will not be further described herein. The subsequent processing of the x-ray data is substantially as described in the said British Patents.

In operation gun 3 provides the beam 4 which is constrained into its circular path by the potentials on electrodes 6 and 7. If the circular path is completed the electrons may be allowed to enter a second circuit but in this example are collected by an electrode 15.

It has been found that two electrodes such as 6 and 7 are capable of maintaining a well defined electron beam on a circular path. In a practical embodiment, in which electrode 6 is at 0.40 metres radius and at a potential of 150kv relative to the electron gun cathode, an electrode 7 at 0.45 metres radius should be at 118kv relative to the cathode to give a suitable path. These values may be varied by those with the appropriate skill to suit a particular arrangement.

The potentials on electrodes 9 are adjusted so that the beam is incident in a predetermined sequence on a large number of different regions on anode/target 8 so that x-rays are emitted from those regions. The regions of incidence can be arranged to be successive adjacent regions by a deflecting potential passing around the ring of electrodes 9. However there are advantages in arranging that successively radiating parts of target 8 are not adjacent and the sequence of deflection may be more complex if that is desired.

In the typical tube referred to hereinbefore, the anode/target may be at a potential of 140kv relative to the electron gun cathode. The relevant considerations for deflection of the electron beam onto the target will be considered in relation to Figure 2. In this Figure it is assumed that the short section of the tube shown is linear, whereas it is curved in a plane perpendicular to the drawing. This does not, however, affect the relevant considerations to a significant extent. There are shown the target 8, at potential V_A, and one electrode 9, at potential V_D. The system will be considered in terms of a y axis parallel to the target and electrode and an x axis perpendicular thereto. The electrode-target separation is a distance s. It is assumed that the electron beam enters this region in the x direction at a point $x = x_o$ and $y = o$ with a velocity v in a direction parallel to the y axis and potential V_o. It is desired that the beam is incident on the target at a point P after travelling a distance Y.

Assuming the y component of velocity is unchanged until impact, then impact occurs after a time t where

$$Y = vt \qquad 1.$$

and

$$\tfrac{1}{2}mv^2 = e\,V_o \qquad 2.$$

where m and $-e$ are the mass of and charge on an electron.

For acceleration a in the x direction

$$a = \frac{e\ (V_A - V_D)}{m\quad s} \qquad 3.$$

and

$$t = [2(S - x_o)/a]^{\frac{1}{2}} \qquad 4.$$

Now

$$V_o = V_D + \frac{x_o}{s}(V_A - V_D) \qquad 5.$$

so that

$$Y = 2\left[\frac{V_D S + xo}{(V_A - V_D)}\right]^{\frac{1}{2}}(S - x_o)^{\frac{1}{2}} \qquad 6.$$

To simplify equation 6 it is convenient to put

$$V_A/V_D = r, x_o = \alpha S \text{ and } Y/S = \varrho$$

giving

$$r - 1 = \frac{4(1 - \alpha)}{\varrho^2 - 4\alpha(1 - \alpha)} \qquad 7.$$

It can be seen that appropriate adjustment of potential V_D for the one electrode 9 will give different points of incidence in the region influenced by that electrode. Thus if $\alpha = \frac{1}{4}$ and $V_A = 140$kv, Y can be set at 2S, 3S, 4S and 5S by setting V_D at 73kV, 103kV, 117kV and 125kV respectively.

A possible arrangement is shown in Figure 3. There are shown eight of a larger number of electrodes 9, each connected by a respective switch 16 to on the one hand a source 17 of the target potential V_A and on the other hand a switch 18. Switches 16 and 18 are controlled by a control unit 19 and may conveniently be electronic switches. Switch 18 connects to one of a plurality of generators 20 of different potentials $V_{D1} - V_{DN}$ for different deflection distances.

In operation all but one electrode 9 are connected to the potential V_A and that electrode is connected to one potential V_D. The scanning sequence for the electron-target incidence is determined in advance to suit the geometry and examination requirements so that control 19 is merely required to control switches 16 and 18 in a predetermined sequence.

It will be appreciated that the electron beam travels over a long distance, between electron gun and target, compared with conventional x-ray tubes. In these circumstances space charge dispersion may occur and to overcome this it may be desirable to arrange for periodic refocussing as shown in Figure 4. This may be provided by suitable means, such as coils 21. As a further refinement the focussing may be dynamically

adjusted prior to deflection, also as shown in Figure 4, to ensure that the beam is always in focus as incident on anode target 8.

It in certain circumstances may be necessary, for avoiding deflection problems, to arrange that no magnetic focussing operates near the region of electrostatic deflection. The currents in the coils should be in sections and adjusted to give focus on the anode while the current, in that section near the region of incidence on the anode, is zero.

In another example the electron beam may be at greater radius than and in the same plane as a transmission target and be deflected radially to be incident thereon. In that case it is desirable to ensure that the electron beam is incident perpendicularly on the target and with sufficient energy to give sufficient transmitted radiation. A suitable energy may be 300KeV.

The anode, for either the transmitted or reflected examples, may be shaped appropriately to attenuate side lobes of the radiation.

Other variations of the arrangement of this invention may readily be devised by those with the appropriate skills, for example the target 8 need not extend over 360° but should be over at least 180°.

CLAIMS

1. An x-ray tube including a substantially circular or part circular x-ray target, means for providing an electron beam constrained to a circular path about the same axis as and adjacent said target and means for deflecting electrons from said circular path to be incident on said target at predetermined positions.

2. An x-ray tube according to claim 1 in which the target extends over at least 180°.

3. An x-ray tube according to claim 2 in which the target extends over 360°.

4. A x-ray tube according to any preceding claim in which the circular path lies in a plane parallel to said target.

5. An x-ray tube according to any of claims 1 to 4 in which the circular path lies in the same plane as said target and at a larger radius and in which the target is a transmission target.

6. An x-ray tube according to any preceding claim in which the means for deflecting is arranged to cause the electrons to be incident on a sequence of adjacent said predetermined positions.

7. An x-ray tube according to any of claims 1 - 5 in which the means for deflecting is arranged to cause the electrons to be incident on a sequence of said predetermined positions of which some successively irradiated positions are not adjacent.

8. An x-ray tube according to any preceding claim including means for periodically refocussing said beam during travel around said circular path.

9. An x-ray tube according to claim 8 including electrostatic means for deflecting the beam on to the target and magnetic means for focussing the beam, arranged so that magnetic focussing is not applied to the beam in a region in which it is being subject to electrostatic deflection on the target.

10. An x-ray tube according to any preceding claim in which means are provided to dynamically adjust the beam focus prior to deflection to be incident on the target at a focus.

11. An x-tube according to any preceding claim arranged to provide a substantially planar fan-shaped distribution of radiation.

12. An x-ray tube substantially as herein described with reference to the drawings filed with the specification.

13. A computerised tomographic radiographic apparatus including an x-ray tube according to any of the preceding claims.

14. A computerised tomographic radiographic apparatus including: an x-ray tube having a substantially circular or part circular x-ray target, means for providing an electron beam constrained to a circular path about the same axis as and adjacent said target and means for deflecting electrons from said circular path to be incident on said target at predetermined positions; means for positioning a patient within the circular path on which at least part of the target lies; and detector means for receiving the radiation after passage through the patient and providing output signals indicative of its intensity.

15. An apparatus according to claim 14 in which the detector means lies on a further circular path on the same axis as and in a parallel plane to said target.

16. An apparatus according to claim 15 in which the detector means comprises a plurality of detector devices.

Printed for Her Majesty's Stationery Office, by Croydon Printing Company Limited, Croydon Surrey, 1980.
Published by the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.