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(54) **ELECTRON BEAM FOCAL SPOT**

(57) The invention relates to a method for X-ray generation with an X-ray tube. The method includes generating (210) an electron beam (140) from a cathode (120) towards a rotating anode (110), wherein the electron beam impinges the rotating anode to form an electron beam focal spot (130) for producing imaging X-rays. The method further includes providing (230) the electron beam focal spot (130) with an asymmetric intensity profile on the anode, the intensity profile having a decreasing intensity in a tangential direction of rotation of the anode, and/or, temporarily increasing (240) an electron beam focal spot size in conjunction with deflecting (220) the electron beam focal spot (130) in the tangential direction of rotation of the anode, whereafter the electron beam focal spot size is decreased.

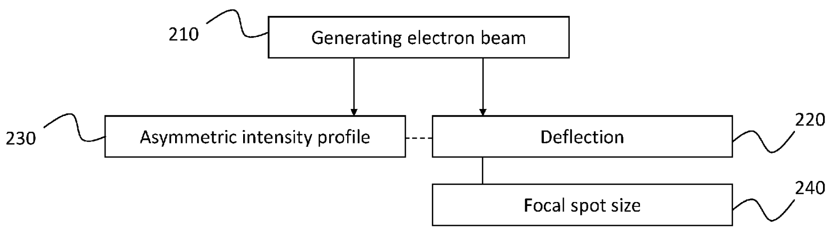

Fig. 2

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Description

FIELD OF THE INVENTION

[0001] The invention relates to a method for X-ray generation with an X-ray tube, an X-ray source assembly for generating X-rays, a cathode configured to be comprised in an X-ray source assembly, and an X-ray imaging system.

BACKGROUND OF THE INVENTION

[0002] A computed tomography (CT) scanner is an example of an X-ray imaging system. A CT scanner generally includes an X-ray tube mounted on a rotatable gantry opposite one or more rows of detectors. The X-ray tube rotates around an examination region located between the X-ray tube and the one or more rows of detectors and emits broadband radiation that traverses the examination region. Electrical power is supplied to the X-ray tube with a high voltage generator.

[0003] The one or more rows of detectors detect radiation that traverses the examination region and generate projection data indicative thereof. A reconstructor reconstructs the projection data to generate volumetric image data, which can be displayed, filmed, archived, conveyed to another device, etc.

[0004] The detector array includes detector pixels that convert detected x-ray photons into electrical signals indicative thereof. For each revolution of the rotating gantry, the detector pixels detect and convert x-ray photons for a plurality of integration periods, each corresponding to a different angular position range. The time duration of an integration period depends on the rotating gantry rotation speed and the number integration periods for each revolution of the scan. With an integrating detector array, at the beginning of each integration period, the integrators for the detector pixels are reset, and then the integrators receive and integrate the electrical signals over the integration period. The integrated signals form the projection data for that integration period.

[0005] The X-ray tube typically includes a cathode with a filament and an anode. A filament current is applied to the filament, which current heats the filament, causing the filament to expel electrons (thermionic emission), creating a space charge a short distance away from the filament. A peak tube voltage is applied across the cathode and the anode and causes a beam of the electrons to accelerate from the cathode and impinge the anode. The X-ray tube current, or emission current, represents the number of electrons per second flowing from the cathode to the anode. Electrostatic or magnetic focusing with e.g. grid electrodes or quadrupoles can be applied to control a size of and steer the beam of electrons. An interaction of the electrons with the material of the anode produces heat and radiation, including X-rays, which pass through a tube window, into an examination region, to a detector.

[0006] A surface area of the anode that receives the beam of electrons is referred to as a focal spot. The size of the focal spot is one factor that affects the image quality of the X-ray image data. For example, the focal spot size affects the spatial resolution, where a smaller focal spot size results in a greater spatial resolution than a larger focal spot size, e.g., due to less focal spot blur from geometric magnification. The size and/or position of the focal spot may depend on the X-ray tube voltage, beam focusing voltage and tube current. With X-ray tubes having rotating anodes, the focal spot forms a so-called focal track on the anode due to the rotation. I.e., the focal track is a (circular) area on the anode where the focal spot moves on the anode due to the anode rotation.

[0007] Due to the high temperature of the focal spot on the anode focal track, degradation of the anode may occur. Such degradation may reduce the lifetime of the X-ray tube, as well as cause limitations to the X-ray tube power specifications and the achievable dose during use of the X-ray tube.

SUMMARY OF THE INVENTION

[0008] It is an object of the invention to reduce degradation of the anode during use of the X-ray tube. The invention is defined by the independent claims. Advantageous embodiments are defined in the dependent claims.

[0009] According to a first aspect the invention, there is provided a method for X-ray generation with an X-ray tube, the method comprising:

> generating an electron beam from a cathode towards a rotating anode, wherein the electron beam impinges the rotating anode to form an electron beam focal spot for producing imaging X-rays, and characterized by
> providing the electron beam focal spot with an asymmetric intensity profile on the anode, the intensity profile having a decreasing intensity in a tangential direction of rotation of the anode,
> and/or
> temporarily increasing an electron beam focal spot size in conjunction with deflecting the electron beam focal spot in the tangential direction of rotation of the anode, whereafter the electron beam focal spot size is decreased.

[0010] Both alternatives above, on their own or in combination, provide a reduction of local anode temperature peaks resulting from electron beam heating due to the rotation of the anode. The focal track has the highest temperature in the region of the focal spot and the lowest temperature in tangential direction just beside the focal spot in the opposite direction of the anode rotation direction. This means that at the side of the focal spot closest to the direction of rotation of the anode, the temperature may locally reach a peak because of the anode rotation. The proposed method mitigates such temperature peaks by reducing the focal spot intensity in the area most susceptible to temperature increase.

[0011] By providing the focal spot with an asymmetric intensity profile, having a decreasing intensity in the tangential direction of rotation of the anode, increased heating of the anode can be mitigated. An asymmetrical focal spot intensity profile means that the focal spot intensity is, permanently or temporarily, not symmetric with respect to a centerline of the spot. E.g., the spot may have an asymmetric shape with a larger 'height' on one side compared to the other side. The intensity profile may be dynamically regulated such as with an electron beam optics unit and/or may be permanently achieved such as with the cathode design.

[0012] Similarly, deflection or other movement of the focal spot in the rotational direction of the anode may lead to a focal spot temperature peak, since the focal spot is deflected to an area that was just heated or may even stay on the same area during movement if the focal spot movement speed matches anode rotation speed. Such peaks may be detrimental for the anode and therefore cause limitations to the X-ray tube power specifications and/or dose degradation during use of the X-ray tube. By temporarily increasing the electron beam focal spot size in conjunction with deflecting the electron beam focal spot in the tangential direction of rotation of the anode, temperature peaks can be reduced. In this way, the lifetime of the anode and the X-ray tube may be improved, and/or increased power specifications of the tube may be possible.

[0013] In the context of the present application, the expression "in conjunction with deflecting the electron beam focal spot" means during deflection of the electron beam focal spot or just before deflection. If not *during* deflection, the time between increasing the electron beam focal spot size and deflecting the electron beam focal spot should be very short to prevent the imaging quality from being negatively influenced. Such as less than 20 μs prior to deflection, preferably less than 10 μs prior to deflection, and more preferably less than 1 μs prior to deflection. After deflection the focal spot size is decreased again to its original size. Preferably, the electron beam focal spot size is only temporarily increased for a total period of less than 25 μs, preferably less than 10 μs, and more preferably less than 5 μs before being reduced again.

[0014] According to an embodiment of the invention, the method comprises:

deflecting the electron beam focal spot repeatedly between a first position and a second position relative to the rotating anode, wherein deflection of the electron beam focal spot from the first position to the second position is in the tangential direction of rotation of the anode, and wherein deflection of the electron beam focal spot from the second position to the first position is against the tangential direction of rotation of the anode,

providing an electron beam of comparable focal spot size and intensity profile during imaging X-ray production in each of the first position and the second position, and

temporarily modifying the electron beam focal spot intensity profile and/or increasing the electron beam focal spot size, in conjunction with deflection of the electron beam focal spot from the first position to the second position.

[0015] In many imaging applications, the focal spot is deflected back and forth with the electron beam optics to improve image quality. However, movement of the focal spot from the first position to the second position may lead to increased temperature. Due to the combination of movement of the focal spot and the rotation of the anode, the same small area of the anode may be continuously heated or heated twice in rapid succession by the focal spot. Thanks to the asymmetric intensity profile of the focal spot and/or the change in size in conjunction with movement in the tangential direction of rotation of the anode, from the first position to the second position, excessive heating of the same area of the rotating anode can be mitigated. In this way temperature peaks due to the focal spot deflection can be avoided or reduced. The method may therefore provide improved image quality from focal spot deflection while mitigating potential negative effects to anode lifetime and/or maximum X-ray tube power specifications.

[0016] Preferably, the size or intensity profile of the focal spot is not changed during or in conjunction with movement back against the tangential direction of rotation of the anode, i.e. in conjunction with movement from the second position to the first position. In this way, a higher improvement of image quality can be achieved. For optimal image quality, the size and intensity profile of the electron beam spot is the same or substantially the same in both positions.

[0017] In the context of the present invention, the term 'comparable' focal spot size and intensity profile is to be understood as for imaging purposes the same or substantially the same. A deviation of about 10% in average focal spot size or intensity profile between the first position and the second position may be acceptable for maintained imaging quality. It is noted that a temporary change of the focal spot, such as in conjunction with deflection, may be much larger, such as more than 200%, since the change only lasts for a short time (microseconds) in comparison to the duration of one image acquisition (typically hundreds of microseconds).

[0018] A frequency of the repeated deflection of the electron beam focal spot between the first position and the second position may be larger than 500 Hz, preferably larger than 2400 Hz, and more preferably larger that 8000 Hz.

[0019] According to an embodiment of the invention, temporarily increasing the electron beam focal spot size comprises elongating the focal spot in the tangential direction of rotation of the anode.

[0020] A temporarily elongated focal spot in the direction of anode rotation, in conjunction with focal spot deflection, provides a reduced intensity at the area of the anode vulnerable to temperature peaks. The elongation may be achieved with so called 'x-direction' electron beam optics. Such electron beam optics may comprise electrostatic focusing grids and/or magnetic focusing coils.

[0021] According to an embodiment of the invention, the increase in size is provided with a temporal delay between deflecting a first side of the electron beam focal spot and deflecting a second side of the electron beam focal spot, wherein the first side of the electron beam focal spot is closer to the tangential direction of rotation of the anode than the second side of the electron beam focal spot.

[0022] The delay may be achieved by controlling electron beam optics of the X-ray tube. The electron beam optics may then be controlled such that the side closest to the direction of rotation of the anode is moved before the other side of the focal spot. E.g., by introducing a delay between grid voltages of 'left' and 'right' electrostatic focusing grids, or between focusing currents of 'left' and 'right' magnetic focusing coils. In this way the focal spot is 'elongated' during the movement. Sudden heating of the electron beam focal spot due to the deflection and anode rotation may therefore be avoided.

[0023] According to an embodiment of the invention, the increase of the electron beam focal spot size comprises increasing a height of the electron beam focal spot in a direction transverse to the tangential direction of rotation of the anode.

[0024] Modulating the size of the focal spot in the 'height' direction, transverse to the tangential direction of rotation of the anode, may be achieved with so called 'y-direction' electron beam optics. Such electron beam optics may comprise electrostatic focusing grids and/or magnetic focusing coils.

[0025] According to an embodiment of the invention, the focal spot has an asymmetric intensity profile with a linearly decreasing intensity in the tangential direction of rotation of the anode. The asymmetric intensity profile may preferably be a trapezoidal profile. It is noted that in practice the focal spot may not have a purely linearly decreasing intensity and the skilled person will appreciate linearly decreasing intensity does not exclude the presence of minor nonlinearities.

[0026] According to an embodiment of the invention, the electron beam focal spot intensity profile and/or change in electron beam focal spot size is provided by an electron beam optics unit. The electron beam optics unit may comprise electrostatic focusing grids and/or magnetic focusing coils.

[0027] According to a second aspect of the invention, there is provided an X-ray source assembly for generating X-rays and configured to carry out the method according to any embodiment of the first aspect, the assembly comprising:

a rotating anode;
a cathode configured to generate an electron beam towards the rotating anode, to form an electron beam focal spot on the rotating anode for producing imaging X-rays;
an electron beam optics unit configured to shape an electron beam focal spot on the rotating anode; and
a controller configured to control the electron beam optics unit and the cathode, characterized in that the cathode and/or the electron beam optics unit is configured to provide the electron beam focal spot with an asymmetric intensity profile on the anode, the intensity profile having a decreasing intensity in a tangential direction of rotation of the anode, and/or to temporarily increase an electron beam focal spot size in conjunction with deflecting the electron beam focal spot in the tangential direction of rotation of the anode, and to decrease the electron beam focal spot size thereafter.

[0028] The controller may be integrated with the assembly, such as part of an X-ray tube or high voltage generator, or may be a remote unit connected to the X-ray tube assembly, such as a local or remote computer, imaging system controller, handheld processing device etc. The controller may regulate electron beam optics, cathode filament currents, X-ray tube peak voltages, cathode (filament) switches etc. The controller may comprise or otherwise interact with a processor, such as but not limited to a computer, a computer network, and/or another programmable apparatus, such as a single and/or multi core processing unit, a graphics processing unit, an accelerated processing unit, a digital signal processor, a field programmable gate array, an application-specific integrated circuit, etc.

[0029] The electron beam optics unit may include electrodes for electrostatic regulation of the electron beam focal spot. The unit may include magnetic coils for electromagnetic regulation of the electron beam focal spot. The electron beam optics unit may be configured to regulate a position of the electron beam focal spot. The electron beam optics unit may be configured to deflect the electron beam focal spot between at least two positions, such as during repeated deflection in the 'x-direction'.

[0030] According to a third aspect of the invention, there is provided a cathode configured to be comprised in an X-ray source assembly for generating X-rays, wherein the cathode is configured to generate an electron beam focal spot on a rotating anode with an asymmetric intensity profile in a tangential direction of rotation of the anode.

[0031] According to a fourth aspect of the invention, there is provided an X-ray source assembly for generating X-rays, the assembly comprising a rotating anode and the cathode according to the third aspect.

[0032] According to a fifth aspect of the invention, there is provided an X-ray imaging system comprising the X-ray source assembly according to the second or fourth aspect of the invention. The X-ray imaging system may be a computed tomography system, a radiography system, a fluoroscopy system, a C-arm X-ray system for interventional guidance etc.

[0033] According to a sixth aspect of the invention, there is provided a computer program element, which, when being executed by a controller, is adapted to cause the controller to control an electron beam optics unit and/or a cathode to perform the method according to any of the embodiments of the first aspect of the invention. The computer program element may be made available for download from a server, e.g. via the internet.

[0034] According to an aspect of the invention, there is provided a computer readable medium having stored thereon the computer program element as mentioned above.

[0035] 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

[0036]

Fig. 1 schematically illustrates an X-ray source assembly with an electron beam focal spot on a rotating anode.

Fig. 2 schematically illustrates a method for X-ray generation with an X-ray tube.

Fig. 3 schematically illustrates a method for X-ray generation with an X-ray tube.

Fig. 4 shows examples of simulated anode temperature profiles.

Fig. 5 schematically illustrates a cathode.

Fig. 6 schematically illustrates an X-ray imaging system comprising an X-ray source assembly.

DETAILED DESCRIPTION OF EMBODIMENTS

[0037] An example of an X-ray source assembly 100 is schematically illustrated in Fig. 1. The X-ray source assembly 100 includes a rotating anode 110, with in this case a rotational direction indicated by the arrow 112. During operation, an electron beam 140 is generated between the cathode 120 and the anode 110. The electron beam 140 impinges the anode at an electron beam focal spot 130. The X-ray source assembly 100 may also include an electron beam optics unit 142, exemplified in Fig. 1 with two electrodes on either side of the electron beam 140. The electron beam optics unit 142 may be used to shape and/or position the focal spot 130.

[0038] With the rotation of the anode 110, the focal spot 130 forms a focal track 134 around the anode 110. The focal track 134 has the highest temperature in the region of the focal spot 130 and the lowest temperature in tangential direction just beside the focal spot in the opposite direction of the anode rotation direction (to the right of the focal spot in Fig. 1). I.e., the temperature is the lowest in the area that has had the most time to cool off during rotation of the anode. The temperature is not constant across the entire area of the focal spot 130. At the side of the focal spot 130 closest to the direction of rotation 112 of the anode, on the left side of the focal spot in the example in Fig. 1, the temperature may locally reach a temperature peak because that area has been heated for a longer time than the opposite side of the focal spot, due to the anode rotation. As will be further elaborated on in the description, the inventors have found that such temperature peaks can be mitigated by providing an electron beam focal spot 130, which has an intensity profile with a decreasing intensity in a tangential direction of rotation of the anode. I.e., in the schematic example in Fig. 1, a lower intensity on the left side of the focal spot 130 as compared to the right side of the focal spot 130. Such an asymmetric intensity profile may be achieved with design of the cathode 120 and/or with use of the electron beam optics unit 142.

[0039] The electron beam optics unit 142 may be used to vary the position of the focal spot 130. When the focal spot is deflected in the direction of rotation of the anode, the risk of a temperature peak increases since the same area of the rotating anode 110 is heated twice in rapid succession or even continuously. To mitigate such a temperature peak, the focal spot size may be temporarily increased in conjunction with deflecting the electron beam focal spot in the tangential direction of rotation of the anode. When the focal spot has finished the deflection or ‘jump’, focal spot size is decreased to the original size again. The temporary electron beam focal spot size change may be on the order of single to tens of microseconds, whereas an acquisition period for imaging is generally on the order of hundreds of microseconds. Therefore, the impact on the temporary focal spot size increase on imaging quality may be negligible.

[0040] In one example, the electron beam optics unit 142 may, during imaging with the X-ray source assembly 100, deflect the focal spot 130 repeatedly back and forth between a first position 131 and a second position 132. Such repeated deflection may be referred to as ‘x-direction focal spot deflection’ and is aimed to improve imaging quality. Also in this example, movement of the focal spot from the first position to the second position, i.e. movement in the direction of rotation of the anode, may lead to temperature peaks on the anode 110. Depending on the anode rotation speed and the focal spot jumping speed, the temperature can locally be as high as a factor 1.5 relative to when no x-direction focal spot deflection is applied. This may lead to specification limitations and/or additional dose degradation. Temperature peaks can be mitigated by temporarily modifying the electron beam focal spot intensity profile and/or electron beam focal spot size, in conjunction with the deflection of the electron beam focal spot 130 from the first position 131 to the second position 132. Thanks to the asymmetric shape of the focal spot and/or the change in size in conjunction with movement in the tangential direction of rotation of the anode, from the first position to the second position, excessive heating of the same area of the rotating anode can be reduced.

[0041] A temporary change in size of the focal spot may be achieved with the electron beam optics unit 142 by first moving one edge of the focal spot, then pulling in the second edge. This may be implemented with a time delay between the grid voltages (or magnet currents) of the electron beam optics electrodes (or magnet coils) on the first side of the electron beam as compared to the second side of the beam. Qualitatively, the temperature reducing effect is in this case similar to increasing the size (width) of the focal spot before the jump is executed, which is another option. Simulation results indicate that in this way the maximum focal spot temperature during x-direction focal spot deflection may be reduced to a level comparable to when no such deflection is applied.

[0042] Fig. 2 schematically illustrates a method for X-ray generation with an X-ray tube. The method includes generating 210 an electron beam 140 from a cathode 120 towards a rotating anode 110, wherein the electron beam impinges the rotating anode to form an electron beam focal spot 130 for producing imaging X-rays. The method further includes providing 230 the electron beam focal spot 130 with an asymmetric intensity profile on the anode, the intensity profile having a decreasing intensity in a tangential direction of rotation of the anode, and/or, temporarily increasing 240 an electron beam focal spot size in conjunction with deflecting 220 the electron beam focal spot 130 in the tangential direction of rotation of the anode, whereafter the electron beam focal spot size is decreased. As discussed above, both approaches mitigate local focal spot temperature peaks on the anode.

[0043] Fig. 3 schematically illustrates a method for X-ray generation, where repeated focal spot deflection, such as x-direction focal spot deflection, is applied for improved imaging quality. Advantages of focal spot deflection for improving imaging quality in computed tomography applications are described in e.g. Nicholas Rubert et. al.. JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOLUME 17, NUMBER 3, 2016, p. 452-466.

[0044] The method in Fig. 3 includes generating 210 an electron beam 140 from a cathode 120 towards a rotating anode 110, wherein the electron beam impinges the rotating anode to form an electron beam focal spot 130 for producing imaging X-rays. The method further includes deflecting 320 the electron beam focal spot repeatedly between a first position 131 and a second position 132 relative to the rotating anode, wherein deflection of the electron beam focal spot 130 from the first position 131 to the second position 132 is in the tangential direction of rotation of the anode, and wherein deflection of the electron beam focal spot 130 from the second position 132 to the first position 131 is against the tangential direction of rotation of the anode, and, providing 330 an electron beam of comparable focal spot size and intensity profile during imaging X-ray production in each of the first position 131 and the second position 132. In order to reduce the temperature peak resulting from movement of the focal spot size in the direction of rotation of the anode, the method comprises temporarily modifying the electron beam focal spot intensity profile 230 and/or increasing the electron beam focal spot size 240, in conjunction with deflection 220 of the electron beam focal spot from the first position 131 to the second position 132.

[0045] Fig. 4 illustrates that also when no focal spot deflection is applied, an asymmetric intensity profile of the focal spot may significantly reduce the local focal spot temperature peak and hence improve power specifications and/or reduce anode degradation. The two curves in Fig. 4 illustrates a simulated temperature distribution on the rotating anode in the case of a focal spot with a square constant intensity profile 410, and for a focal spot with a trapezoidal intensity profile 420 where the intensity decreases in the tangential direction of anode rotation. Calculations show that for identical tube loads (pulse power and length) the trapezoidal intensity profile 420 may lead to a temperature reduction of about 8-10% of the local focal spot temperature compared to a focal spot with a square intensity profile 410. An asymmetric focal spot intensity profile may be achieved with driving the different sides of an electron beam optics unit 142 with asymmetrical voltages/currents. Alternatively, or additionally, an asymmetric focal spot intensity profile may be achieved with the cathode 120, such as illustrated in Fig. 5 below.

[0046] Fig. 5 schematically illustrates an example of a cathode for generation of an electron beam 140. The cathode has a filament 510 for thermionic emission of electrons. The filament 510 is in this example placed in a slit between a first focusing element 520 and a second focusing element 530. However, the cathode 120 may alternatively be designed without focusing elements, to provide for a simpler structure. In Fig. 5, the first and second focusing elements 520, 530 respectively have a defined depth (d1, d2) and width (w1, w2) with respect to the filament slit. The first and second focusing elements respectively may be connected to a source for a first and second focusing element voltage to drive the focusing elements. The cathode 120 in Fig. 5 is surrounded by a cathode cup 540. During operation of the cathode 120 in an X-ray tube assembly 100, an X-ray tube voltage is applied between the cathode cup 540 and the rotating anode 110. Multiple design options, and combinations thereof, are possible for the cathode 120 to generate an electron beam 140 that intersects a rotating anode at an electron beam focal spot 130 with an asymmetric intensity profile. By way of example, the shapes (depth, width) of the optional focusing elements 520, 530 and/or the focusing element voltages may be asymmetric. Such as with a smaller and/or deeper focusing element on one side of the filament 510 compared to the other side. Alternatively, or additionally, the filament 510 may be placed asymmetrically inside the slit. The filament 510 may have an asymmetric shape. The shape of the cathode cup 540 may be designed to provide asymmetry to the focal spot intensity profile.

[0047] A cathode 120 for being comprised in an X-ray source assembly may, alternatively or additionally to the design options discussed above, include multiple filaments 510 of different sizes and/or shapes, and may include switches to alternate between filaments 510. The cathode 120 may be configured to temporarily increase the electron beam focal spot size 130. E.g. by switching between filaments 510 and/or via temporarily adapting voltages at the focusing elements 520, 530.

[0048] Fig. 6 schematically illustrates an imaging system 600 for generating imaging X-rays 620. The imaging system 600 may be e.g. a computed tomography system, a radiography system, a fluoroscopy system, or a C-arm X-ray system for interventional guidance. The imaging system 600 comprises an X-ray source assembly 100. The X-ray source assembly 100 in this example includes a rotating anode 110, a cathode 120 configured to generate an electron beam 140 towards the rotating anode, and an electron beam optics unit 142 configured to shape an electron beam focal spot 130 on the rotating anode. The imaging system in Fig. 6 includes a high voltage generator 630 for providing power to the X-ray tube, such as to provide the tube voltage between the anode 110 and the cathode 120 and the filament current. The high voltage generator may also drive the voltage/current of the electron beam optics unit 142. The high voltage generator 630 in the imaging system 600 in Fig. 6 includes a controller 610 configured to control the electron beam optics unit 142 and the cathode 120. The high voltage generator 630 may alternatively be located externally to the X-ray source assembly 100.

[0049] The controller 610 may be configured to carry out the method as described in relation to the first aspect of the invention, such as any of the methods as described in relation to Fig. 2 and Fig. 3. The controller 610 may be separate from the high voltage generator. E.g., the controller 610 may be a remote unit connected to the X-ray tube assembly, such as a local or remote computer, imaging system controller, handheld processing device etc. The controller may comprise or otherwise interact with a processor, such as but not limited to a computer, a computer network, and/or another programmable apparatus, such as a single and/or multi core processing unit, a graphics processing unit, an accelerated processing unit, a digital signal processor, a field programmable gate array, an application-specific integrated circuit, etc. The controller 610 may be configured to execute a computer program element, which, when being executed by the controller 610, is adapted to cause the controller to control an electron beam optics unit and/or a cathode to perform the method as described in relation to the first aspect of the invention.

[0050] It should be noted that the above-mentioned embodiments illustrate rather than limit the invention, and that those skilled in the art will be able to design many alternative embodiments without departing from the scope of the appended claims. In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim. The word "comprising" does not exclude the presence of elements or steps other than those listed in a claim. The word "a" or "an" preceding an element does not exclude the presence of a plurality of such elements. The invention may be implemented by means of hardware comprising several distinct elements, and/or by means of a suitably programmed processor. In the device claim enumerating several means, several of these means may be embodied by one and the same item of hardware. Measures recited in mutually different dependent claims may advantageously be used in combination.

Claims

1. A method for X-ray generation with an X-ray tube, the method comprising:

generating (210) an electron beam (140) from a cathode (120) towards a rotating anode (110), wherein the electron beam impinges the rotating anode to form an electron beam focal spot (130) for producing imaging X-rays, and **characterized by**

providing (230) the electron beam focal spot (130) with an asymmetric intensity profile on the anode, the intensity profile having a decreasing intensity in a tangential direction of rotation of the anode,

and/or

temporarily increasing (240) an electron beam focal spot size in conjunction with deflecting (220) the electron beam focal spot (130) in the tangential direction of rotation of the anode, whereafter the electron beam focal spot size is decreased.

2. The method according to claim 1, the method comprising:

deflecting (320) the electron beam focal spot repeatedly between a first position and a second position relative to the rotating anode, wherein deflection of the electron beam focal spot from the first position to the second position is in the tangential direction of rotation of the anode, and wherein deflection of the electron beam focal spot from the second position to the first position is against the tangential direction of rotation of the anode,

providing (330) an electron beam of comparable focal spot size and intensity profile during imaging X-ray production in each of the first position and the second position, and
temporarily modifying the electron beam focal spot intensity profile (230) and/or increasing the electron beam focal spot size (240), in conjunction with deflection (220) of the electron beam focal spot from the first position to the second position.

3. The method according to claim 2, wherein a frequency of the repeated deflection (320) of the electron beam focal spot between the first position and the second position is larger than 500Hz, preferably larger than 2400Hz, and more preferably larger than 8000Hz.

4. The method according to claim 1 or 2 or 3, wherein temporarily increasing the electron beam focal spot size (240) comprises elongating the focal spot in the tangential direction of rotation of the anode.

5. The method according to claim 4, wherein the increase in size (240) is provided with a temporal delay between deflecting a first side of the electron beam focal spot and deflecting a second side of the electron beam focal spot, and wherein the first side of the electron beam focal spot is closer to the tangential direction of rotation of the anode than the second side of the electron beam focal spot.

6. The method according to any of the preceding claims, wherein the increase of the electron beam focal spot size (240) comprises increasing a height of the electron beam focal spot in a direction transverse to the tangential direction of rotation of the anode.

7. The method according to any of the preceding claims, wherein the electron beam focal spot (130) has an asymmetric intensity profile with a linearly decreasing intensity in the tangential direction of rotation of the anode.

8. The method according to claim 7, wherein the asymmetric intensity profile is a trapezoidal profile.

9. The method according to any of the preceding claims, wherein the electron beam focal spot intensity profile (230) and/or change in electron beam focal spot size (240) is provided by an electron beam optics unit (142).

10. An X-ray source assembly (100) for generating X-rays and configured to carry out the method according to any of the preceding claims, the assembly comprising:

a rotating anode (110);
a cathode (120) configured to generate an electron beam (140) towards the rotating anode, to form an electron beam focal spot (130) on the rotating anode for producing imaging X-rays;
an electron beam optics unit (142) configured to shape an electron beam focal spot (130) on the rotating anode; and
a controller (610) configured to control the electron beam optics unit (142) and the cathode (120),
characterized in that the cathode (120) and/or the electron beam optics unit (142) is configured to provide (230) the electron beam focal spot (130) with an asymmetric intensity profile on the anode, the intensity profile having a decreasing intensity in a tangential direction of rotation of the anode, and/or to temporarily increase (240) an electron beam focal spot size in conjunction with deflecting (220) the electron beam focal spot (130) in the tangential direction of rotation of the anode, and to decrease the electron beam focal spot size thereafter.

11. A cathode (120) configured to be comprised in an X-ray source assembly (100) for generating X-rays, wherein the cathode (120) is configured to generate an electron beam focal spot (130) on a rotating anode with an asymmetric intensity profile in a tangential direction of rotation of the anode.

12. An X-ray source assembly (100) for generating X-rays, the assembly comprising:

a rotating anode (110); and
the cathode (120) according to claim 11.

13. An X-ray imaging system (600) comprising the X-ray source assembly (100) according to claim 10 or 12.

14. A computer program element, which, when being executed by a controller, is adapted to cause the controller to control an electron beam optics unit and/or a cathode to perform the method according to any of claims 1-9.

15. A computer readable medium having stored thereon the computer program element of claim 14.

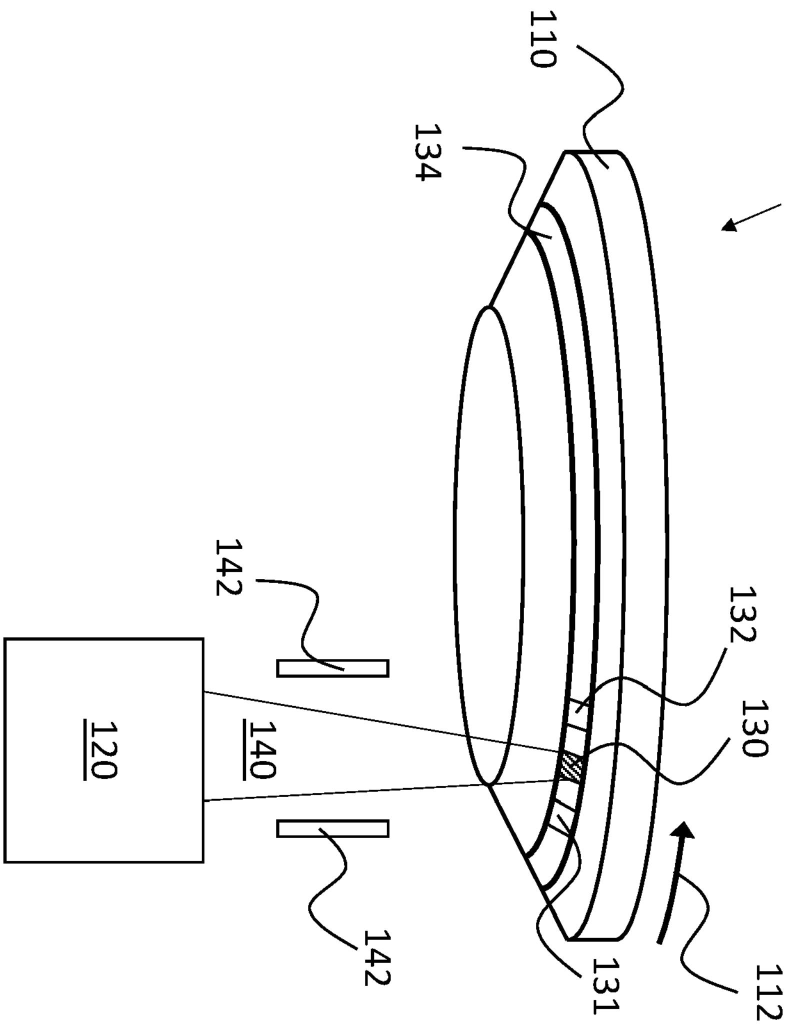

Fig. 1

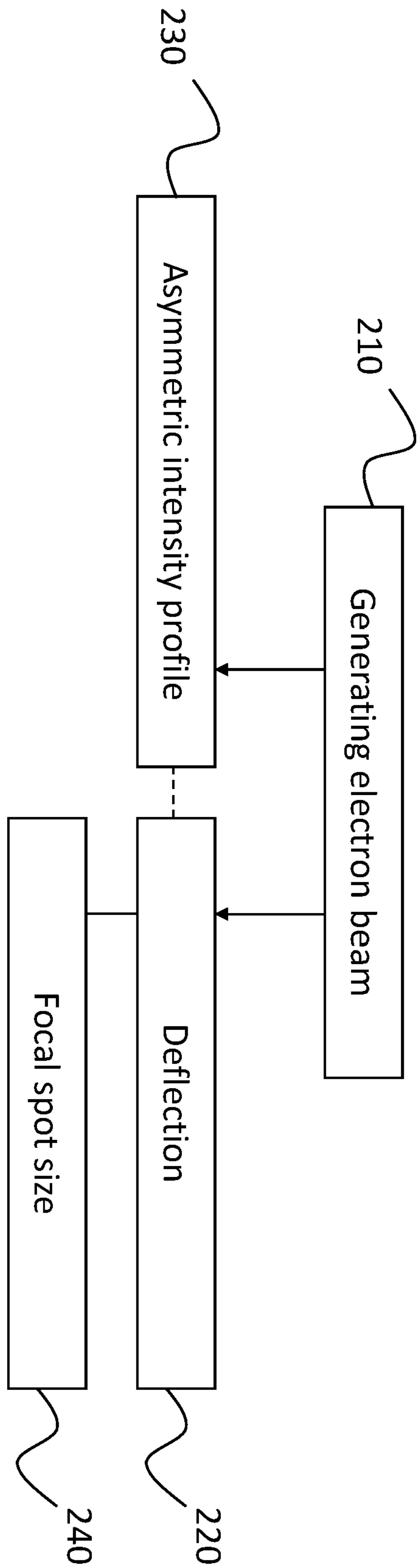
210
Generating electron beam
230
Asymmetric intensity profile
Deflection
220
Focal spot size
240

Fig. 2

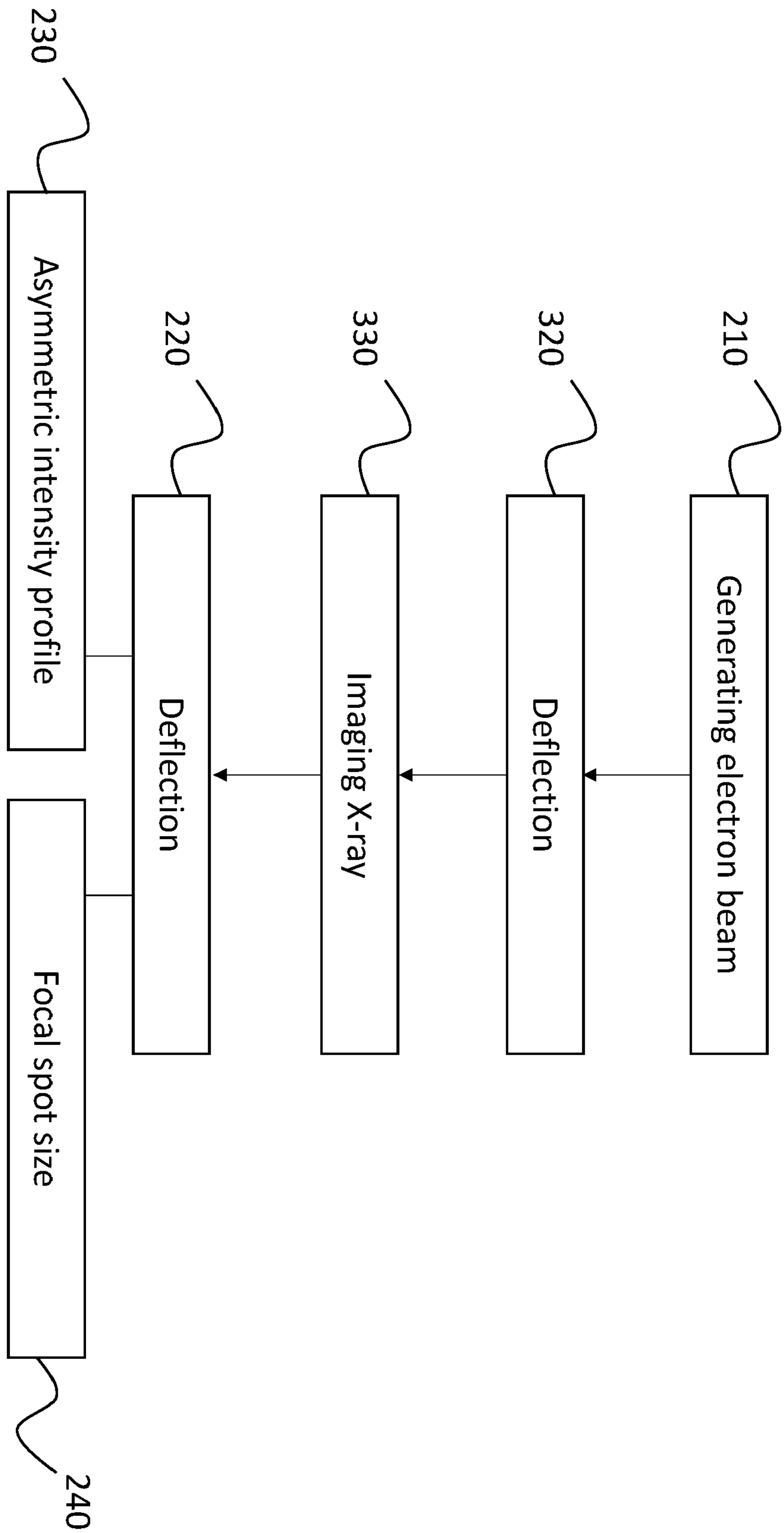
Generating electron beam
210
Deflection
320
Imaging X-ray
330
Deflection
220
Asymmetric intensity profile
230
Focal spot size
240

Fig. 3

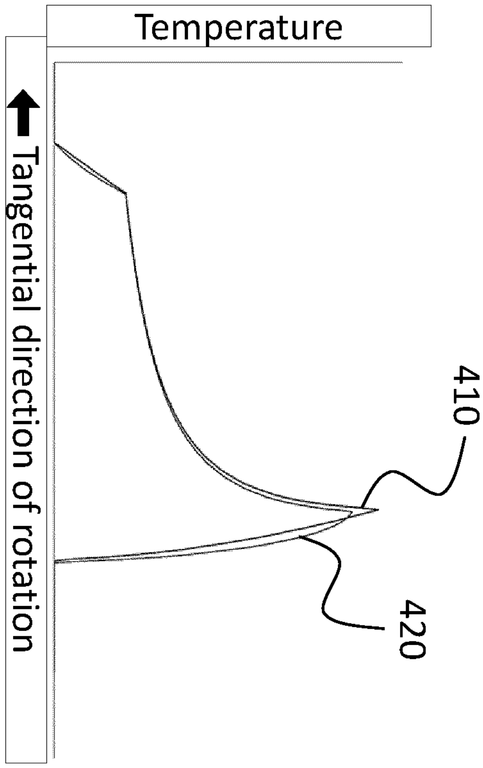

Fig. 4

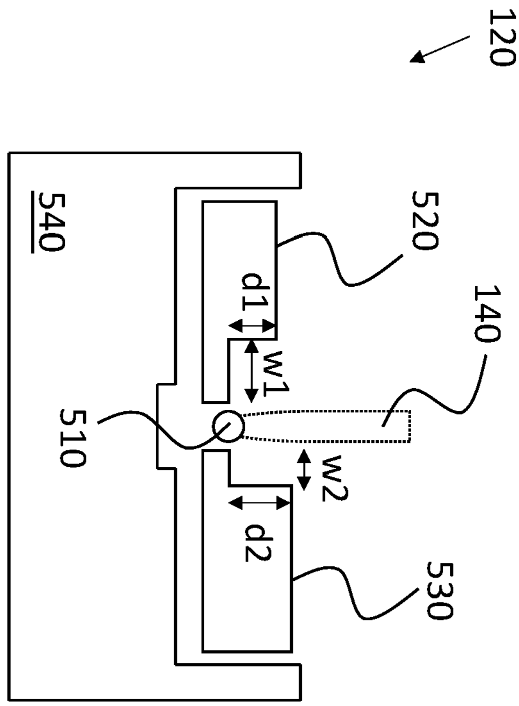

Fig. 5

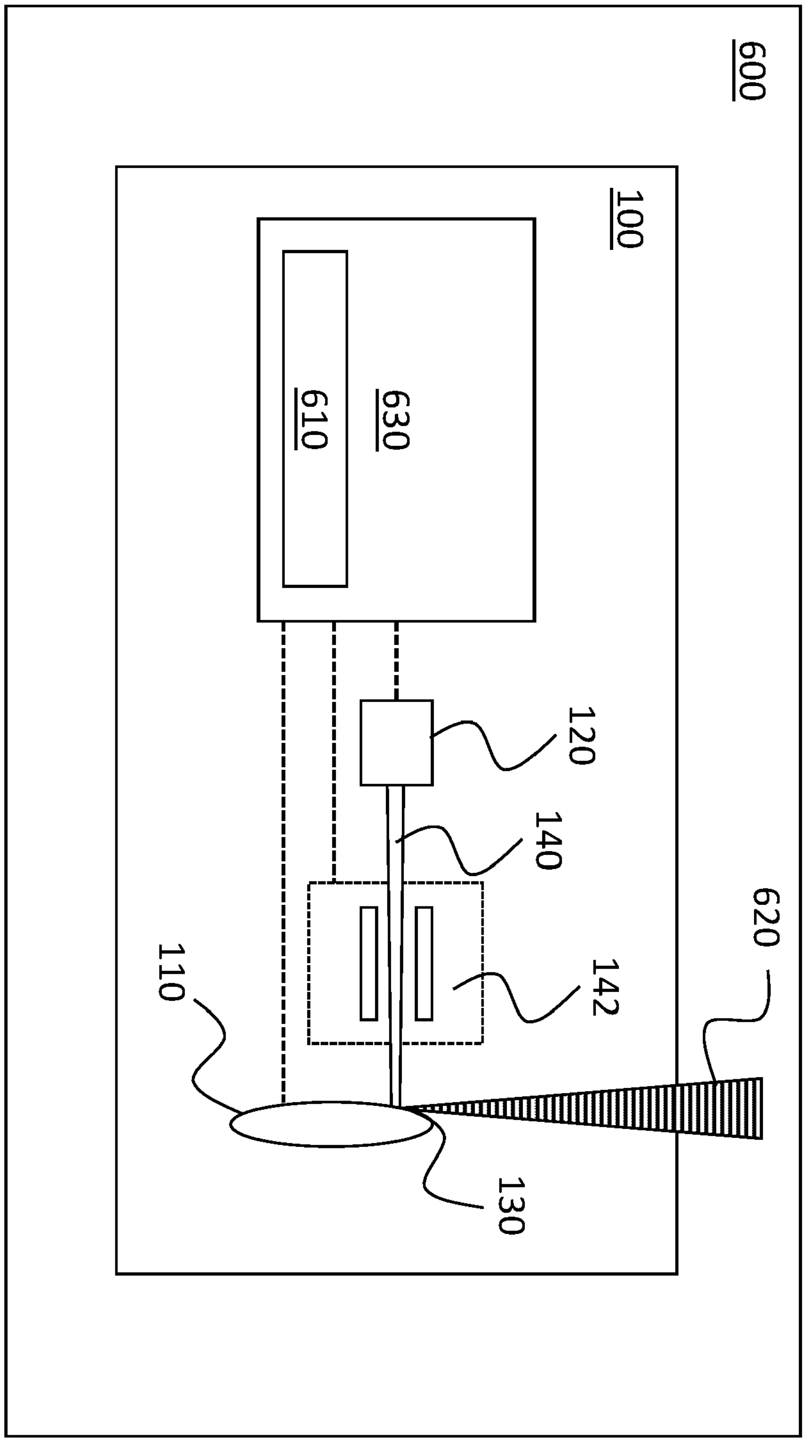

Fig. 6

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EUROPEAN SEARCH REPORT

Application Number
EP 23 21 4842

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	Anonymous: "R?ntgenr?hre - Wikipedia", , 3 December 2023 (2023-12-03), XP093158624, Retrieved from the Internet: URL:https://de.wikipedia.org/w/index.php?title=R?ntgenr?hre&oldid=239697903 [retrieved on 2024-05-02] * pages 1, 4-6 *	1	INV. H01J35/06 H01J35/14 H01J35/30
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X	US 2018/068823 A1 (UTSCHIG MICHAEL JOHN [US] ET AL) 8 March 2018 (2018-03-08) * figs. 1 to 4, 6, 8 and related text; paragraphs [0004], [0026] *	1-5,9, 10,13-15	TECHNICAL FIELDS SEARCHED (IPC)
X	US 2008/043916 A1 (LEMAITRE SERGIO [US]) 21 February 2008 (2008-02-21) * figs. 1 to 4 and related text *	1-3,6,9, 10,13-15	H01J
A	US 2013/266115 A1 (FAN JIAHUA [US] ET AL) 10 October 2013 (2013-10-10) * paragraph [0055] *	1	

The present search report has been drawn up for all claims

2

Place of search	Date of completion of the search	Examiner
Munich	28 June 2024	Krauss, Jan

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
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T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons
....
& : member of the same patent family, corresponding document

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Application Number
EP 23 21 4842

CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing claims for which payment was due.

- [ ] Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due and for those claims for which claims fees have been paid, namely claim(s):

- [ ] No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

see sheet B

- [X] All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.

- [ ] As all searchable claims could be searched without effort justifying an additional fee, the Search Division did not invite payment of any additional fee.

- [ ] Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:

- [ ] None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:

- [ ] The present supplementary European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims (Rule 164 (1) EPC).

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LACK OF UNITY OF INVENTION SHEET B

Application Number
EP 23 21 4842

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

1. claims: 7, 8, 11(completely); 1, 9, 10, 12-15(partially)

   directed to a method for X-ray generation with an X-ray tube with providing the electron beam focal spot with an asymmetric intensity profile on the anode, the intensity profile having a decreasing intensity in a tangential direction of rotation of the anode as defined in the first alternative of present independent claim 1 and corresponding subject matter form other claims

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2. claims: 2-6(completely); 1, 9, 10, 12-15(partially)

   directed to a method for X-ray generation with an X-ray tube with temporarily increasing an electron beam focal spot size in conjunction with deflecting the electron beam focal spot in the tangential direction of rotation of the anode, whereafter the electron beam focal spot size is decreased as defined in the second alternative of present independent claim 1 and corresponding subject matter form other claims

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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 23 21 4842

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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28-06-2024

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REFERENCES CITED IN THE DESCRIPTION

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Non-patent literature cited in the description

- **NICHOLAS RUBERT**. *JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS*, 2016, vol. 17 (3), 452-466 **[0043]**