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(54) X-RAY TUBE FOR FAST KILOVOLT-PEAK SWITCHING

(57) The present invention relates to a hybrid anode structure (100) for fast-kilovolt-peak switching for dual energy CT, the hybrid anode structure comprising: an auxiliary anode (10), which comprises a first target area (12), which is configured to receive a first portion (42) of an electron beam; a main anode (20), which comprises a second target area (22), which is configured to receive a second portion (44) of the electron beam and to convert the second portion of the electron beam into X-rays (50); and a deflector (30), which is configured to deflect an incident electron beam (40) and to spread the incident electron beam (40) between the first target area (12) of the auxiliary anode (10) and the second target (22) area of the main anode (20).

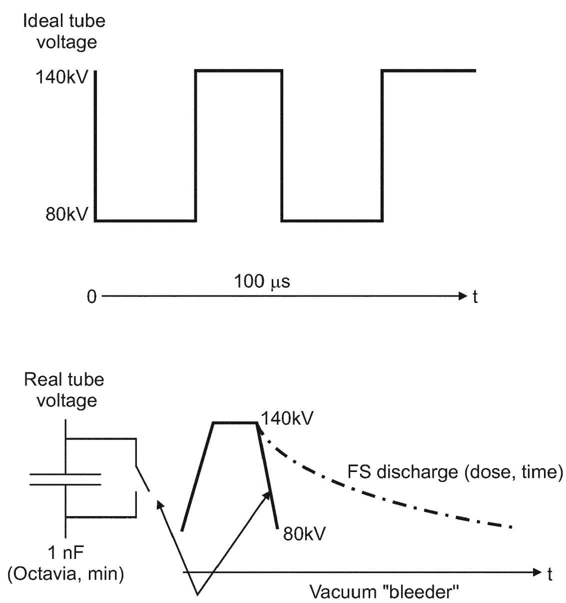


Fig. 1

EP 3 648 136 A1

Description

FIELD OF THE INVENTION

[0001] The invention relates to an X-ray tube with a hybrid anode structure.

BACKGROUND OF THE INVENTION

[0002] Spectral imaging seems to become mainstream in X-ray computed tomography. Fast-kilovolt-peak, abbreviated kVp, switching is the easiest route for implementing spectral capabilities to the mid-range segment based on a voltage switching between energy levels and acquiring imaging data at more than one energy range. The drawback of the simplest implementations is that not all needed features are readily implemented in such an X-ray system.

[0003] The main problem with a fast-kilovolt-peak implementation is that is very difficult to implement a fast dose modulation which is necessary for low dose scans. It is also difficult to use very low current protocols as this increases the time to discharge the high voltage capacitor and allows only for slow change in voltage.

[0004] US 2012/0326031 A1 describes a medical imaging method comprising generating a radiation at a first energy level by a radiation source, generating a radiation at a second energy level different from the first energy level by the radiation source, emitting the generated radiations at an output of the radiation source towards a detector, and blocking or diverting the emitted radiations during at least one intermediate phase during which the radiation source switches in a transient way from one of the first energy level and the second energy level to the other of the first energy level and the second energy level. US 2005/0163281 A1 describes an X-ray tube which includes a device for substantially protecting an object to be examined against the incidence of undesirable X-rays which can be produced notably by the decay of a residual or surplus charge present in a high-voltage circuit after an X-ray exposure. To this end there is provided at least one for deflecting and/or defocusing the electron beam produced by the residual and/or surplus charge in such a manner that at least it is not incident to a significant extent on a region of an anode wherefrom X-rays excited thereby are directed towards an object to be examined. US 2010/0172475 A1 describes a fast dose modulation method using a z-deflection in a rotating anode or a rotating frame tube, where the electron beam is deflected from a first focal spot region to a second focal spot region being formed on the anode, wherein only the electromagnetic beam generated in the first focal spot region contributes to the useful electromagnetic exposure beam, wherein the second focal spot region is designed to avoid emission of electromagnetic beams into the direction of a useful electromagnetic beam direction.

[0005] Sending X-rays of different spectra allows imaging the patient with spectral material decomposition. This technique has proven to yield better diagnostics, and save toxic contrast die.

[0006] Switching the tube high voltage as provided by fast-kilovolt-peak implementation is challenging, however. Smoothening capacitance in the generator and cables have to be charged and discharged at a fast pace.

[0007] Charging up, for example from 80 kV to 140 kV is merely a matter of generator power. In contrast, discharging from 140 kV down to 80 kV is a challenge unless extra expensive means like additional switchable resistors are used. The discharge current is then the tube current through the X-ray tube. This provides a lower limit to the time for ramp-down.

[0008] Higher tube current usually produces higher X-ray flux to the patient. This is mostly unwanted. Instead, the X-ray flux in the used beam should be rather independent of the higher tube current.

SUMMARY OF THE INVENTION

[0009] There may be a need to overcome the drawbacks from existing switching or fast-kilovolt-peak implementations for X-ray tubes.

[0010] This need is met by the subject-matter of the independent claims. Further exemplary embodiments are evident from the dependent claims and the following description.

[0011] A first aspect of the invention relates a hybrid anode structure for fast kVp switching for dual energy CT, the hybrid anode structure comprising:

i) an auxiliary anode, which comprises a first target area, which is configured to receive a first portion of an electron beam;

ii) a main anode, which comprises a second target area, which is configured to receive a second portion of the electron beam and to convert the second portion of the electron beam into X-rays; and

iii) a deflector, which is configured to deflect an incident electron beam and to spread the incident electron beam between the first target area of the auxiliary anode and the second target area of the main anode.

[0012] The present invention advantageously uses an X-ray tube, wherein the current of the X-ray tube is kept at maximum and the X-ray flux is controlled by at least partially deflecting the electron beam across the anode such that the electron beam only partially hits the anode and sending the rest of the electron beam into a beam dump under the edge of the anode, which is biased such that its absolute voltage is slightly less, for instance 1 kV, than the absolute voltage of the cathode.

[0013] Based on the present invention, an X-ray tube may be provided with an auxiliary anode in terms of a fixed anode and a main, e.g. rotating anode, and a magnetic or electric field, for example by z-deflection, for directing an electron beam to either anode, or distributing the current between the first and the second anode , whereby the electron beam passes, at least partially, at the rim of the second anode, which serves as X-ray generator, and with variable and adjustable ratio also hits the first anode, which serves as an electron dump. The present invention advantageously provides a minimal waste of energy as well as a minimal leakage radiation due to low impact electron beam energy. A practical point to consider is also the effort in calibration needed. As any current setting needs its own calibration, it is desired to have only a few of them while all clinical protocols shall be feasible. A grooved anode is a solution to this problem, but it imposes a high load to the rotating anode and cooling becomes an issue.

[0014] According to an embodiment of the invention, the auxiliary anode is for instance V-shaped and is located below and at the side of the second anode. The thermal load of the second anode is substantially reduced.

[0015] According to an embodiment of the invention the auxiliary anode and the main anode are configured to have an at least partially gapless overlap between the first target area of the auxiliary anode and the second target area of the main anode within the beam path of the electron beam

[0016] According to an embodiment of the invention, the auxiliary anode is configured to be biased with an offset voltage to an auxiliary anode voltage, which is less than a main anode voltage of the main anode.

According to an embodiment of the invention, the auxiliary anode is configured to be biased with the offset voltage to the auxiliary anode voltage, which is varied between a first voltage value and a second voltage value.

[0017] According to an embodiment of the invention, the first target area of the auxiliary anode is configured to receive the first portion of the electron beam in a grazing incidence and wherein the auxiliary anode is configured to dissipate energy of the first portion of the electron beam. This advantageously provides improved heat dissipation inside the anode structure.

[0018] According to an embodiment of the invention, the first target area of the auxiliary anode is configured to receive the first portion of the electron beam in the grazing incidence by means of an inclined plane, tilted to a beam axis of the first portion of the electron beam. This advantageously provides improved heat dissipation inside the anode structure.

[0019] According to an embodiment of the invention, the first target area of the auxiliary anode is configured to receive the first portion of the electron beam in the grazing incidence by means of a groove, at least one side wall of which is tilted to an beam axis of the first portion of the electron beam. This advantageously provides improved heat dissipation inside the anode structure.

[0020] According to an embodiment of the invention, the auxiliary anode comprises a shielding portion, which is configured to prevent generated X-rays to leave the hybrid anode structure. This advantageously provides improved X-ray shielding. According to an embodiment of the invention, the shielding portion comprises carbon and/or wherein the shielding portion is configured to prevent back scattering of electrons. This advantageously provides improved X-ray shielding.

[0021] According to an embodiment of the invention, the auxiliary anode is a circular ring segment, which is optionally V-shaped, and the main anode is a rotating anode tube.

[0022] According to an embodiment of the invention, the auxiliary anode is configured to be cooled. This advantageously provides higher X-ray fluxes.

[0023] According to an embodiment of the invention, the auxiliary anode comprises molybdenum or tungsten. This advantageously provides improved X-ray tube reliability.

[0024] According to an embodiment of the invention, the deflector is configured to spread first portion of an electron beam over the first target area of the auxiliary anode and configured to increase an irradiated surface of the first target area of the auxiliary anode.

[0025] According to an embodiment of the invention, the deflector comprises a single-stage or a multistage collector and/or the deflector is configured to spread the beam by an angled structure and/or the deflector is configured to use:

a static electric field; and/or
a dynamic electric field; and/or
a magnetic field
to spread the incident electron beam between the first target area of the auxiliary anode and the second target area of the main anode.

[0026] Besides spreading the beam by the angled structure, it is also possible to use a static and or dynamic electric or magnetic field to spread the electrons over the surface to reduce power density. This is best combined with a shallow angle of the electron impact.

[0027] According to an embodiment of the invention, a first target is constructed in a shallow angle where most of the electrons get scattered off and a second electron target surface is provided at a distance with even higher surface area, essentially a "hohlraum" absorber, a black body or blackbody as an idealized physical body that absorbs all incident electromagnetic radiation.

[0028] A "hohlraum" - a non-specific German word for a "hollow space" or "cavity" - is a cavity whose walls are in radiative equilibrium with the radiant energy within the cavity.

[0029] According to an embodiment of the invention electron scattering is achieved by using a set of fine, for instance Wollaston wires, which comprise a diameter of 50 nm to 100 nm in an example, to scatter the electrons to the target surface. Such small wires can radiate the energy away without being harmed. A Wollaston wire is a very fine, for instance less than 0.01 mm thick, platinum wire clad in silver.

[0030] The density of the wires in the hohlraum is such that the almost all of the primary beam touches a small wire while the scattered electrons are likely to strike the surface of the hohlraum.

[0031] A second aspect of the invention relates an X-ray tube comprising the hybrid anode structure according to the first aspect or according to any implementation of the first aspect.

[0032] These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0033] Below, embodiments of the present invention are described in more detail with reference to the attached drawings.

FIG. 1 shows a schematic diagram of a diagram of the ideal tube voltage versus time according to an embodiment of the invention.

FIG. 2 shows a schematic diagram of a hybrid anode structure for fast fast-kilovolt-peak switching for dual energy CT according to an embodiment of the invention.

FIG. 3 shows a schematic diagram of a hybrid anode structure for fast fast-kilovolt-peak switching for dual energy CT according to an embodiment of the invention.

FIG. 4 shows a schematic diagram of a hybrid anode structure for fast fast-kilovolt-peak switching for dual energy CT according to an embodiment of the invention.

In principle, identical parts are provided with the same reference symbols in the figures.

DETAILED DESCRIPTION OF EMBODIMENTS

[0034] FIG. 1 shows a schematic diagram of a diagram of the ideal tube voltage versus time according to an embodiment of the invention.

[0035] Sending X-rays of different spectra allows imaging the patient with spectral material decomposition. This technique has proven to yield better diagnostics, and save toxic contrast die.

[0036] Switching the tube high voltage is challenging, however. Smoothening capacitance in the generator and cables have to be charged and discharged at a fast pace. Charging up, for example from 80 kV to 140 kV in times of several 10 μs or 100 μs is merely a matter of generator power. However, discharging from 140 kV down to 80 kV is a challenge unless extra expensive means like additional switchable resistors are used. The discharge current is then the tube current through the X-ray tube. This provides a lower limit to the time for ramp-down.

[0037] High tube current usually produces high X-ray flux to the patient. This is mostly unwanted. Instead, the X-ray flux in the used beam should be rather independent of the high tube current.

[0038] To have a well performing kVp switching system, it is a criterion that the current consumed by the X-ray tube, or in other words, the current over voltage, is the same at all times of the scan. This ensures that the high kVp and low kVp times as well as the transition times remain constant and therefore the average high kVp and low kVp spectra.

[0039] This is advantageously achieved, if the condition at the cathode - for instance to be defined by parameters like filament current, acceleration voltages, temperature, pressure, electric resistance, heat capacitance - are kept constant. To modulate the X-ray flux, a part of the electron beam is dumped where it cannot produce image relevant X-rays. According to an embodiment of the invention, this can be realized with a groove at the anode and a large-scale z-deflection unit, best a magnetic one.

[0040] However, as the current is always set to the highest value needed for the scan, and all energy is dumped to the rotating anode, issues with cooling arise which may impair work flow. As a further drawback, the groove impairs heat flow towards the axle of the anode and further increases heat issues. To overcome this, according to an embodiment of the invention, the fixed anode is provided below and to the side of the rotating anode, as shown in Fig. 1.

[0041] According to an embodiment of the invention, the - optionally dynamic - electric or magnetic field deflects the electron beam at least partially off the rotating anode. However, the fixed anode needs to have a special shape to cope with the high power density of the electron beam.

[0042] According to an embodiment of the invention, it is a V-shaped groove directed to the axis. According to an embodiment of the invention, the width of the V-shaped groove is more than the width of the electron beam, for example the width of the V-shaped groove more than 1 mm or more than 0.5 mm or more than 100 μm.

[0043] According to an embodiment of the invention, the length of the groove is at least the length of the electron beam i.e. about at least 1 cm or at least 5 mm or at least 1 mm. The energy absorbing surface needs to be at least 30 times of the equivalent area as provided by rotation of the rotating anode.

[0044] This is for example achieved by making the groove at least 15 mm deep or at least 20 mm deep or at least 30 mm deep. The depth of the groove of at least 15 mm is enough as due to the scattered electrons, both surfaces of the V-structure are about equally subjected to the beam power, i.e. the depth of the groove of at least 15 mm is larger than any characteristic electron scattering length of the decay of hot electron in the anode.

[0045] According to an embodiment of the invention, the V-structure is sealed at both ends with an X-ray absorbing material to prevent the generated X-rays to leave the X-ray tube. The V-structure is made of a highly heat resistant material like molybdenum or preferably tungsten.

The fixed anode has to be actively cooled and therefore should be connected to the oil system of the tube to prevent overheating. The needed length of the V-structure, for example 15 mm plus structural thickness of 20 to 25 mm, may be difficult to implement in some X-ray tube designs. In order to reduce the power density at the fixed anode, it is possible to use only one side of the V-structure to be exposed to the electron beam.

[0046] According to an embodiment of the invention, as the majority of the electrons are scattered away from the surface, the power density on this surface is rater low. The other V-structure face is retracted from this side and possibly some more grooves are added to this. This helps the electrons to spread out over a larger surface.

[0047] FIG. 2 shows a schematic diagram of a hybrid anode structure for fast fast-kilovolt-peak switching for dual energy CT according to an embodiment of the invention. According to an embodiment of the invention, maintaining the highest tube current may be applied, a current which the tube can deliver and sustain at highest tube voltage, e.g. 140 kV). This is typically done by setting the temperature of the thermionic electron emitter accordingly.

[0048] According to an embodiment of the invention, bias voltages in the cathode are adjusted as well. According to an embodiment of the invention, the maximal tube current discharges the generator capacitance in the fastest way possible.

[0049] According to an embodiment of the invention, in order to reduce the used X-ray flux, steering the electron beam across the anode such that the electron beam only partially hits the anode is performed. This portion creates the finally used X-rays, while steering the rest of the electron beam into a beam dump is conducted. According to an embodiment of the invention, the beam dump may be biased or charged in such a way the electrons hits with minimal power.

[0050] According to an embodiment of the invention, the absolute of its negative voltage should be only a little less than the absolute of the momentary cathode voltage. Electrons will be absorbed, but their impact energy will be minimal, as will be the heat generated

[0051] According to an embodiment of the invention, the beam dump is configured such that electron backscattering is minimal, for instance by using carbon-based materials, or by using a grazing impact of the electron beam towards the auxiliary anode. According to an embodiment of the invention, the beam dump in terms of the auxiliary anode is configured to be fluid-cooled.

FIG. 3 a schematic diagram of a hybrid anode structure for fast kilo-volt-peak switching for dual energy CT according to an embodiment of the invention.

[0052] According to an embodiment of the invention, the beam dump is a current source. Actively steer the bias of the beam dump by the generator. This must be done according to the predicted discharge pattern and the dumped portion of the electron beam. Re-use the energy supplied in the generator.

[0053] According to an embodiment of the invention, the beam dump may be configured to be basically float, and discharged by passive load.

[0054] According to an embodiment of the invention, the beam dump may be coupled to a resistor and/or to a capacitor and/or to an inductor to be discharged by passive load.

[0055] According to an embodiment of the invention, an electric current through the beam dump maybe used for monitoring purposes or the active tube current. For instance, an X-ray quantity of the generate X-rays may be measured by an X-ray sensor quantifying the X-ray flux or the tube voltage may be used and measured.

[0056] FIG. 4 a schematic diagram of a hybrid anode structure for fast kVp switching for dual energy CT according to an embodiment of the invention.

[0057] According to an embodiment of the invention, the X-ray tube is rotating about the patient, generating a fan beam of X-rays. Opposite to the X-ray tube and with it on a gantry rotor rotates a detector system, which converts the attenuated X-ray into electrical signals. A computer system reconstructs an image of the patients anatomy.

[0058] According to an embodiment of the invention, the X-ray tube as shown in Fig. 4 comprises a hybrid anode structure, a house, an anode support shaft and a rotor body. The rotor body may for instance comprise cooper. The X-ray tube as shown in Fig. 4 comprises an anode disc which is rotating and a fixed anode.

[0059] It has to be noted that embodiments of the invention are described with reference to different subject matters. In particular, some embodiments are described with reference to method type claims whereas other embodiments are described with reference to the device type claims.

[0060] However, a person skilled in the art will gather from the above and the following description that, unless otherwise notified, in addition to any combination of features belonging to one type of subject matter also any combination between features relating to different subject matters is considered to be disclosed with this application. However, all features can be combined providing synergetic effects that are more than the simple summation of the features.

[0061] While the invention has been illustrated and described in detail in the drawings and foregoing description, such illustration and description are to be considered illustrative or exemplary and not restrictive; the invention is not limited to the disclosed embodiments. Other variations to the disclosed embodiments can be understood and effected by those skilled in the art and practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims.

[0062] In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. A single processor or controller or other unit may fulfil the functions of several items recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. Any reference signs in the claims should not be construed as limiting the scope.

Claims

1. A hybrid anode structure (100) for fast-kilovolt-peak switching for dual energy CT, the hybrid anode structure comprising:

    - an auxiliary anode (10), which comprises a first target area (12), which is configured to receive a first portion (42) of an electron beam;
    - a main anode (20), which comprises a second target area (22), which is configured to receive a second portion (44) of the electron beam and to convert the second portion of the electron beam into X-rays (50); and
    - a deflector (30), which is configured to deflect an incident electron beam (40) and to spread the incident electron beam (40) between the first target area (12) of the auxiliary anode (10) and the second target (22) area of the main anode (20).

2. The hybrid anode structure according to claim 1, wherein the auxiliary anode (10) and the main anode (20) are configured to have an at least partially gapless overlap between the first target area (12) of the auxiliary anode (10) and the second target (22) area of the main anode (20) within the beam path of the electron beam.

3. The hybrid anode structure according to claim 1 or 2, wherein the auxiliary anode is configured to be biased with an offset voltage to an auxiliary anode voltage, which is less than a main anode voltage of the main anode (20).

4. The hybrid anode structure according to any one of the claims 1 to 3,
wherein the auxiliary anode is configured to be biased with the offset voltage to the auxiliary anode voltage, which is varied between a first voltage value and a second voltage value.

5. The hybrid anode structure according to any one of the claims 1 to 4,
wherein the first target area of the auxiliary anode is configured to receive the first portion of the electron beam in a grazing incidence and wherein the auxiliary anode is configured to dissipate energy of the first portion of the electron beam.

6. The hybrid anode structure according to claim 5, wherein the first target area of the auxiliary anode is configured to receive the first portion of the electron beam in the grazing incidence by means of an inclined plane, tilted to a beam axis of the first portion of the electron beam.

7. The hybrid anode structure according to claim 6, wherein the first target area of the auxiliary anode is configured to receive the first portion of the electron beam in the grazing incidence by means of a groove, at least one side wall of which is tilted to a beam axis of the first portion of the electron beam.

8. The hybrid anode structure according to any one of the claims 1 to 7,
wherein the auxiliary anode comprises a shielding portion, which is configured to prevent generated X-rays to leave the hybrid anode structure.

9. The hybrid anode structure according to claim 8, wherein the shielding portion comprises carbon and/or wherein the shielding portion is configured to prevent back scattering of electrons.

10. The hybrid anode structure according to any one of the claims 1 to 9,
wherein the auxiliary anode (10) is a circular ring segment, which is optionally V-shaped, and the main anode (20) is a rotating anode tube.

11. The hybrid anode structure according to any one of the claims 1 to 10,
wherein the auxiliary anode (10) is configured to be cooled.

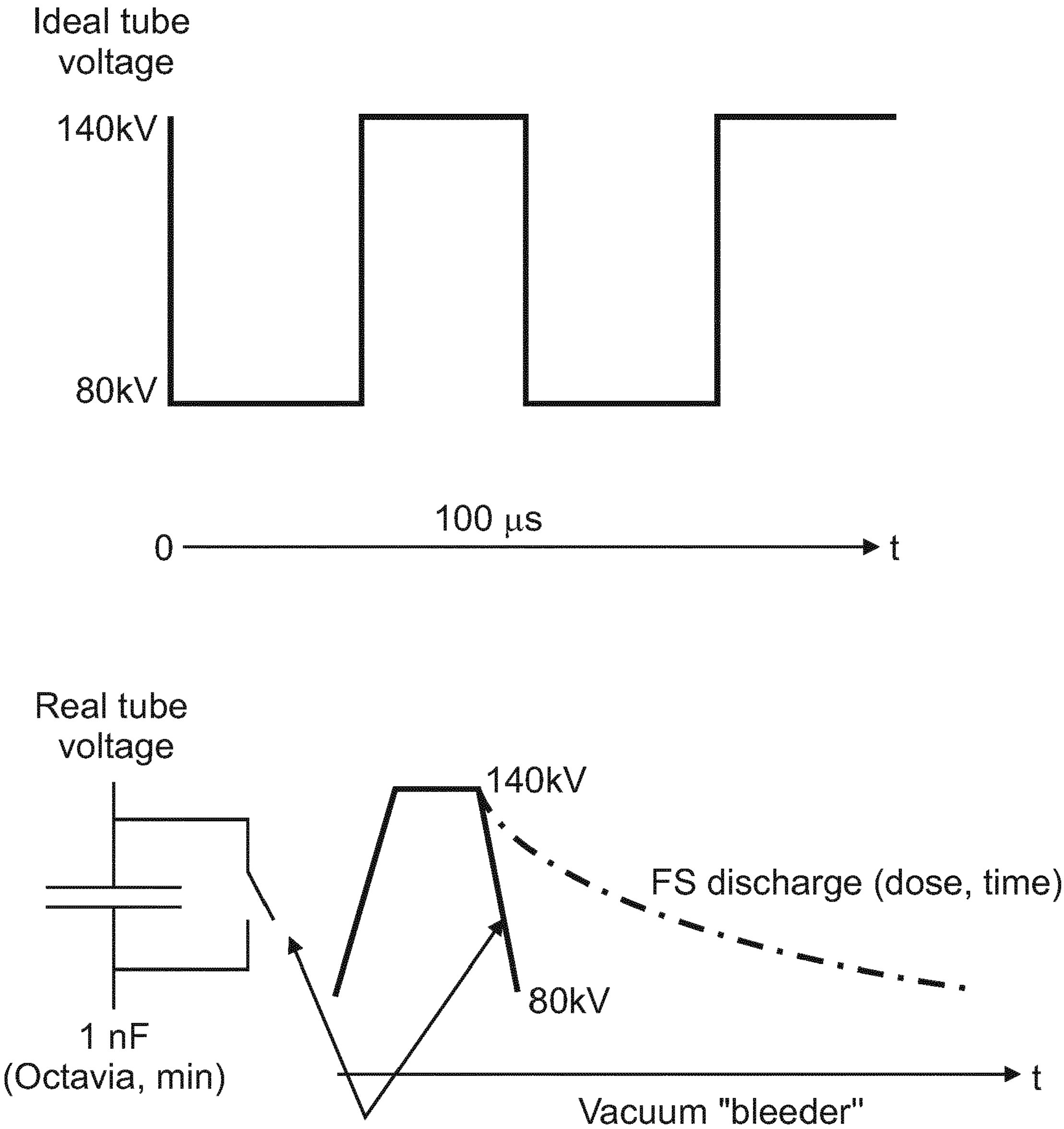
12. The hybrid anode structure according to any one of the claims 1 to 11,
wherein the auxiliary anode (10) comprises molybdenum or tungsten.

13. The hybrid anode structure according to any one of the claims 1 to 12,
wherein the deflector (30) is configured to spread first portion of an electron beam over the first target area (12) of the auxiliary anode and configured to increase an irradiated surface of the first target area (12) of the auxiliary anode.

14. The hybrid anode structure according to any one of the claims 1 to 14,
wherein the deflector (30) comprises a single-stage or a multistage collector and/or the deflector (30) is configured to spread the beam by an angled structure and/or the deflector (30) is configured to use:

a static electric field; and/or
a dynamic electric field; and/or
a magnetic field
to spread the incident electron beam (40) between the first target area (12) of the auxiliary anode (10) and the second target (22) area of the main anode (20).

15. An X-ray tube comprising the hybrid anode structure according to any one of the claims 1 to 14.


Ideal tube
voltage
140kV
80kV
100 μs
0
t
Real tube
voltage
140kV
FS discharge (dose, time)
80kV
1 nF
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t
Vacuum "bleeder"

Fig. 1

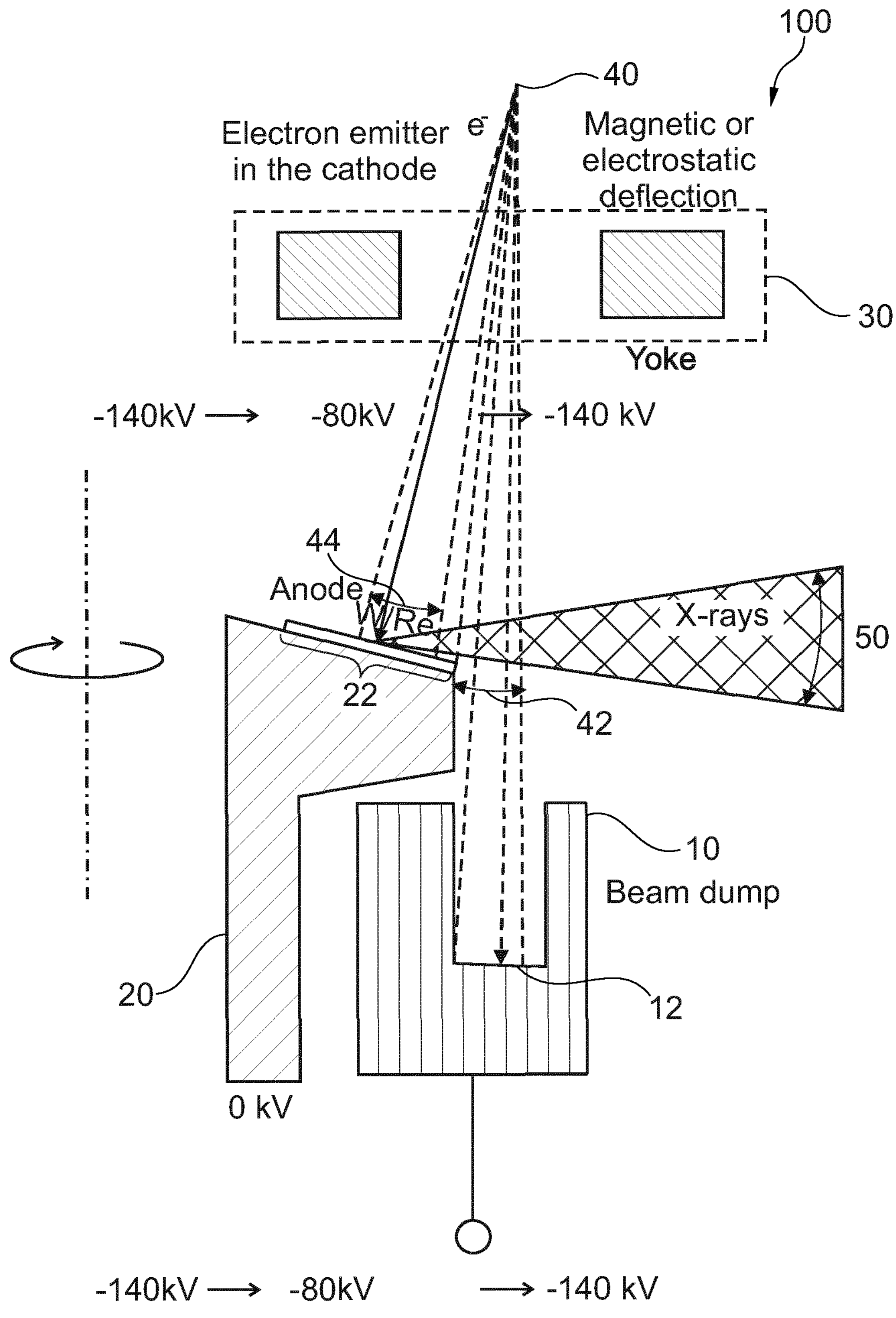
100
40
Electron emitter in the cathode
e-
Magnetic or electrostatic deflection
30
Yoke
-140kV → -80kV → -140 kV
44
Anode
W/Re
X-rays
50
22
42
10
Beam dump
12
20
0 kV
-140kV → -80kV → -140 kV

Fig. 2

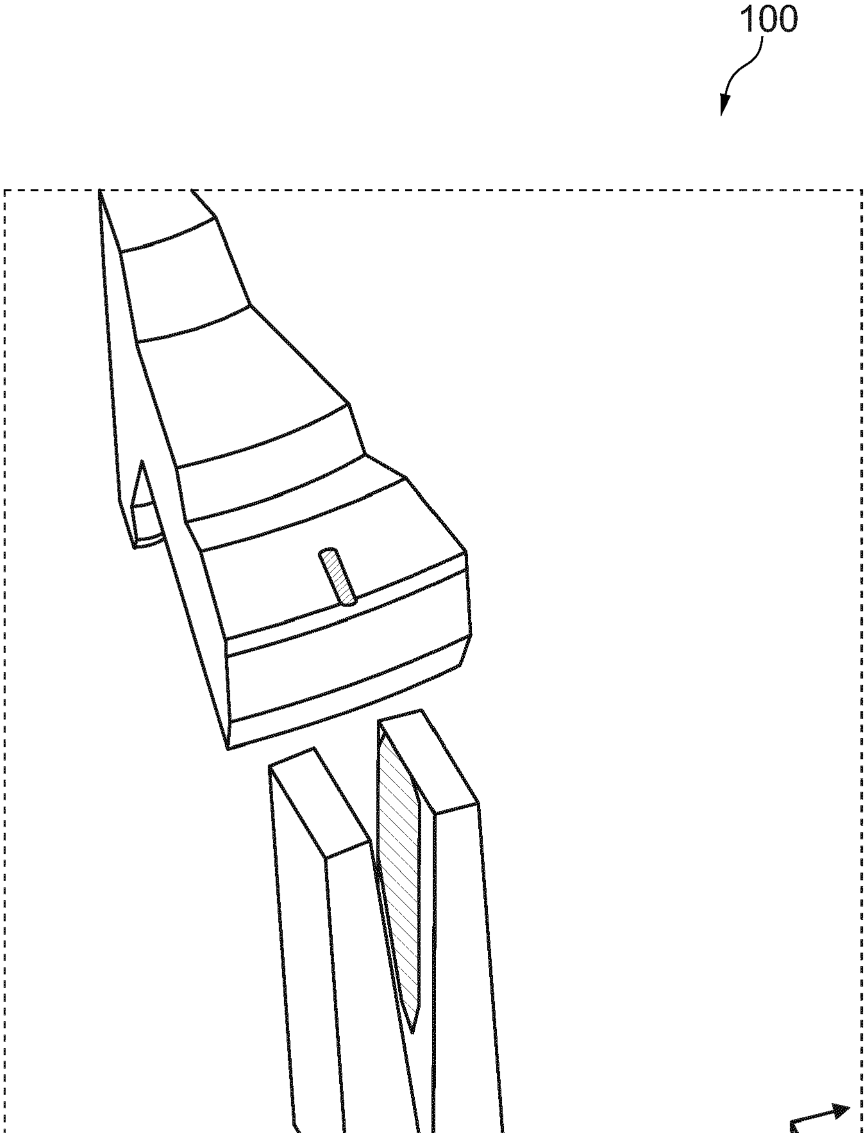

Fig. 3

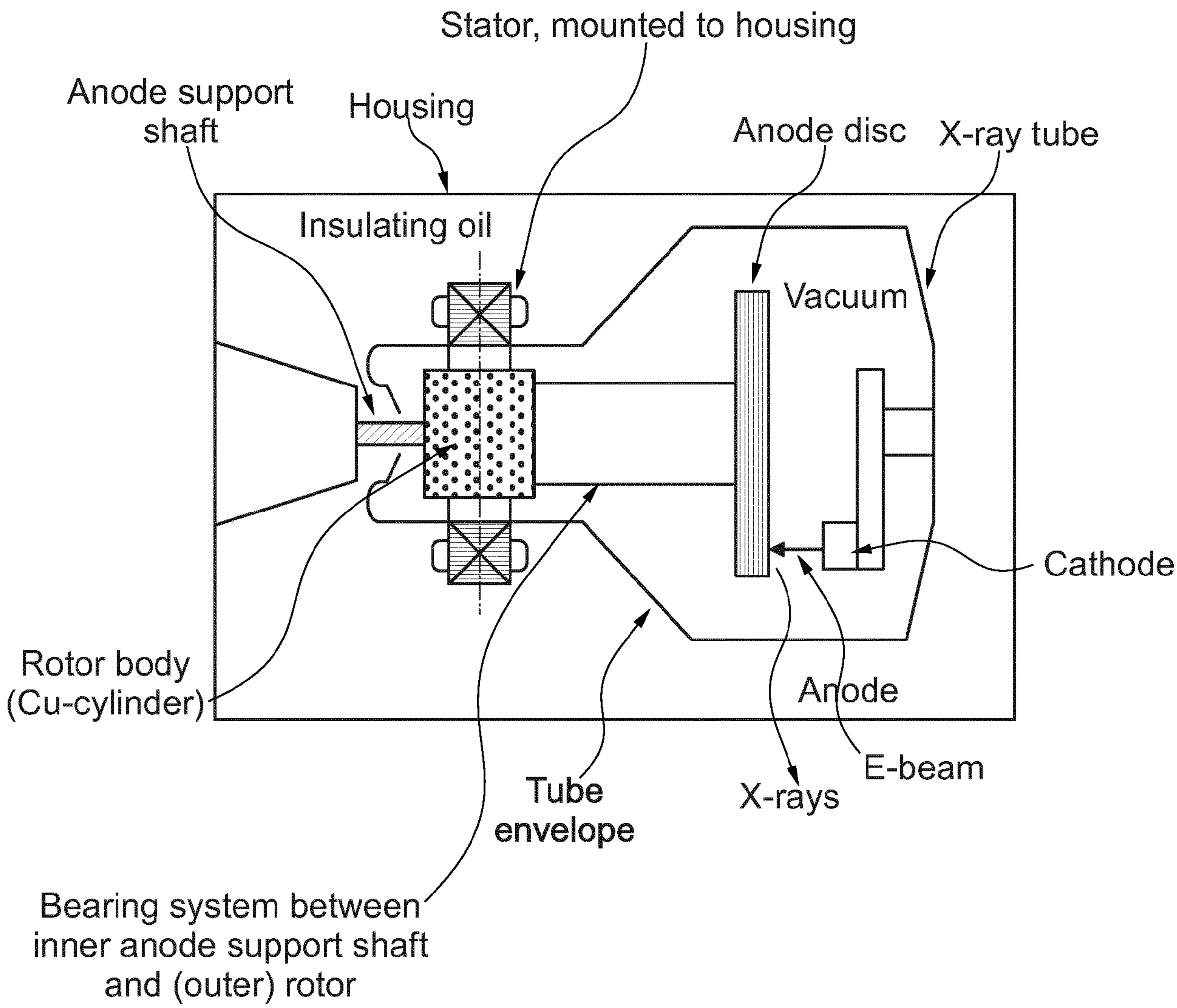
Stator, mounted to housing
Anode support shaft
Housing
Anode disc
X-ray tube
Insulating oil
Vacuum
Cathode
Rotor body (Cu-cylinder)
Anode
E-beam
X-rays
Tube envelope
Bearing system between inner anode support shaft and (outer) rotor

Fig. 4

Europäisches Patentamt
European Patent Office
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EUROPEAN SEARCH REPORT

Application Number
EP 18 20 3239

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X Y	US 2012/269321 A1 (BEHLING ROLF KARL OTTO [DE]) 25 October 2012 (2012-10-25) * see fig. 1, 2 and the description thereof * * paragraphs [0074], [0075] * -----	1-6,8, 12-15 7,9,10	INV. H01J35/10 H01J35/14 H01J35/16 H01J35/30 H05G1/58 H05G1/70
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Y	US 2010/172475 A1 (BEHLING ROLF KARL OTTO [DE]) 8 July 2010 (2010-07-08) * see fig. 6 and the description thereof * -----	10	
			TECHNICAL FIELDS SEARCHED (IPC)
			H01J H05G

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	1 April 2019	Angloher, Godehard

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
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EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 18 20 3239

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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