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(56) Documents cited
**GB 1351689**
**GB 1084015**
**GB 1043397**
**GB 749567**
**GB 734425**
**GB 461334**
**GB 458401**
**GB 401727**
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(54) **X-ray tubes**

(57) For CT examination it a conical X-ray tube (half-, full or intermediate cone) having an anode in the form of a ring extending at least halfway around the body of the patient is used, the space charge dispersion being reduced by maintaining the pressure in the drift region higher than in the evacuated gun region. The arrangement is applied to tubes with long drift regions. The beam which is preferably ribbon shaped and may be formed by a stigmator with the lens/deflection coil system, may be rotated by a coil system (Fig 4 not shown) or by a rotating electron gun and may be continuously or step scanned. A gun is described (w.r.t. Fig 3 not shown). The pressure of for example nitrogen or inert gas may be maintained by a needle valve servo controlled by a pressure transducer. Dimensions and pressures are specified, oil enclosure 17 surrounds the gun, and the cone sides need not be straight.

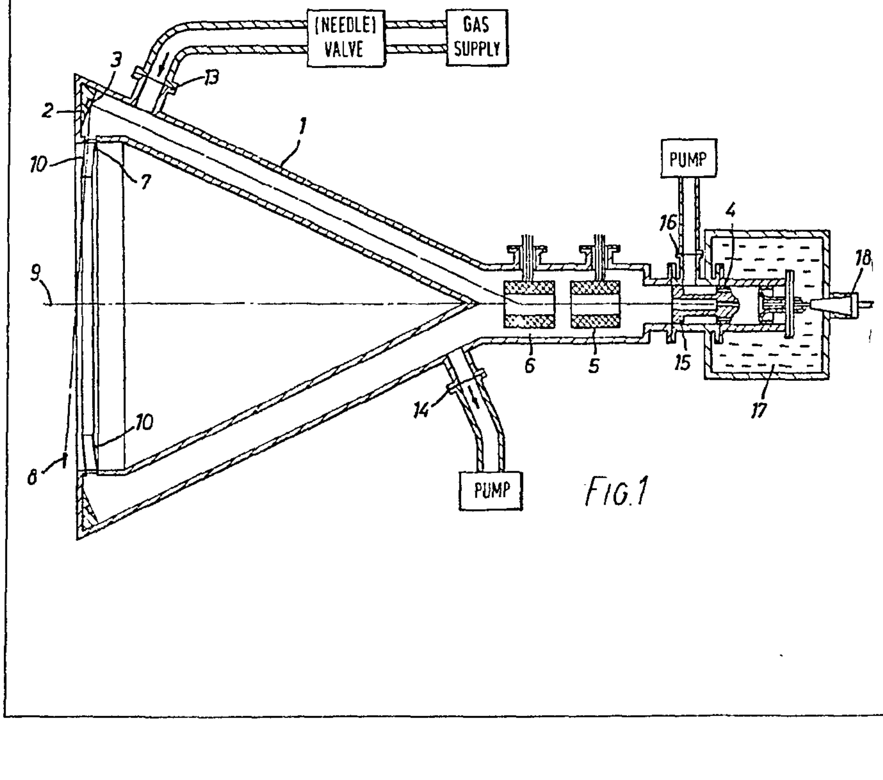

FIG.1

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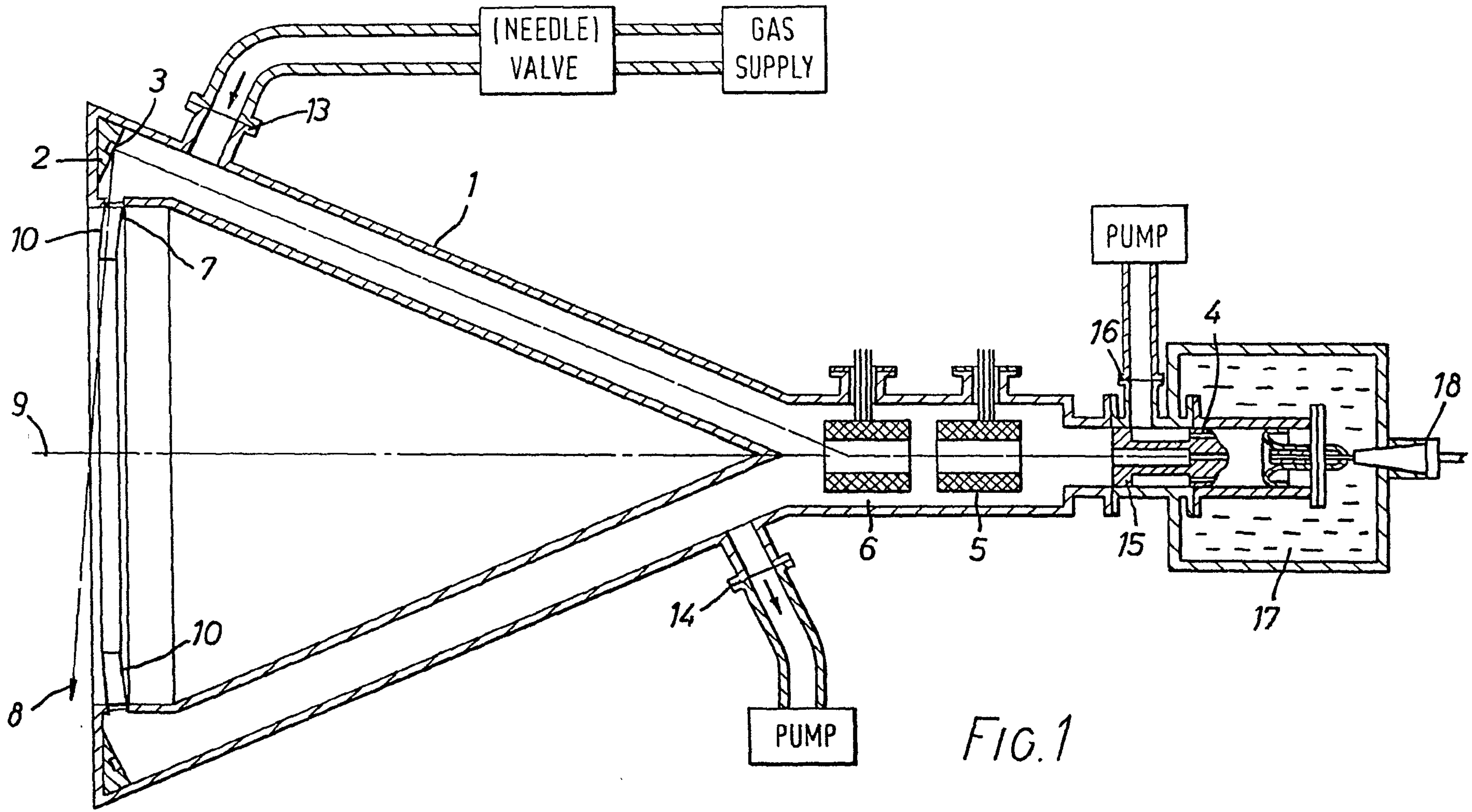
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FIG.1

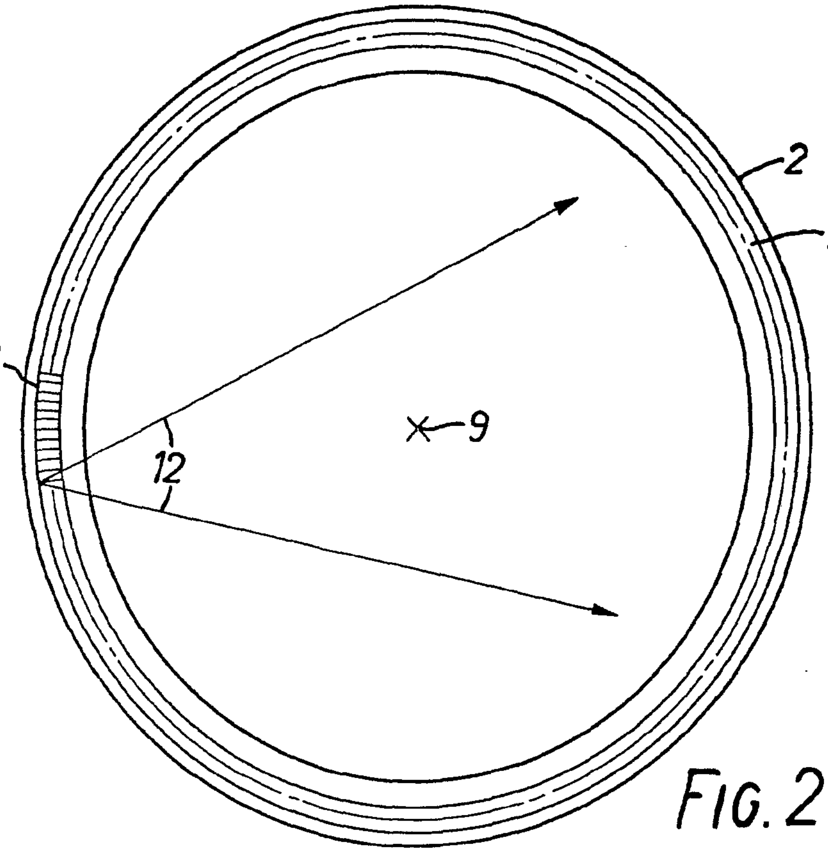


FIG. 2

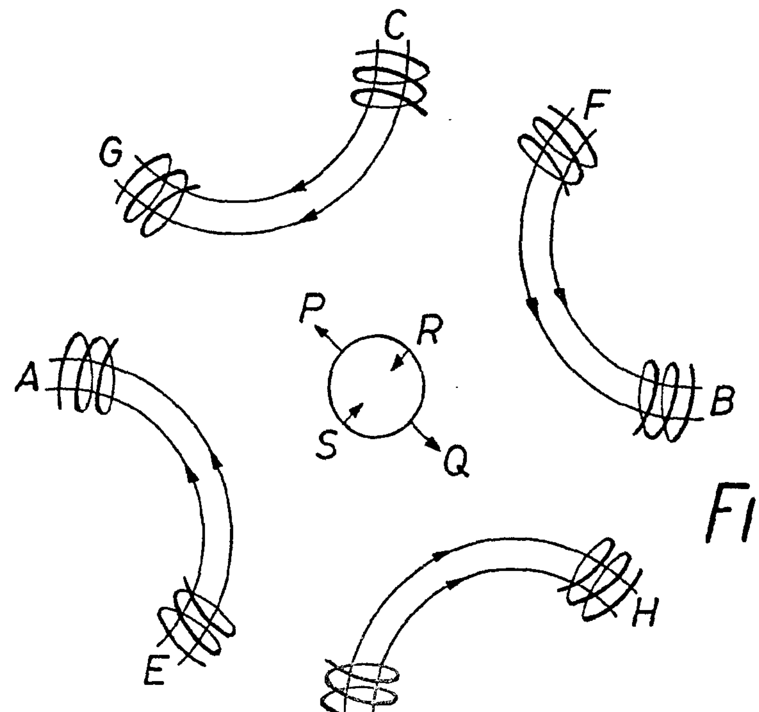


FIG. 4

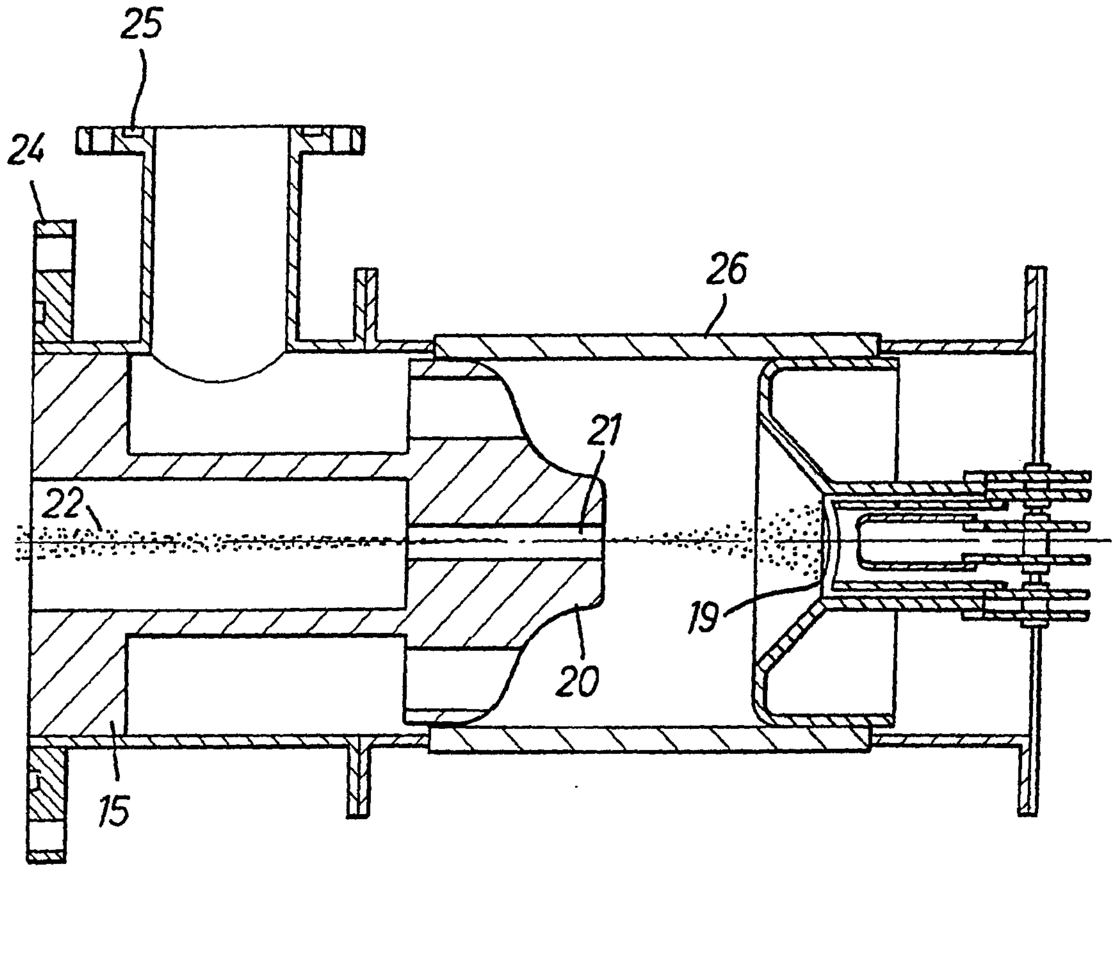


FIG. 3

SPECIFICATION

## X-ray tubes

The present invention relates to x-ray tubes in which there is a relatively long distance between an electron gun, producing an electron beam, and a target on which the beam is incident to provide x-rays. The invention is particularly, although not exclusively, applicable to x-ray tubes of this kind for use in radiographic apparatus known as computerised tomographic (CT) apparatus.

In British Patent Specification 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 Specification No. 1471531. To allow suitably accurate processing, beams of radiation must be directed through the body from a large number of directions and it has been the practice to scan 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 may be conical with the electron gun disposed on the cone axis and suitable deflection used to direct the electron beam to the target and to scan the beam along the target. Apparatus using such systems includes that disclosed by T. A. Linuma et al in a paper in the Journal of Computer Assisted Tomography (Computer Tomography) 1,4 1977, pp. 494–499.

The technique is straightforward in theory but more difficult in practice and problems include that in examining a human patient, who must be introduced into the apparatus so that any region of interest can be irradiated, the electron beam, from gun to target, will extend typically for several feet. Furthermore it must be brought to a suitable 'focus' (i.e. small incident spot or line) at the target and must not diverge sufficiently to strike the walls of a reasonably dimensioned tube envelope.

These requirements are difficult to satisfy and it is an object of this invention to provide a form of x-ray tubes giving satisfactory 'focussing' of such long electron beams.

According to the invention there is provided an x-ray tube including an electron gun for producing an electron beam, a target for generating x-rays in response to the electron beam incident thereon, an elongated drift tube region at least 1.5m long through which the beam is propagated to be incident on the target and means for neutralising, at least in part, a space charge in the beam to reduce dispersion thereof during said propagation.

According to a further aspect of the invention there is provided an x-ray tube including a conical vacuum chamber, an electron gun at the apex of the conical chamber to project an electron beam into the chamber, an annular or part annular x-ray target at the opposite end of the conical chamber, on which the beam is incident to produce x-rays and means for neutralising, at least in part, space charge in the beam to reduce dispersion thereof during progagation of the beam from the electron gun to the target.

According to another further aspect of the invention there is provided a method of reducing dispersion of an electron beam travelling over a path of at least 1.5m length between the electron gun and x-ray target of an x-ray tube, the method comprising neutralising, at least in part, space charge in the beam.

In order that the invention may be clearly understood and readily carried into effect an example thereof will now be described with reference to the accompanying drawings, of which:–

*Figure 1* shows a conical x-ray tube incorporating the invention,

*Figure 2* is illustrative of the operation of the tube for x-ray examination of a patient,

*Figure 3* shows an electron gun suitable for use with the tube of Figure 1, and

*Figure 4* illustrates the operation of a double stigmator to provide the effect shown in Figure 2.

Vacuum electron guns used in conventional x-ray tubes provide electron beams having high current densities. At these current densities space charge dispersion of the beam is significant but in general the distance to the target is only of the order of a few centimetres and dispersion is not a problem. However for gun-to-target distances of at least 1.5m as required for the scanning tubes discussed hereinbefore, dispersion can become a severe problem so that satisfactory focussing is difficult. Furthermore it is not desirable to reduce current densities if a satisfactory x-ray output is to be obtained.

It is proposed that the dispersion be reduced by partly or wholly neutralising the space charge and the neutralisation be achieved by operating the beam in a partial vacuum to produce positive ions.

If an electron gun projects a converging electron beam into a region of a partial vacuum, through an aperture in the gun anode, then ions are produced by electron collisions with the gas atoms. These ions oscillate within the electron beam to form a cluster of ions along the beam axis. As a result of the anode-cathode field there is a drainage of ions through the aperture to the cathode. This loss decreases with distance from the aperture to the target or other collector until a maximum ion density is achieved. If a sufficiently large number of ions is achieved then complete charge neutralisation can there be achieved. Electrons entering this region will, neglecting collisions, have substantially linear paths. It is found in practice that there is a critical pressure at which paths parallel to the beam axis are achieved.

In one practical arrangement 1 amp electron beams at 140 k volts can be focussed without substantial space charge dispersion over relatively long distances (at least several feet) by transmitting them in a partial vacuum of $10^{-3} - 10^{-5}$ torr (mm Hg). At such pressures the portion of electrons scattered from the beam by collisions is less than 1%.

For optimum operation it is important to control the gas pressure. This can be achieved with a continuously pumped system with adjustable gas flow in a manner well known for other partial vacuum systems.

At such pressures thermionic cathodes suffer poisoning. It is therefore necessary to operate the electron gun in vacuum and to extract the beam through a small aperture. Because of this it is not proposed to use a single electrostatically focussed gun of long focal length. Instead a cross-over is formed in the aperture and an image of the cross-over is projected on the x-ray target by a magnetic lens.

Systems, in which the electron gun and the operating part of the tube are at different pressures, require differential pumping. However such systems have been proposed for other purposes and the arrangements described, for example in British Patent No. 1,448,298 and British Patent No. 749567, can be adapted for this purpose.

The essential parts of a suitable x-ray tube, for the invention, are shown in Figure 1.

A conical vacuum chamber 1 comprises a metal envelope, for example mild steel, which is maintained at earth potential. An annular anode 2 has inset thereon an annular target surface 3 to generate x-rays in response to incident electrons. The envelope is typically 1.5m from the cone apex to the target 3.

An electron gun 4 generates a beam of electrons which is focussed by a magnetic lens 5 and propagates through the conical drift tube formed by the conical vacuum chamber to be incident on target 3. Deflection coils 6 are provided so that the point or line of incidence of the electrons can be scanned along the annular target to follow a circular path. Lens 5 and coils 6 may be disposed around the neck of the conical tube but because the vacuum is relatively poor for other reasons it is possible to place them inside as illustrated. This arrangement is preferred to reduce power requirements.

The tube includes, on the inside surface of the cone, an annular x-ray window 7. X-rays generated by the incident electrons are then directed along paths, such as 8, substantially perpendicular to the axis 9 of the cone. Preferably these are defined by collimators such as 10. The radiation will normally be in the form of a fan in a plane perpendicular to the drawing, the arrangement being substantially as described in the aforesaid paper by Linuma et al. Further details including x-ray detectors are not shown in Figure 1, since they do not form part of this invention, but as the point of impact of the electrons, on the target, orbits about axis 9, the x-ray fan correspondingly orbits to properly examine a patient disposed substantially axial of the cone.

The electrons and their point of origin may be orbited continuously around the cone. However it is proposed to use a stepped scan providing in effect as may as 500 to 2000 individual x-ray sources, on the target annulus, in succession in a scan time of 0.01 to 0.1 seconds.

Figure 2 shows the anode 2 and target 3 as viewed from the deflection coils 6. There are shown at 11 twelve out of the total of 500 x-ray source points. These are shown at slightly exaggerated spacing and the remaining points are indicated by the chain dotted circle. Each x-ray source is in fact a line disposed radially. To produce such a line source a ribbon-shaped electron beam is required and that will be discussed further hereinafter.

Each line source produces a fan of x-rays such as the one indicated at 12. In operation the sources are energised in sequence so that the fan of radiation is effectively rotated about axis 9.

It should be understood that for proper CT examination the patient's body need not be irradiated from points disposed over 360° and in general 180° will suffice. For such purposes a half ring target will be satisfactory and tube 1 may be a half cone or intermediate. Furthermore the cone need not be straight sided as shown but could be 'wine-glass' shaped or other shapes provided means are provided to deflect the beam along the shaped paths required. In this specification a conical tube is intended to include such incomplete conical shapes particularly including half of a full cone bisected along a diameter.

Referring to Figure 1, the cone section of the tube is filled with gas, such as nitrogen or an inert gas, introduced at a port 13 from a gas supply via a valve. A further port 14 is provided to evacuate the tube prior to use, for reduction of contaminants, but this is closed in use. As mentioned herebefore, the electron gun 4 should be operated in a vacuum and so it is separated from the main tube by a diaphragm 15, having an aperture through which the electron beam can pass. Beyond the aperture the gun is continuously pumped by a port 16 to remove gas entering by the aperture. To make up pressure which would be reduced by this loss of gas, a continuous input is maintained at port 13; the balance being maintained by a known gas pressure regulating system such a needle valve servo controlled by a pressure transducer (not shown). The entire gun 4 is surrounded by an oil filled enclosure 17 through which the tube high voltage supplies are fed at 18.

It is convenient to provide the electron gun 4 as a detachable component which is attached to the tube envelope by suitable vacuum joints such as demountable flanges with gaskets or '0'-rings

A suitable gun design is shown in Figure 3. Electrons are generated by an indirectly heated cathode

19, which is at -140kV with respect to earth. They are accelerated towards a gun anode structure 20 which is at earth potential, and which includes aperture 21, to provide electron beam 22. The unit includes flanges 24 and 25, by which the gun is fixed to the tube envelope and pumping system respectively, and includes ceramic insulating sections 26 by which the potentials may be maintained. It has been mentioned that the beam is preferably although not necessarily ribbon shaped to provide a line focus and with a gun such as that of Figure 3 this would be achieved by including a beam shaper, such as a known stigmator, associated with the lens/deflection coil system. Of course other gun arrangements can be used and those could include a gun which itself produces a ribbon beam.

As shown in Figure 2, the beam must be rotated as it is orbited so that the ribbon, and hence the line focus on target 3, is maintained radial to axis 9. For a gun which produces a ribbon beam this may be achieved by rotating the gun on suitable rotary seals. For a gun such as that of Figure 3 separate means should be provided to rotate the ribbon beam or produce a rotating beam. The problem is analogous to that discussed in British Patent Application No. 29182/75 to correctly align a ribbon beam on a linear or substantially linear target/anode and the solution may be achieved by similar coil systems.

A suitable coil system, known as a double stigmator, is illustrated in diagrammatic form in Figure 4. That arrangement does not form a part of this invention although it may benefically be used with the invention. Two sets of coils are disposed so that coils A, B, C, D are at 45° to coils E, F, G, H. It will be understood that coils AB and EF would be sufficient to achieve the desired fields, CD and GH being desirable but not necessary.

Coils A, B, C, D are substantially the same as a known single stigmator and, if opposing coils are energised with currents in opposite directions a circular electron beam 22 passing through the system would become divergent in plane PQ and convergent in orthogonal plane RS to provide a ribbon beam. In the double stigmator shown coils E, F, G, H are also energised with the currents in A, E opposite to those in E, F and so on as shown. They are also energised with alternating current so that the currents in A, B, C, D are 90° out of phase with E, F, G, H. The result in that, as the coils change phase, the field, pattern changes and planes PQ and RS rotate at half the frequency of the coil currents Thus the ribbon beam formed rotates at a frequency set by the coil current frequency. This merely needs to be synchronised with the scanning coil frequency to provide the result shown in Figure 2. It will be understood that it would be convenient to combine the double stigmator with the scanning coils but that is not necessary.

Although specific arrangements of electron gun and quadrupole beam shaping devices have been described for a practical system, it will be appeciated that the invention is not limited to those shown. Other variations may be devised for producing and scanning a suitable electron beam which is maintained in focus over a long distance by propagation in partial vacuum in the manner of this invention.

CLAIMS

1. An x-ray tube including a conical vacuum chamber, an electron gun at the apex of the conical chamber to project an electron beam into the chamber, an annular or part annular x-ray target at the opposite end of the conical chamber, on which the beam is incident to produce x-rays and means for neutralising, at least in part space charge in the beam to reduce dispersion thereof during propagation of the beam from the electron gun to the target.

2. An x-ray tube according to Claim 1 including a conical vacuum chamber, said electron gun being at the apex of the chamber to direct the electron beam into the chamber and said x-ray target being of annular or part annular form at the opposite end of the chamber so that the drift tube region is of conical shape and means being also provided to deflect said beam to propagate through different parts of the drift tube region and be incident on different regions of said target.

3. An x-ray tube according to either of claims 1 and 2 in which the means for neutralising the space charge comprises means for providing a partial vacuum in the drift tube region.

4. An x-ray tube according to Claim 3 in which the partial vacuum is in the range $10^{-3}$ to $10^{-5}$ torr.

5. An x-ray tube according to either of Claims 3 and 4 in which the means for providing a partial vacuum comprises means for maintaining pressure in the drift tube region higher than the operating pressure in the electron gun.

6. An x-ray tube according to Claim 5 in which the means for maintaining pressure comprises means for introducing gas at regulated pressure to the drift tube region and means for removing from the electron gun gas leaking into it.

7. An x-ray tube according to Claim 6 in which the gas is an inert gas.

8. An x-ray tube according to Claim 6 in which the gas is nitrogen.

9. An x-ray according to any preceding claim in which the electron gun is arranged to provide a beam of electrons having a cross-over in the aperture by which the beam passes from the gun to the drift tube region and means are provided to focus the beam to produce an image of the cross-over at the target.

10. An x-ray tube according to Claim 9 in which the said means for focussing is a magnetic lens.

11. An x-ray tube including a conical vacuum chamber, an electron gun at the apex of the conical chamber to project an electron beam into the chamber, an annular or part annular x-ray target at the opposite end of the conical chamber, on which the beam is incident to produce x-rays and means for neutralising, at least in part space charge in the beam to reduce dispersion thereof during propagation of the beam from the electron gun to the

target.

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

13. A method of reducing dispersion of an electron beam travelling over a path of at least 1.5m length between the electron gun and x-ray target of an x-ray tube, the method comprising neutralising, at least in part, space charge in the beam.

14. A method according to Claim 13 in which the neutralisation is provided by position ions provided by propagating the beam in a partial vacuum.

15. A method according to Claim 14 in which the beam is propagated in gas at a pressure in the range of $10^{-3}$ to $10^{-5}$ torr.

16. A method, of reducing dispersion of an electron beam travelling over a path of at least 1.5m length between the electron gun and x-ray target of an x-ray tube, the method being substantially as herein described with reference to the accompanying drawings.

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