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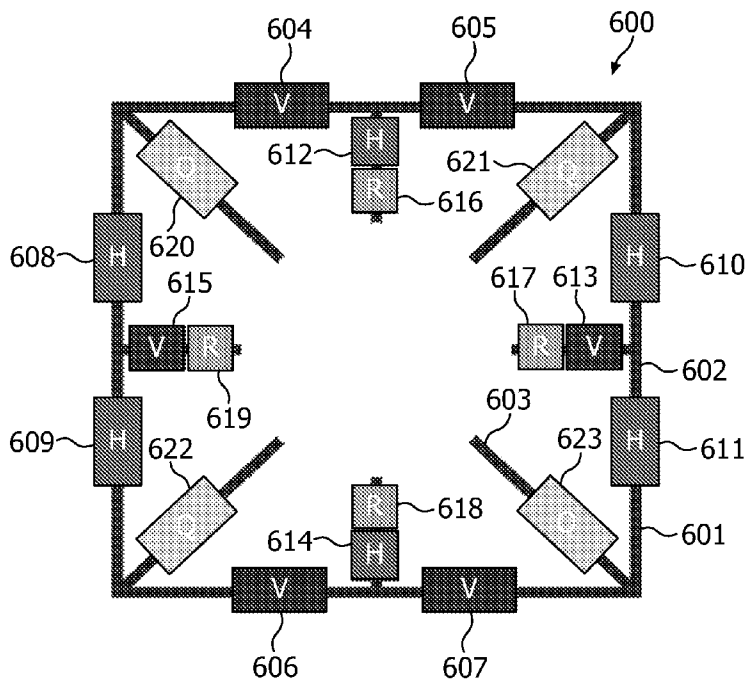


FIG. 6

(57) Abstract: According to an exemplary embodiment of the present invention, additional poles are added to the anode-side quadrupole of a double-quadrupole magnetic lens system. Such an octopole, hexapole or dodecapole creates a quadrupole field which enables a rotational compensation of disturbances caused by misalignment of the lenses. This may provide for an improved spot quality.

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MAGNETIC LENS SYSTEM FOR SPOT CONTROL IN AN X-RAY TUBE

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The invention relates to the field of X-ray imaging. In particular, the invention relates to a magnetic lens system, an X-ray tube, an examination apparatus, a method, a program element and a computer-readable medium.

10 A lens system for spot control in X-ray tubes may be based on the so-called double quadrupole concept, thereby comprising two magnetic quadrupole lenses. However, such a double quadrupole system may not be able to compensate for a rotational misalignment (i.e. a mechanical rotation of one quadrupole relative to the other) by electrical means. As a result, the tolerances on relative orientation of the quadrupole lenses may be strict.

15 Furthermore, the double-quadrupole lens system may only then be able to shift the region of non-rotated spots to one side of the field of view, if the lens assembly is mechanically rotated with respect to the rest of the system.

Furthermore, a double-quadrupole lens system may be required to create spot deflections, which may result in an appreciable distortion of the deflected spot over
20 the required range of spot deflection.

It may be desirable to have an improved focusing of a spot in an X-ray imaging system.

The invention provides a magnetic lens system, an X-ray tube, an examination apparatus, a method, a computer-readable medium, a program element and
25 a processing device with the features according to the independent claims.

It should be noted that the following described exemplary embodiments of the invention apply also for the X-ray tube, the examination apparatus, the method, the program element, the computer-readable medium and the processing device.

According to an exemplary embodiment of the present invention, a
30 magnetic lens system for controlling a size and a position of a spot on an anode of an X-

ray tube is provided, the magnetic lens system comprising a first magnetic lens element having a first group of poles and a second group of further poles, and a second magnetic lens element having a third group of poles, wherein the first and the second magnetic lens elements are adapted for focusing the spot and wherein the further poles of the
5 second group of the first magnetic lens element are adapted for generating an independent field which is independent from a field generated by the first group of poles, wherein the independent field is able to compensate for a rotation of the spot caused by a rotational misalignment of the first and second magnetic lens elements.

In other words, the magnetic lens system comprises two magnetic lens
10 elements for controlling the spot on the anode. The first magnetic lens comprises two groups of magnetic poles which can be operated independently from each other. Thus, a compensation of a spot rotation may be performed by generating a corresponding independent magnetic field with the second group of further magnetic poles.

Thus, an improved lens system may be provided which is able for
15 compensating a rotational misalignment between the two lens elements and which can change the spot geometry over the field-of-view. Furthermore, the magnetic lens system may provide for a lower spot distortion during deflection. It should be noted that to achieve a deflection field that causes lower distortion of a deflected spot, the field created by the second group of poles (excited by 'C'-coils in Fig. 7) may not be
20 independent of the deflection field created by the first group of poles (excited by 'B'-coils in Fig. 7) but may be intimately linked to that field. See Fig. 7 and the text referring to Fig. 7 for the case of an octopole with all identical poles.

According to another exemplary embodiment of the present invention, the first magnetic lens element is located at an anode side of the magnetic lens system and the second magnetic lens element is located at a cathode side of the magnetic lens
25 system.

According to another exemplary embodiment of the present invention, the first magnetic lens element comprises a first quadrupole and the further poles, wherein the second magnetic lens element is adapted as a second quadrupole.

According to another exemplary embodiment of the present invention, the first magnetic lens element is adapted as one of an octopole, a hexapole and a dodecapole.

Thus, for example, the number of poles of the anode-side quadrupole
5 may be doubled (octopole) or tripled (dodecapole), or two further poles may be added (hexapole).

It should be noted, however, that the number of poles of the original quadrupole may be increased by other numbers of further poles, for example by six poles or ten poles, or even more poles.

10 According to another exemplary embodiment of the present invention, the poles of the second group of the first magnetic lens element are adapted for generating an independent field which is able to control a rotation of the spot for modification of an effective spot shape in a particular region of a field-of-view.

Furthermore, according to another exemplary embodiment of the present
15 invention, the first quadrupole of the first magnetic lens element has poles with a first cross-sectional area, wherein the further poles of the first magnetic lens element have a second cross-sectional area. The first cross-sectional area is bigger than the second cross-sectional area.

Thus, the further poles used for spot rotation compensation may be
20 smaller than the original quadrupole poles.

According to another exemplary embodiment of the present invention, the poles of the first quadrupole of the first magnetic lens element have a first length, wherein the further poles of the first magnetic lens element have a second length, and
wherein the first length is different from the second length.

25 Thus, the (original) quadrupole poles and the further magnetic poles may be different in design. For example, they may have a different length, a different cross-sectional area, and their coils may have a different number of windings. This may provide for an individual design of the magnetic lens system, thereby providing for an effective spot rotation compensation.

30 According to another exemplary embodiment of the present invention, an X-ray tube for examination of an object of interest with an examination apparatus is

provided, the X-ray tube comprising a magnetic lens system for controlling a size and a position of a spot on an anode of the X-ray tube, wherein the magnetic lens system comprises a first magnetic lens element having a first group of poles and a second group of further poles, and a second magnetic lens element having a third group of poles, wherein the first and second magnetic lens elements are adapted for focusing the spot, wherein the further poles of the second group of the first magnetic lens element are adapted for generating an independent field which is independent from a field generated by the first group of poles, and wherein the independent field is able to compensate for a rotation of the spot caused by a rotational misalignment of the first and second magnetic lens elements.

Furthermore, according to another exemplary embodiment of the present invention, an examination apparatus for examination of an object of interest is provided, which comprises an X-ray tube with a magnetic lens system for controlling a size and a position of a spot on an anode of the X-ray tube, wherein the magnetic lens system comprises a first magnetic lens element having a first group of poles and a second group of poles, and a second magnetic lens element having a third group of poles. The first and second magnetic lens elements are adapted for focusing the spot, wherein the further poles of the second group of the first magnetic lens element are adapted for generating an independent field which is independent from a field generated by the first group of poles, and wherein the independent field is able to compensate for a rotation of the spot caused by a rotational misalignment of the first and second magnetic lens elements.

According to another exemplary embodiment of the present invention, a method for controlling a size and a position of a spot on an anode of an X-ray tube and for examination of an object of interest with an examination apparatus is provided, wherein a first magnetic lens element has a first group of poles and a second group of poles, the method comprising the steps of focusing the spot by the first magnetic lens element and a second magnetic lens element, and generating, by the further poles of the second group of the first magnetic lens element, an independent field which is independent from a field generated by the first group of poles, wherein the independent

field is able to compensate for a rotation of the spot caused by a rotational misalignment of the first and second magnetic lens elements.

Furthermore, a program element for controlling a size and a position of a spot on an anode of an X-ray tube and for examination of an object of interest with an examination apparatus is provided, wherein a first magnetic lens element has a first group of poles and a second group of further poles, and wherein the program element, when being executed by a processor, is adapted to carry out the above-mentioned method steps.

According to another exemplary embodiment of the present invention, a computer-readable medium is provided, in which a computer program for controlling a size and a position of a spot on an anode of an X-ray tube and for examination of an object of interest with an examination apparatus is stored, wherein the first magnetic lens element has a first group of poles and a second group of further poles, and which, when being executed by a processor, is adapted to carry out the above-mentioned method steps.

According to another exemplary embodiment of the present invention, a processing device for controlling a size and a position of a spot on an anode of an X-ray tube and for examination of an object of interest with an examination apparatus is provided, the processing device adapted to carry out the above-mentioned method steps.

The method for controlling the size and position of the spot may be embodied as the computer program, i.e. by software, or may be embodied using one or more special electronic optimization circuits, i.e. in hardware, or the method may be embodied in hybrid form, i.e. by means of software components and hardware components.

The program element according to an exemplary embodiment of the invention may preferably be loaded into working memories of a data processor. The data processor may thus be equipped to carry out exemplary embodiments of the methods of the present invention. The computer program may be written in any suitable programming language, such as, for example, C++ and may be stored on a computer-readable medium, such as a CD-ROM. Also, the computer program may be available from a network, such as the WorldWideWeb, from which it may be downloaded into

image processing units or processors, or any suitable computers.

It may be seen as the gist of an exemplary embodiment of the present invention that additional poles are located at the anode-side quadrupole of a double-quadrupole system. For example, the number of poles on the anode-side may be
5 doubled, thus resulting in an octopole. The added poles are adapted for creating a quadrupole field which is linearly independent of the field generated by the original four poles. By properly controlling the relative strength and signs of the generated quadrupole field, the superposition of these fields may form a quadrupole field of arbitrary strength and orientation, thus enabling an effective compensation of spot
10 rotation.

These and other aspects of the present invention will become apparent from and be elucidated with reference to the embodiments described hereinafter.

Exemplary embodiments of the present invention will now be described in the following, with reference to the following drawings.
15

Fig. 1 shows a simplified schematic representation of a CT apparatus according to an exemplary embodiment of the present invention.

Fig. 2 shows spot sizes attainable with a magnetic double-quadrupole focusing system.
20

Figs. 3A, 3B, 3C and 3D show shapes of a spot in a double-quadrupole system.

Fig. 4A shows a variation of a focal spot geometry and size in various directions away from the center of radiation.

Fig. 4B shows a schematic representation of the relation between the electronic and optical focal spot.
25

Fig. 5 shows shapes of deflected spots in a magnetic double-quadrupole focusing system.

Fig. 6 shows a configuration of coils on an octopole according to an exemplary embodiment of the present invention.
30

Fig. 7 shows coil turn ratios for a single deflection direction according to an exemplary embodiment of the present invention.

Fig. 8 shows shapes of deflected spots according to an exemplary embodiment of the present invention.

5 Fig. 9A, 9B, 9C and 9D show different optical spots.

Fig. 10A, 10B and 10C show spot shape variations over the field-of-view.

Fig. 10D shows a spot on an anode and a spot in the field-of-view.

10 Fig. 11 shows a flow-chart of an exemplary embodiment of a method according to the invention.

Fig. 12 shows an exemplary embodiment of a processing device for executing an exemplary embodiment of a method in accordance with the present invention.

15 Fig. 13 shows the location of the magnetic lens elements.

The illustration in the drawings is schematically. In different drawings, similar or identical elements are provided with the same reference numerals.

20 Fig. 1 shows an exemplary embodiment of a computed tomography scanner system according to the present invention, in which a magnetic lens system according to an aspect of the invention is implemented..

The computer tomography apparatus 100 depicted in Fig. 1 is a cone-beam CT scanner. However, the invention may also be carried out with a fan-beam geometry. In order to generate a primary fan-beam, the aperture system 105 can be
25 configured as a slit collimator. The CT scanner depicted in Fig. 1 comprises a gantry 101, which is rotatable around a rotational axis 102. The gantry 101 is driven by means of a motor 103. Reference numeral 104 designates a source of radiation such as an X-ray source, which, according to an aspect of the present invention, emits polychromatic or monochromatic radiation.

30 Reference numeral 105 designates an aperture system which forms the radiation beam emitted from the radiation source to a cone-shaped radiation beam 106.

The cone-beam 106 is directed such that it penetrates an object of interest 107 arranged in the center of the gantry 101, i.e. in an examination region of the CT scanner, and impinges onto the detector 108. As may be taken from Fig. 1, the detector 108 is arranged on the gantry 101 opposite to the source of radiation 104, such that the surface of the detector 108 is covered by the cone-beam 106. The detector 108 depicted in Fig. 1 comprises a plurality of detector elements 123 each capable of detecting X-rays which have been scattered by or passed through the object of interest 107.

During scanning the object of interest 107, the source of radiation 104, the aperture system 105 and the detector 108 are rotated along the gantry 101 in the direction indicated by an arrow 116. For rotation of the gantry 101 with the source of radiation 104, the aperture system 105 and the detector 108, the motor 103 is connected to a motor control unit 117, which is connected to a reconstruction unit 118 (which might also be denoted as a calculation or determination unit).

In Fig. 1, the object of interest 107 is a human being which is disposed on an operation table 119. During the scan of, e.g., the heart 130 of the human being 107, while the gantry 101 rotates around the human being 107, the operation table 119 displaces the human being 107 along a direction parallel to the rotational axis 102 of the gantry 101. By this, the heart 130 is scanned along a helical scan path. The operation table 119 may also be stopped during the scans to thereby measure signal slices. It should be noted that in all of the described cases it is also possible to perform a circular scan, where there is no displacement in a direction parallel to the rotational axis 102, but only the rotation of the gantry 101 around the rotational axis 102.

Moreover, an electrocardiogram device 135 may be provided which measures an electrocardiogram of the heart 130 of the human being 107 while X-rays attenuated by passing the heart 130 are detected by detector 108. The data related to the measured electrocardiogram are transmitted to the reconstruction unit 118.

The detector 108 is connected to the reconstruction unit 118. The reconstruction unit 118 receives the detection result, i.e. the read-outs from the detector elements 123 of the detector 108 and determines a scanning result on the basis of these read-outs. Furthermore, the reconstruction unit 118 communicates with the motor

control unit 117 in order to coordinate the movement of the gantry 101 with motors 103 and 120 with the operation table 119.

The reconstruction unit 118 may be adapted for reconstructing an image from read-outs of the detector 108. A reconstructed image generated by the reconstruction unit 118 may be output to a display (not shown in Fig. 1) via an interface 122.

The reconstruction unit 118 may be realized by a data processor to process read-outs from the detector elements 123 of the detector 108.

The measured data, namely the cardiac computer tomography data and the electrocardiogram data are processed by the reconstruction unit 118 which may be further controlled via a graphical user-interface (GUI) 140. This retrospective analysis may be based on a helical cardiac cone-beam reconstruction scheme using retrospective ECG gating. It should be noted, however, that the present invention is not limited to this specific data acquisition and reconstruction.

It should be noted, that the magnetic lens system is not limited to an implementation in a CT system, but may be implemented in other examination apparatus, such as, for example, a C-arm system.

Fig. 2 shows spot sizes attainable with a magnetic double-quadrupole focusing system.

Unipolar X-ray tubes may have a distance between the cathode and the anode of about 2 cm in older generation tubes and up to about 10 cm in newer generation tubes to make room for a field-free region containing a collecting electrode for electrons backscattered from the anode. Because the backscattered electrons no longer land on the anode, the thermal load on the anode may be reduced considerably (by up to about 40 %). Due to the longer cathode-to-anode distance, however, explicit means for controlling the focus of the electron beam on the anode (the "spot") may be required. The objective of spot control is to create an elongated spot on the slanted part of the anode, such that, when viewed from the X-ray exit window, the effective (projected) X-ray source has an approximately equal size in width and length dimension (to achieve this, the spot length may have to be larger than the width by a factor of typically around 8 which depends on the anode slant angle).

The size of the spot has to depend on the dissipated power: at high powers the size will have to increase to prevent overheating of the anode. Such a spot control may be achieved by using a double-quadrupole magnetic focusing system. The magnetic double-quadrupole may be capable of reaching the required spot sizes, as depicted in Fig. 2.

The horizontal axis 201 shows the length of the line focus in mm, and the vertical axis 202 shows the width in mm, ranging from 0 to 2 mm, wherein the length of line focus ranges from 0 to 14 mm.

Each curve, such as curves 203, 204, represents a value of the average quadrupole current (average of the currents through the cathode-side and anode-side quadrupole), while the markers on each curve correspond to different values of the current ratio. Currents are in units of ampere-turns. The dimensions indicate the true size of the spot on the anode, not the effective (projected) size of the X-ray spot. The rectangles 205, 206, 207 and 208 indicate IEC specifications for the spot size, i.e. IEC 0.4, 0.5, 0.6 and 0.8, respectively.

As already noted above, the double-quadrupole concept may not provide for a compensation of rotational misalignments (i.e. a mechanical rotation of one quadrupole relative to the other) by electrical means. As a result, the tolerances on relative orientation are strict.

Fig. 3A to 3D show shapes of a spot in a double-quadrupole system in which the two quadrupoles are perfectly oriented (Figs. 3A, 3C) and in which they are rotated in opposite directions over 0.5° (i.e. a relative rotation of 1°) (Figs. 3B, 3D).

With respect to Figs. 3A to 3D it should be noted that the rotational misalignment of the two quadrupoles causes a net rotation of the spot, resulting in an increase in apparent spot width. When this increase in apparent spot width is compensated by refocusing the spot, the temperature on the anode will increase, thereby decreasing the maximum power allowable in the spot.

The spots 303, 304 shown are projected spots (as viewed from the exit window).

The horizontal axis 301 in Figs. 3A and 3B depicts the length direction in mm, ranging from -2 to 2 mm. The vertical axis 302 depicts the width direction in mm, ranging from -2 to 2 mm. The scale bar 305 ranges from 0 to 1 .

The horizontal axis 306 in Figs. 3C and 3D depict the relative position in mm, ranging from -2 to 2 mm. The vertical axis 307 depicts the normalized intensity, ranging from 0 to 1.2 . Curve 308 depicts the length profile of the spots and curve 309 depicts the width profile of the spot in case of perfect orientation of the spot. The length is 1.26 mm, the width 0.93377 mm, as measured at line 312.

The length profile of the rotated spot 304 is depicted by curve 310 and the width profile by curve 311. The overall length is 1.2764 mm, and the overall width is 0.97165 mm.

Fig. 4A shows an example of the variation of a focal spot geometry and size in various directions away from the center of radiation (i.e. over the field-of-view). As it can be seen from Fig. 4A the X-ray spot appears rotated when viewed off-center in the width direction (the horizontal direction of emerging radiation 401). In some cases, it may be desirable to be able to shift the region of non-rotated spots to one side of the field-of-view, e.g. when the most interesting features of an X-ray image are not in the center. However, a double-quadrupole lens system is not able to shift the region of the non-rotated spots to one side of the field-of-view, unless the lens assembly can be mechanically rotated with respect to the rest of the system.

The vertical axis 402 of Fig. 4A depicts the vertical direction of emerging radiation, ranging from about -20° to $+20^\circ$. The horizontal axis 401 ranges from around -20° to $+20^\circ$ as well.

As may be seen from Fig. 4A, the focal spot may be increasingly rotated when moving away from the tube axis 403. Furthermore, the spot may be more and more elongated, when changing the vertical direction of the emerging radiation from $+20^\circ$ (405) to -20° (406, 407). Horizontal line 404 depicts the disk angle, 20° in this example. It should be noted, that the value of 20 degrees is exaggerated compared to a real anode, and is chosen for purposes of illustration.

Fig. 4B shows a conventional x-ray tube without magnetic lens elements, showing the relation between the electronic focal spot 410 and the optical focal spot

411. Furthermore, the cathode 408 and the rotating anode 409 are schematically depicted. 412 depicts the focal spot trajectory on the rotating anode 409.

As may be seen from Fig. 4B, the electronic focal spot 410 has a length l which is bigger than the width w , whereas the optical focal spot width and length are more or less identical.

For use in CT applications, it may be required that the spot can be dynamically deflected (“spot jumping”) without an appreciable change in shape. Although it is possible, with a proper coil configuration, to excite a dipole (deflection) field on a quadrupole lens element, the quality of such a dipole field may not be very high. In case of a double-quadrupole lens system, the deflection may result in an appreciable distortion of the deflected spot over the required range of spot deflection, as may be seen from Fig. 5.

Fig. 5 shows the shape of deflected spots in a magnetic double-quadrupole focusing system. The spot is deflected simultaneously in the length (horizontal) and width (vertical) direction over multiples of 2.7 mm and 0.42 mm, respectively, by application of appropriate dipole fields on the anode-side quadrupole. The deflection distances of 2.7 mm and 0.42 mm are measured on the anode. Notice the deflection-induced spot asymmetry. The rectangle 501 indicates the undeflected spot 502. The spots shown are projected spots (as viewed from the exit window). The positions of the shown spots are not to scale.

Spot 503 corresponds to a length deflection of $-2\times$ and to a width deflection of $3\times$, i.e. to a length deflection of -2×2.7 mm and to a width deflection of 3×0.42 mm. Similarly, spot 504 corresponds to a length deflection (l) of $-1\times$ and to a width deflection (w) of $3\times$. Spot 503 corresponds to $l = 0\times$, $w = 3\times$. Spot 505 corresponds to $l = 1\times$, $w = 3\times$. Spot 506 corresponds to $l = -2\times$, $w = 0\times$. Spot 507 corresponds to $l = -1\times$, $w = 0\times$. Spot 508 corresponds to $l = 1\times$, $w = 0\times$. Spot 509 corresponds to $l = -2\times$, $w = -3\times$. Spot 510 corresponds to a $l = -1\times$, $w = -3\times$. Spot 511 corresponds to $l = 0\times$, $w = -3\times$. Spot 512 corresponds to $l = 1\times$, $w = -3\times$.

Apart from dynamic deflection, static deflection may be required as well, to properly adjust the spot position to the desired position in an X-ray imaging system,

e.g. a CT system. The limited useful deflection range may severely restrict the compensation range for inaccuracies in mechanical positioning of the tube in a system. Moreover, the required static deflection may further decrease the range available for dynamic deflection.

5 According to an aspect of the present invention, additional poles may be added to the anode-side quadrupole. According to an exemplary embodiment of the present invention, the number of poles may be doubled, i.e. the anode-side quadrupole is replaced by an octopole. The four added poles may create a quadrupole field which is linearly independent of the field generated by the original four poles. By properly
10 controlling the relative strengths and signs of the generated quadrupole fields, the superposition of these fields may form a quadrupole field of any desired strength and orientation. However, an octopole is not the only way; it is also possible to create a quadrupole field of arbitrary orientation using a different number of poles, e.g. six poles (hexapole) or 12 poles (dodecapole).

15 In the following, it will be assumed that the anode-side lens element is an octopole. The field generated by the four additional poles may be used to compensate spot rotations which are caused by rotational misalignments of the cathode- and anode-side lens elements, or may be used to intentionally create a spot rotation, e.g. to modify the effective spot shape in a certain part of the field-of-view. The compensating field is
20 chosen such the resulting spot has the desired orientation. It should be noted that within limits both rotational misalignments of the lens elements relative to each other as well as a rotation of the lens unit as a whole may be compensated by the field of the additional poles. In the case of compensating for rotational misalignments, the strength of the additional, compensating field may only be a small fraction of the strength of the
25 original focusing field, and there may be no danger of magnetic saturation of the additional poles. Consequently, the additional poles are allowed to have a smaller cross-sectional area than the original four poles that provide the main focusing function. The additional poles also need not have the same length as the four original poles.

 Moreover, an octopole (or hexapole, dodecapole, etc.) may create a
30 dipole field of much better quality than the dipole field created by a simple quadrupole, resulting in much lower spot distortion when deflecting, and providing a larger range of

compensation for shifts of the electron gun unit (here defined as emitter plus focusing element) relative to the rest of the X-ray tube, or for shifts of the X-ray tube as a whole relative to the rest of the imaging system. It should be noted that this may require a precise ratio of the excitations of the first and second set of poles.

5 The capability to adjust spot orientation may allow for relaxed tolerances for rotational misalignments, and the increased deflection range may relax the tolerance on lateral mechanical misalignments. Apart from providing a better tube performance, these factors may, therefore, also contribute to a lower manufacturing cost, in spite of the added complexity.

10 Fig. 6 shows a possible configuration of coils on an octopole that replaces the anode-side quadrupole. The configuration 600 contains coils and current supplies (not depicted in Fig. 6) to generate the main quadrupole focusing field, the additional quadrupole field for control of spot orientation, and fields for horizontal and vertical deflection.

15 The thick lines 601, 602, 603, etc. correspond to the yoke and pole pieces. The rectangles 604, 605, 606, etc. drawn on the yoke and pole pieces indicate the coils. The coils of the same colour (namely coils 604 to 607, 613, 615; 608 to 611, 612, 614; 616 to 619, 620 to 623) can be connected in series and are attached to their respective current supply (not depicted in Fig. 6). Coils 620 to 623 are the main
20 quadrupole focusing coils; coils 616 to 619 are the additional (possibly smaller) quadrupole coils to provide a net rotation of the effective quadrupole field; coils 604 to 607, 613, 615 are vertical deflection coils and coils 608 to 611, 612, 614 are for horizontal deflection.

Alternative coil configurations, in which the main quadrupole focusing
25 coils are not on the pole pieces but on the outer part of the yoke, may require a larger total number of ampere-turns to create the quadrupole field than the configuration depicted in Fig. 6, and may therefore be less desirable.

Fig. 7 shows the relations between the number of turns on the deflection
30 coils to arrive at a low-distortion deflection field. For a low-distortion deflection field, the magnetic scalar potential of the pole pieces should be proportional to the sine (or cosine) of the pole piece's azimuthal angle (assuming that all pole pieces are identical in

size and are equally distributed around the optical axis), resulting in $(B+C)/B = \sqrt{2} = 1.414$, or $C/B = 0.414$. When the additional poles are not identical in length or cross-sectional area to the first group of poles, a different value of C/B will be required to arrive at a low-distortion deflection field.

5 Reference numerals 701, 702, 703 and 704 depict the B-coils and reference numerals 705, 706 depict the C-coils.

The deflection coils B (701 – 704) in Fig. 7 are placed on the outer part of the yoke to keep the diagonal pole pieces free for the main focusing coils that create the greatest part of the quadrupole field. These focusing coils carry the largest current, and it may be advantageous to have much space available for them

10

It should be noted with respect to Fig. 7 that the coils on the yoke ('B' in Fig. 7) are not related to the 'further' poles but are for the deflection function that should already be present even without the added 'further' poles. Their location is not really a part of this invention. These coils have been placed on the yoke in the example shown in Fig. 7 to have more space available for coils of the first group of poles.

15

The improved quality of deflection may be seen when the plots of deflected spots in Fig. 8 are compared to those in Fig. 5. The asymmetry of deflected spots, clearly visible in Fig. 5, is no longer present. The larger deflection range is also beneficial for the tolerance of the lens system to translational misalignments between the two lens elements. Such shifts between elements may give rise to a displacement of the spot, which must be compensated by application of a deflection field. Better quality of deflection (a larger deflection range) may thus imply an improved tolerance to translational misalignments.

20

Similarly to Fig. 5, spot 803 corresponds to $l = -3\times$, $w = 3\times$, i.e. to a length deflection of -3×2.7 mm and to a width deflection of 3×0.42 mm, 804 corresponds to $l = -2\times$, $w = 3\times$; spot 805 corresponds to $l = -1\times$, $w = 3\times$; spot 806 corresponds to $l = 0\times$, $w = 3\times$; spot 807 corresponds to $l = 1\times$, $w = 3\times$; spot 808 corresponds to $l = -2\times$, $w = 0\times$; spot 809 corresponds to $l = -2\times$, $w = 0\times$; spot 810 corresponds to $l = -1\times$, $w = 0\times$; spot 802 corresponds to $l = 0\times$, $w = 0\times$ and shows the undeflected spot, as indicated by rectangular 801. Spot 811 corresponds to $l = 1\times$, $w =$

25

30

0×; spot 812 corresponds to $l = -3\times$, $w = -3\times$; spot 813 corresponds to $l = -2\times$, $w = -3\times$; spot 814 corresponds to $l = -1\times$, $w = 3\times$; spot 815 corresponds to $l = 0\times$, $w = -3\times$; and spot 816 corresponds to $l = 1\times$, $w = -3\times$.

In Figs. 9A – 9D it is shown that the rotational degree of freedom
5 provided by the additional quadrupole coils (which are “R” coils 616 – 619 in Fig. 6) may successfully be used to compensate the effects of rotationally misaligned lens elements. With a current of 3.5 % of the current in the main focusing coils 520 – 523 (assuming an equal number of turns of the coils 616 - 619 and 620 - 623), the effects of the 1° relative misalignment between the focusing elements may be compensated.

10 The horizontal axis 901 depicts the length direction in mm, ranging from –2 to 2 mm. The vertical axis 902 depicts the width direction in mm, ranging from –2 to 2 mm. Furthermore, the scale bar 904 depicts the spot intensity of the spots 903, 905.

The horizontal axis 906 in Figs. 9C, 9D corresponds to the relative
15 position in mm, ranging from –2 to 2 mm. The vertical axis 907 depicts the normalized intensity, ranging from 0 to 1.2.

Curves 908, 910 depict the length profile and curves 909, 911 depict the width profile of the respective spot.

Figs. 9A, 9C show the optical spot when the lens elements of a
20 quadrupole-octopole focusing system are rotated in opposite directions over 0.5° (i.e. a relative rotation of 1° , as in Fig. 3). Fig. 9B, 9D depict a spot when the additional quadrupole coils (“R”-coils 616 – 619 of Fig. 5) have been excited with 3.5 % of the current of the main quadrupole coils (“Q”-coils 620 – 623) to compensate for the orientational mismatch (1°) between the octopole and the quadrupole. Notice how the spot has regained its proper orientation, resulting in a decrease in apparent width.

25 Fig. 10A – 10C show spot shape variation over the field-of-view and how it can be influenced by deliberately introducing a rotation of the spot on the anode. Fig. 10A shows the spot shape variation for a well-aligned system without spot rotation. The spot shapes are for combinations of horizontal and vertical viewing angles from the set $\{-6^\circ, 0^\circ, +6^\circ\}$, for an anode angle of 7.125° . Thus, spot 1012 corresponds to a
30 vertical viewing angle of $+6^\circ$ and a horizontal viewing angle of -6° , wherein spot 1013 corresponds to a horizontal viewing angle of -6° and a vertical viewing angle of -6° . In

Fig. 10A no rotation of the quadrupole field in the anode-side lens element has been performed. In Fig. 10B, a 2° rotation of the field has been performed, wherein in Fig. 10C a 3° rotation has been performed. Note how the variation and spot shape over the width direction becomes asymmetric for non-zero field rotation. In Figs. 10B and 10C
5 the apparent spot width in the lower part of the field of view has improved (decreased) at the cost of the spot width in the upper part of the field of view. This may be desirable when features in the lower part of the field of view require the best resolution. By changing the sign of the rotation, the best resolution may be placed in the upper part of the field of view, if so desired.

10 Fig. 10D shows a schematic representation of the spot 1004 on the anode 1003 and the spot 1005 in the field-of-view. Horizontal axis 1001 depicts the spot length direction and vertical axis 1002 depicts the spot width direction.

Field-of-view spot 1004 is shortened in comparison to the spot 1005 on the anode.

15 Fig. 11 shows a method of an exemplary embodiment of the present invention. In step 1, a focusing of the spot by the first magnetic lens element and the second magnetic lens element is performed. Then, in step 2, an independent field is generated by the further poles of the first magnetic lens element by means of which a rotational compensation of the spot caused by a rotational misalignment of the two
20 magnetic lens elements is performed.

Fig. 12 shows an exemplary embodiment of a data processing device 500 according to the present invention for executing an exemplary embodiment of a method in accordance with the present invention. The data processing device 500 depicted in Fig. 12 comprises a central processing unit (CPU) or processor 501 connected to a
25 memory 502 for storing an image depicting an object of interest, such as a patient or an item of baggage. The data processor 501 may be connected to a plurality of input/output network or diagnosis devices, such as a CT device. The data processor 501 may furthermore be connected to a display device 503, for example, a computer monitor, for displaying information or an image computed or adapted in the data processor 501. An
30 operator or user may interact with the data processor 501 via a keyboard 504 and/or other output devices, which are not depicted in Fig. 12.

Furthermore, via the bus system 505, it may also be possible to connect the image processing and control processor 501 to, for example, a motion monitor, which monitors a motion of the object of interest. In case, for example, a lung of a patient is imaged, the motion sensor may be an exhalation sensor. In case the heart is imaged, the motion sensor may be an electrocardiogram.

Exemplary embodiments of the invention may be sold as a software option to CT scanner console, imaging workstations or PACS workstations.

Fig. 13 schematically shows the location of the cathode-side and anode-side lens elements 1301, 1302 of a double quadrupole magnetic lens system or of a system according to the present invention. Electrons emitted by the cathode 1303 are accelerated by a potential difference between the cathode 1303 and the inner tube wall 1304. The electron beam 1305 thus created then passes through the magnetic fields created by the cathode-side and anode-side lens elements before striking the anode 1306. The size of the electronic spot on the anode can be controlled by properly tuning the signs and strengths of the quadrupole fields generated by the lens elements; the position of the beam in the x direction and y direction can be influenced by dipole fields of the appropriate strengths.

It should be noted that the term “comprising” does not exclude other elements or steps and the “a” or “an” does not exclude a plurality. Also elements described in association with different embodiments may be combined.

It should also be noted that reference signs in the claims shall not be construed as limiting the scope of the claims.

CLAIMS:

5

1. A magnetic lens system for controlling a size and a position of a spot on an anode of an X-ray tube, the magnetic lens system comprising:

10 a first magnetic lens element having a first group of poles and a second group of further poles;

a second magnetic lens element having a third group of poles;

wherein the first and second magnetic lens elements are adapted for focusing the spot;

15 wherein the further poles of the second group of the first magnetic lens element are adapted for generating an independent field which is independent from a field generated by the first group of poles; and

wherein the independent field is able to compensate for a rotation of the spot caused by a rotational misalignment of the first and second magnetic lens elements.

20 2. The magnetic lens system of claim 1,

wherein the first magnetic lens element is located at an anode side of the magnetic lens system; and

wherein the second magnetic lens element is located at an cathode side of the magnetic lens system.

25

3. The magnetic lens system of claim 1,

wherein the first magnetic lens element comprises a first quadrupole and the further poles; and

wherein the second magnetic lens element is adapted as a second quadrupole.

30

4. The magnetic lens system of claim 1,
 wherein the first magnetic lens element is adapted as one of an octopole, an
 hexapole, and a dodecapole.
- 5 5. The magnetic lens system of claim 1,
 wherein the poles of the second group of the first magnetic lens element are
 adapted for generating an independent field which is able to control a rotation of the
 spot for modification of an effective spot shape in a particular region of a field-of-view.
- 10 6. The magnetic lens system of claim 1,
 wherein the first quadrupole of the first magnetic lens element has poles with a
 first cross-sectional area;
 wherein the further poles of the first magnetic lens element have a second cross-
 sectional area; and
15 wherein the first cross-sectional area is bigger than the second cross-sectional
 area.
7. The magnetic lens system of claim 1,
 wherein the poles of the first quadrupole of the first magnetic lens element have
20 a first length;
 wherein the further poles of the first magnetic lens element have a second
 length; and
 wherein the first length is different from the second length.
- 25 8. An X-ray tube for examination of an object of interest with an
 examination apparatus, the X-ray tube comprising a magnetic lens system for
 controlling a size and a position of a spot on an anode of the X-ray tube, wherein the
 magnetic lens system comprises:
 a first magnetic lens element having a first group of poles and a second group of
30 further poles;
 a second magnetic lens element having a third group of poles;

wherein the first and second magnetic lens elements are adapted for focusing the spot;

wherein the further poles of the second group of the first magnetic lens element are adapted for generating an independent field which is independent from a field
5 generated by the first group of poles; and

wherein the independent field is able to compensate for a rotation of the spot caused by a rotational misalignment of the first and second magnetic lens elements.

9. An examination apparatus for examination of an object of interest, the
10 examination apparatus comprising an X-ray tube with a magnetic lens system for controlling a size and a position of a spot on an anode of the X-ray tube, wherein the magnetic lens system comprises:

a first magnetic lens element having a first group of poles and a second group of further poles;

15 a second magnetic lens element having a third group of poles;

wherein the first and second magnetic lens elements are adapted for focusing the spot;

wherein the further poles of the second group of the first magnetic lens element are adapted for generating an independent field which is independent from a field
20 generated by the first group of poles; and

wherein the independent field is able to compensate for a rotation of the spot caused by a rotational misalignment of the first and second magnetic lens elements.

10. A method for controlling a size and a position of a spot on an anode of an
25 X-ray tube and for examination of an object of interest with an examination apparatus, wherein a first magnetic lens element has a first group of poles and a second group of further poles, the method comprising the steps of:

focusing the spot by the first magnetic lens element and a second magnetic lens element;

30 generating, by the further poles of the second group of the first magnetic lens element, an independent field independent from a field generated by the first group of

poles, which independent field is able to compensate for a rotation of the spot caused by a rotational misalignment of the first and second magnetic lens elements.

11. A program element for controlling a size and a position of a spot on an anode of an X-ray tube and for examination of an object of interest with an examination apparatus, wherein a first magnetic lens element has a first group of poles and a second group of further poles, and which, when being executed by a processor (401), is adapted to carry out the steps of:

10 focusing the spot by a first magnetic lens element and a second magnetic lens element;

generating, by the further poles of the second group of the first magnetic lens element, an independent field independent from a field generated by the first group of poles, which independent field is able to compensate for a rotation of the spot caused by a rotational misalignment of the first and second magnetic lens elements.

15

12. A computer-readable medium in which a computer program for controlling a size and a position of a spot on an anode of an X-ray tube and for examination of an object of interest with an examination apparatus is stored, wherein a first magnetic lens element has a first group of poles and a second group of further poles, and which, when being executed by a processor, is adapted to carry out the steps of:

20 focusing the spot by a first magnetic lens element and a second magnetic lens element;

25 generating, by the further poles of the second group of the first magnetic lens element, an independent field independent from a field generated by the first group of poles, which independent field is able to compensate for a rotation of the spot caused by a rotational misalignment of the first and second magnetic lens elements.

13. An processing device for controlling a size and a position of a spot on an anode of an X-ray tube and for examination of an object of interest with an examination apparatus, the processing device adapted to carry out the steps of:

30

focusing the spot by a first magnetic lens element and a second magnetic lens element;

generating, by the further poles of the second group of the first magnetic lens element, an independent field independent from a field generated by the first group of poles, which independent field is able to compensate for a rotation of the spot caused by
5 a rotational misalignment of the first and second magnetic lens elements.

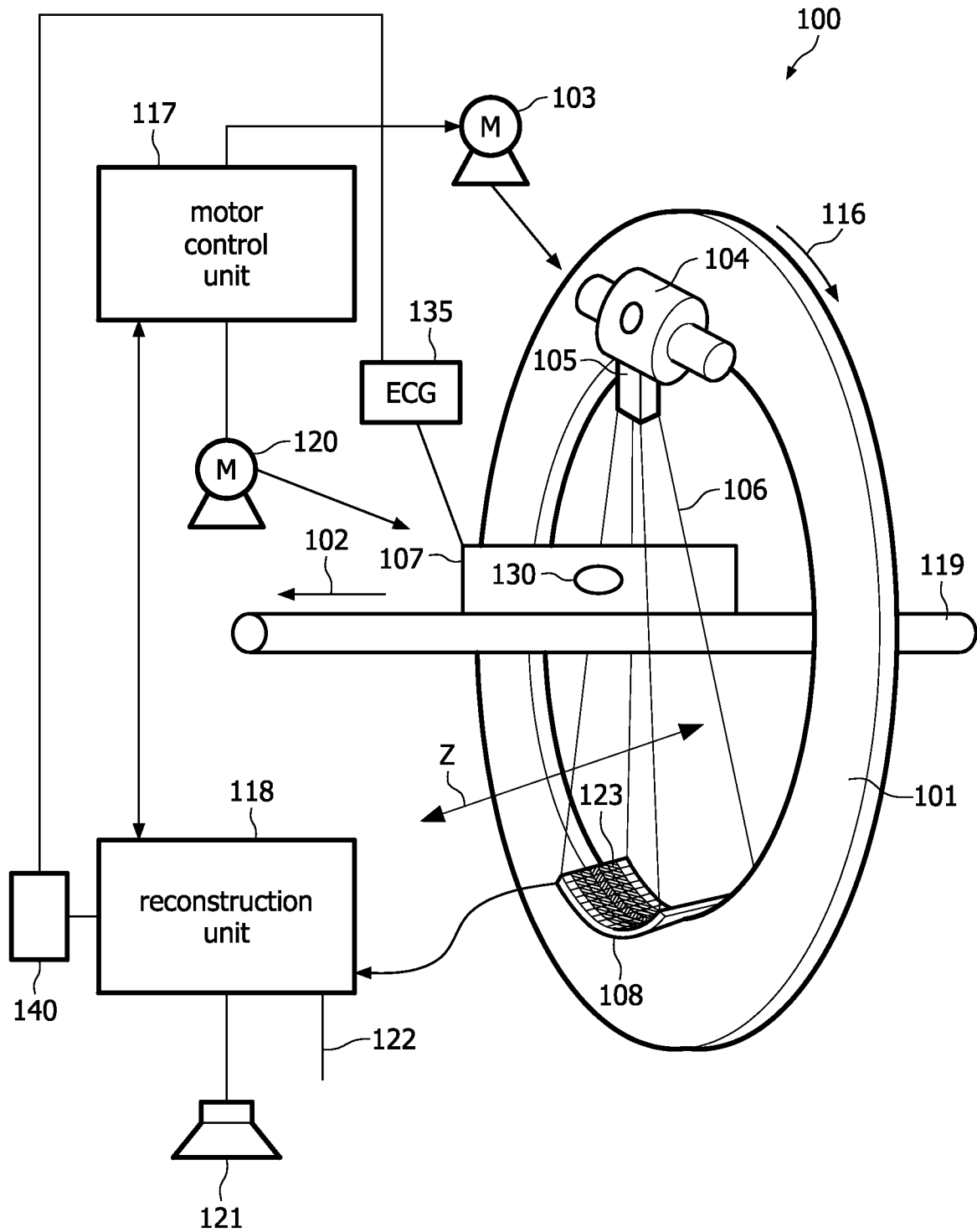


FIG. 1

75 kV spot size (2650 K; 15% level; mode 2)
square emitter 7x7 mm; BiQuad RealDesignV2

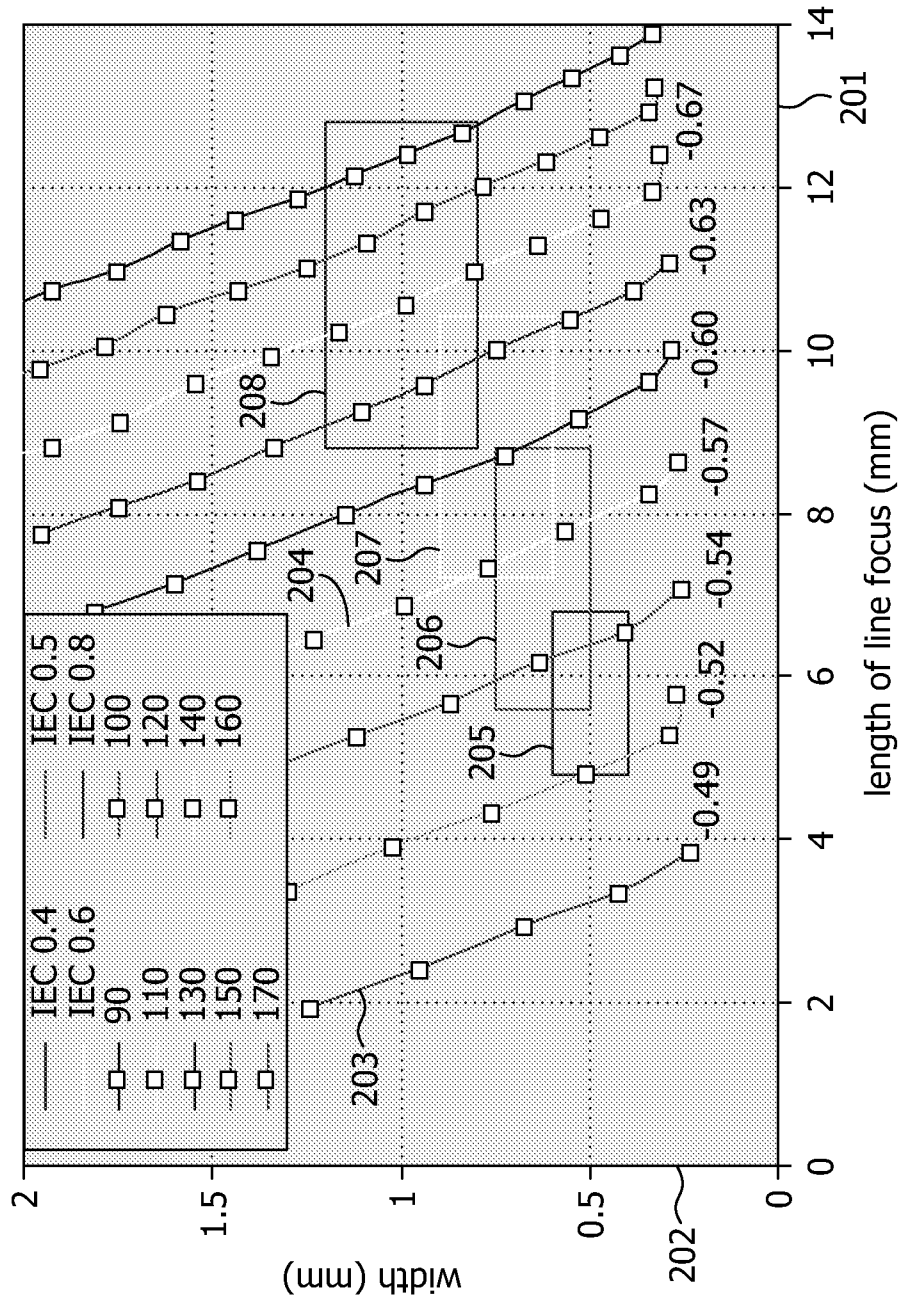


FIG. 2

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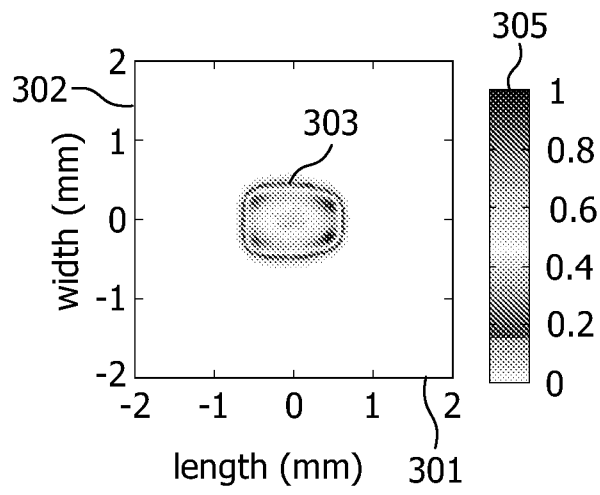


FIG. 3A

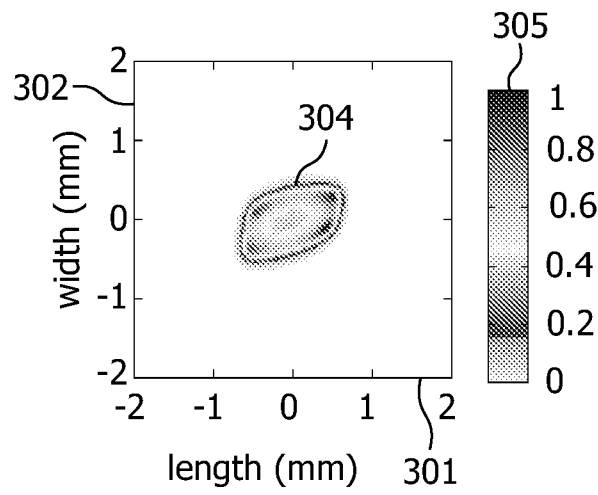


FIG. 3B

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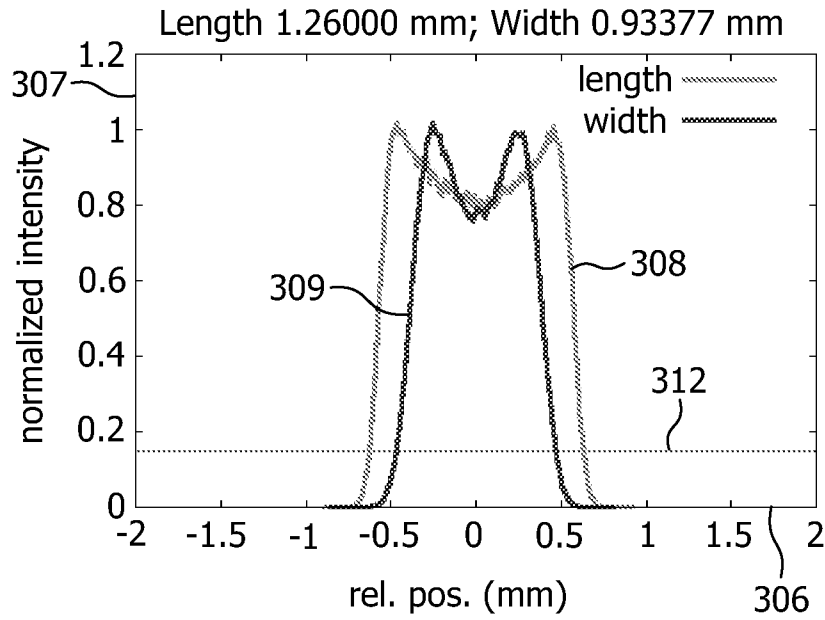


FIG. 3C

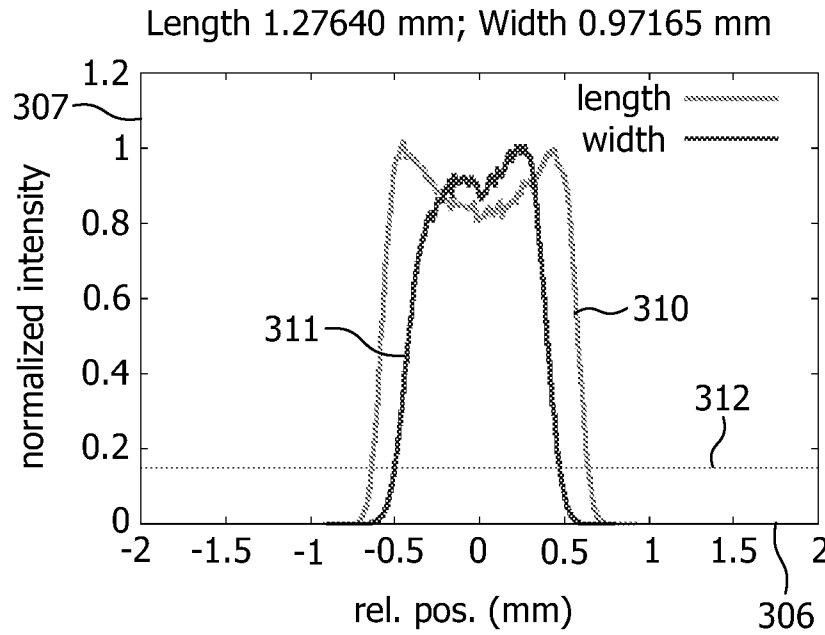


FIG. 3D

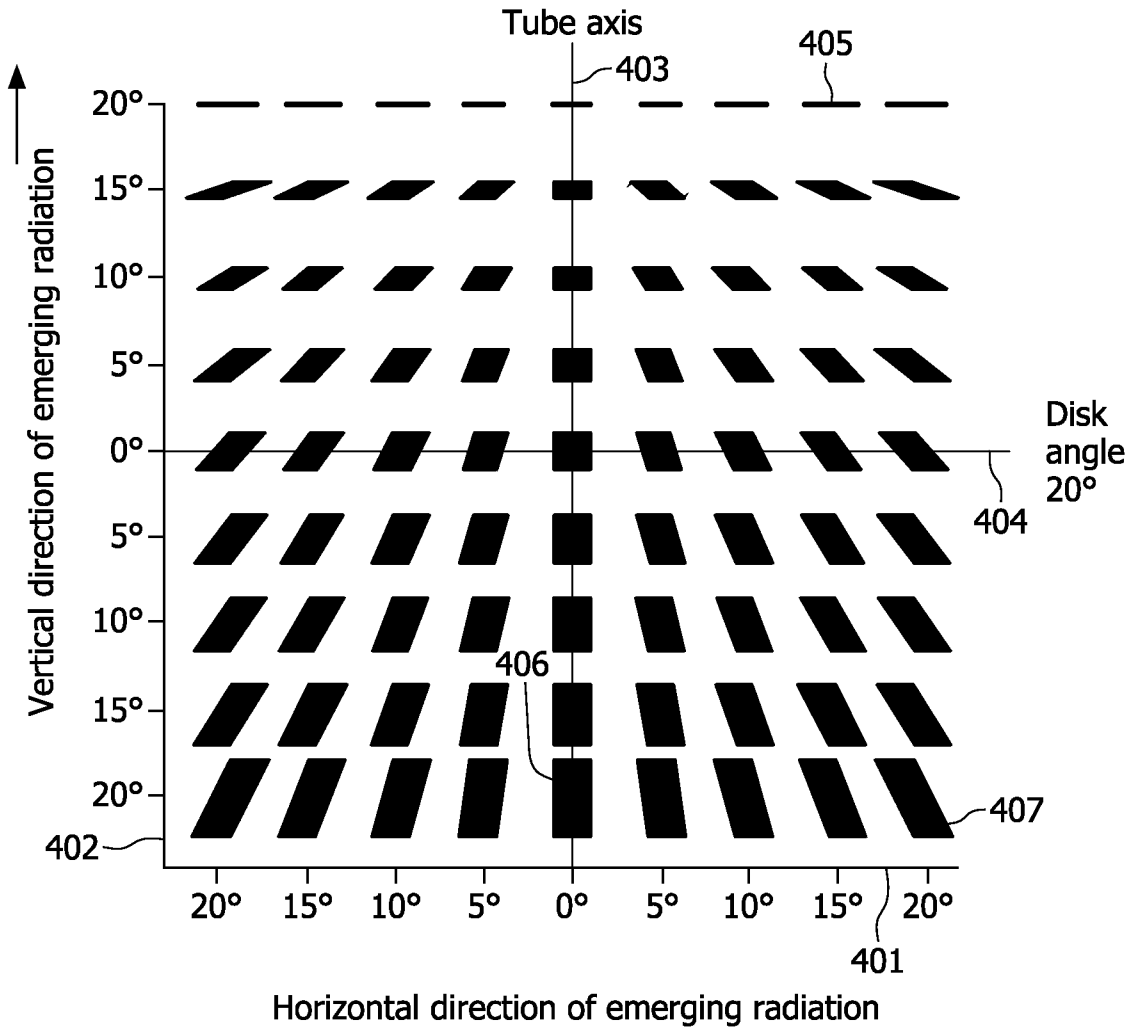


FIG. 4A

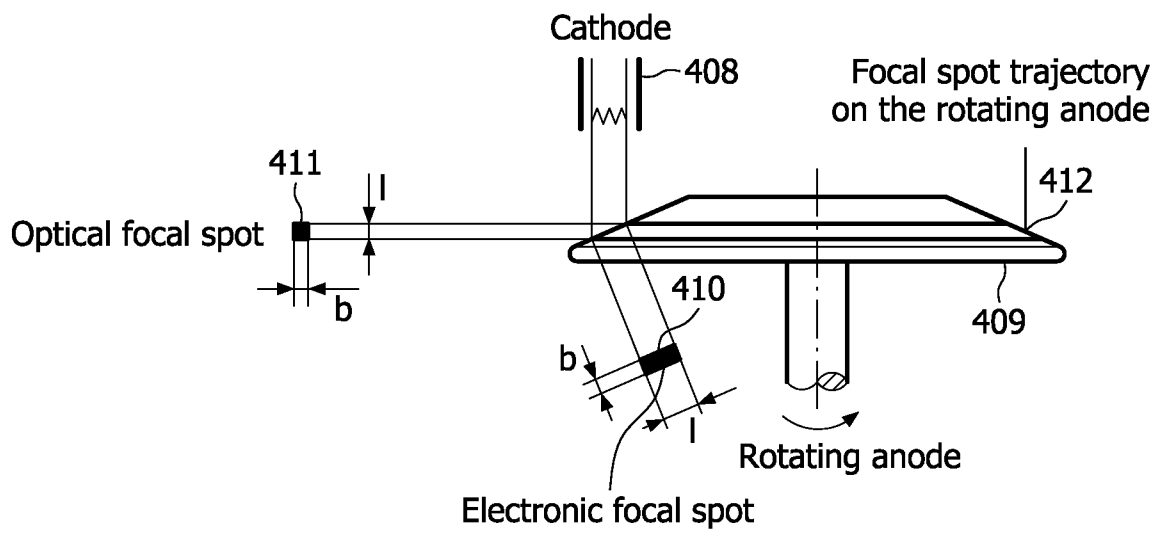


FIG. 4B

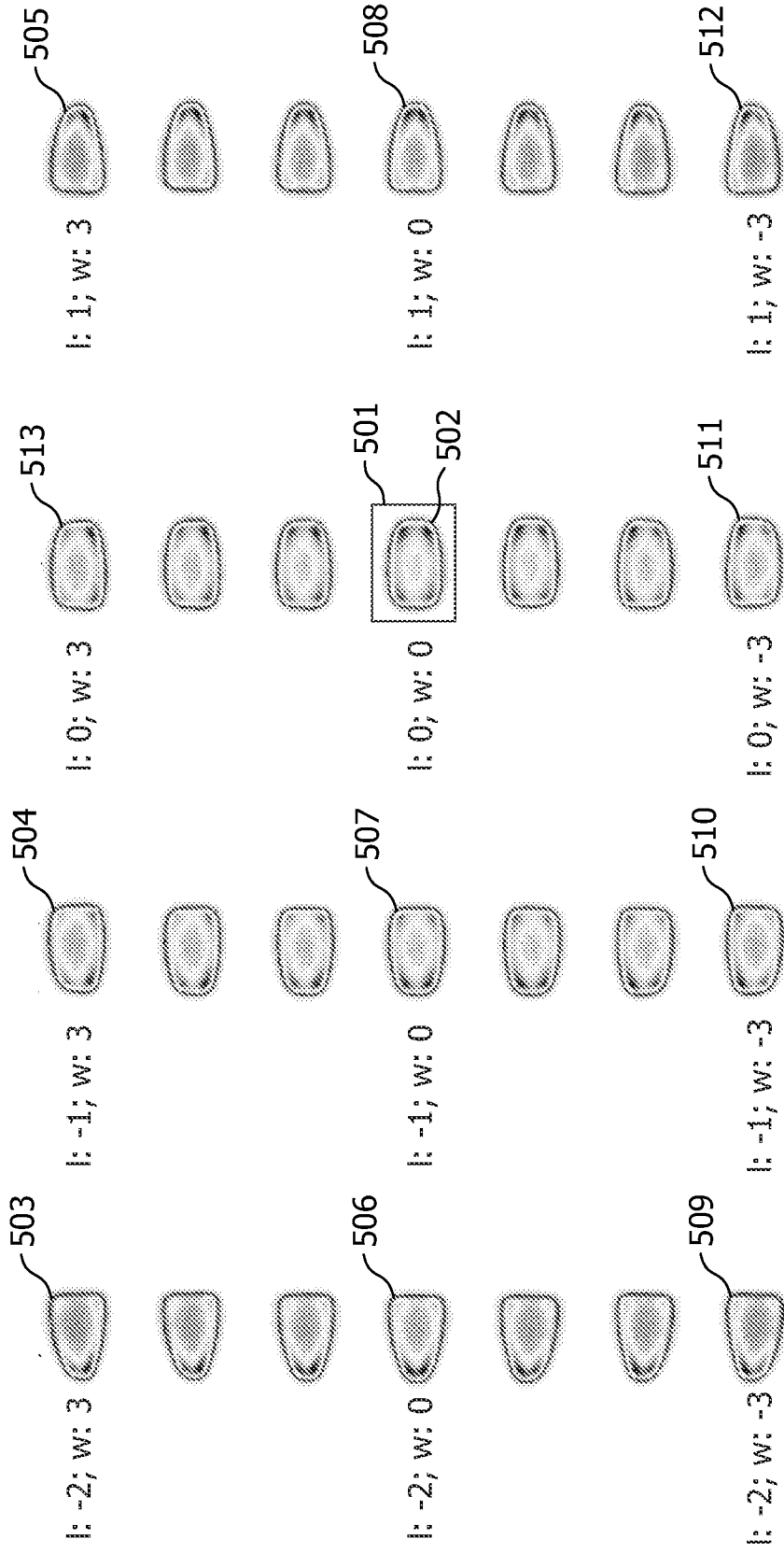


FIG. 5

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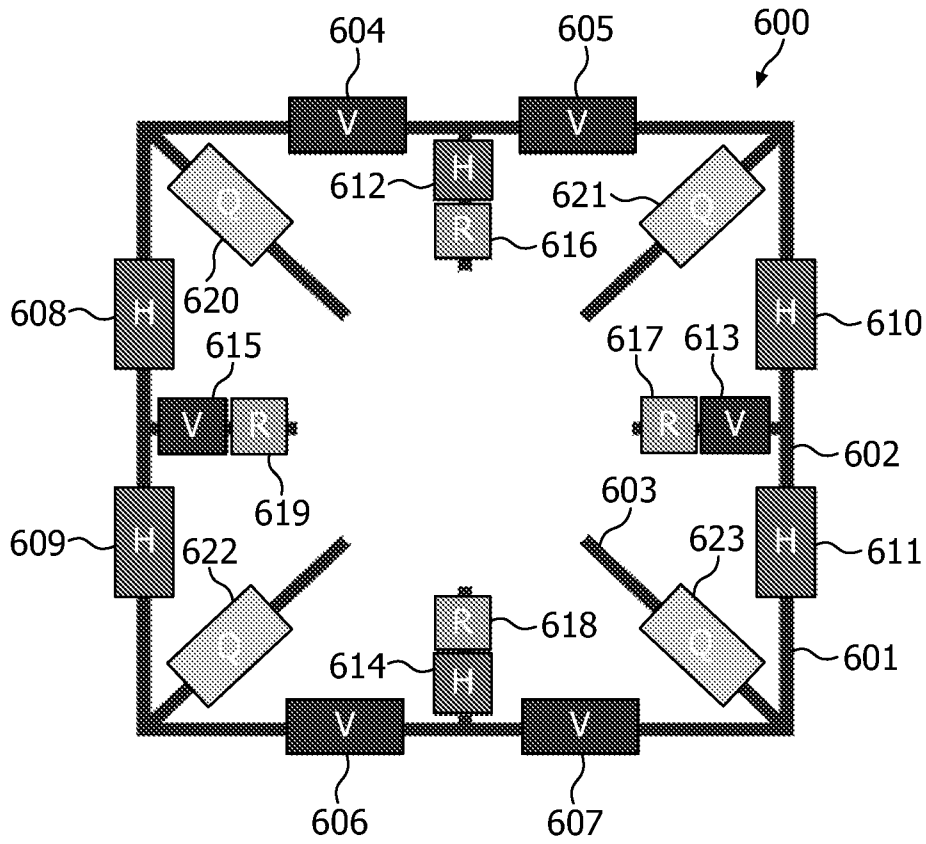


FIG. 6

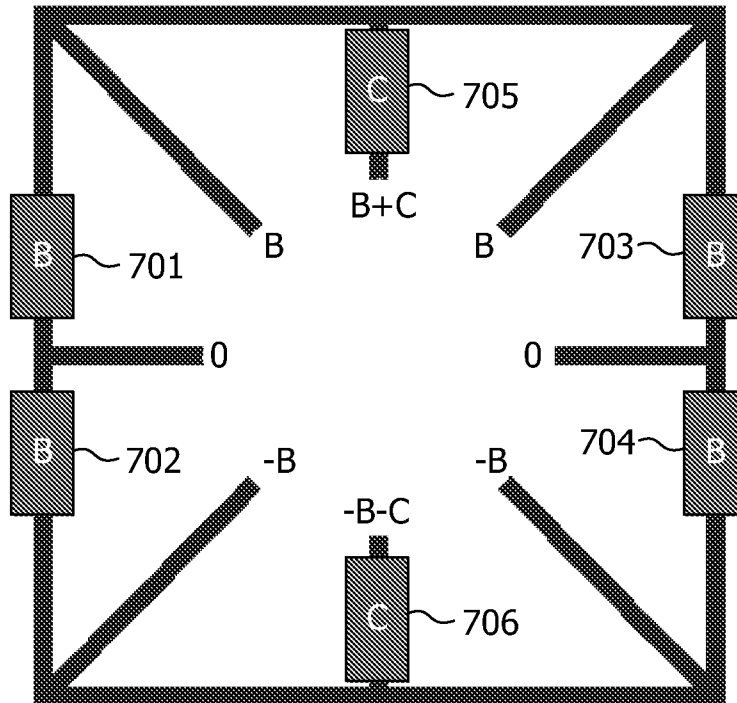


FIG. 7

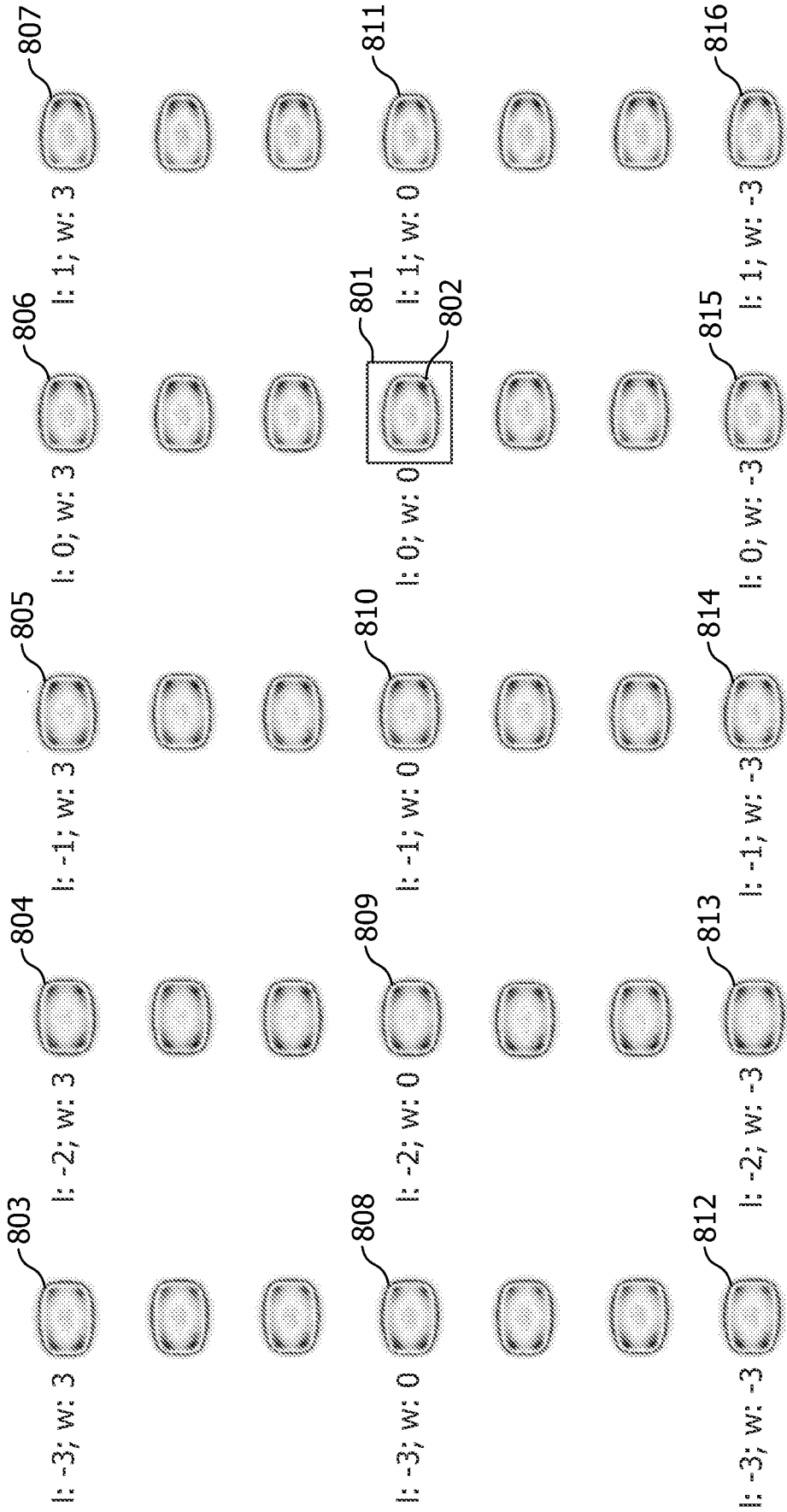


FIG. 8

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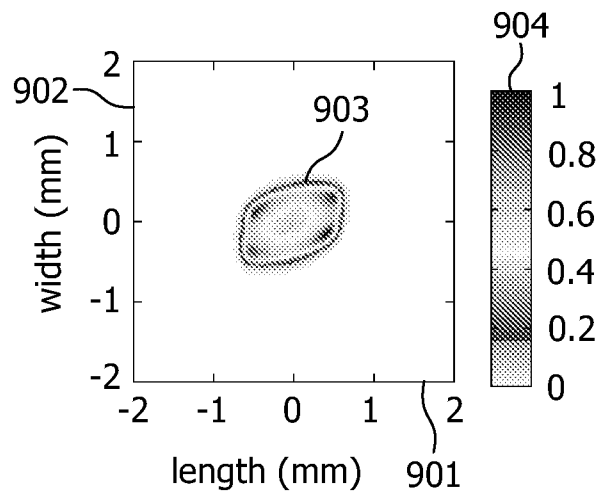


FIG. 9A

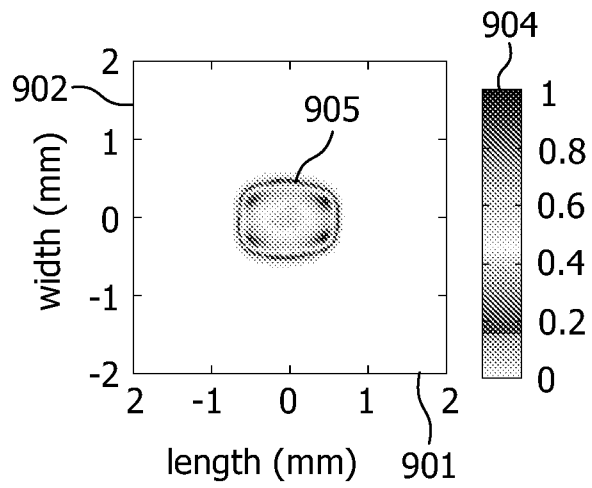


FIG. 9B

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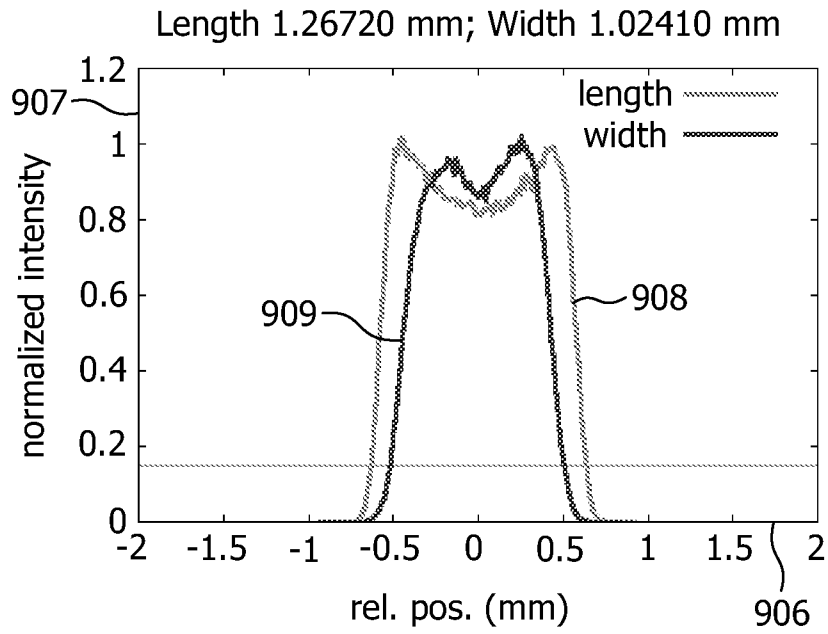


FIG. 9C

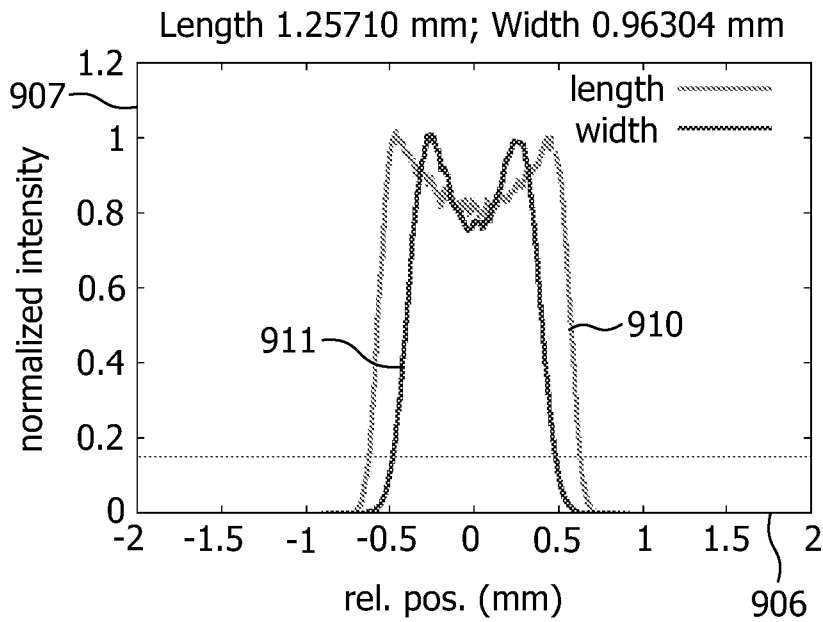


FIG. 9D

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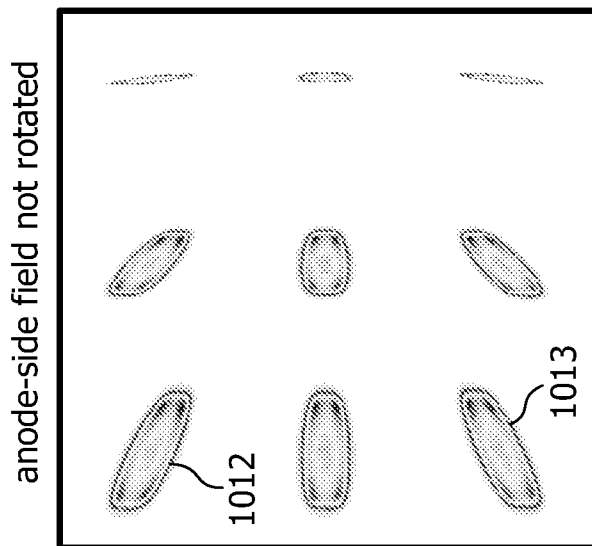
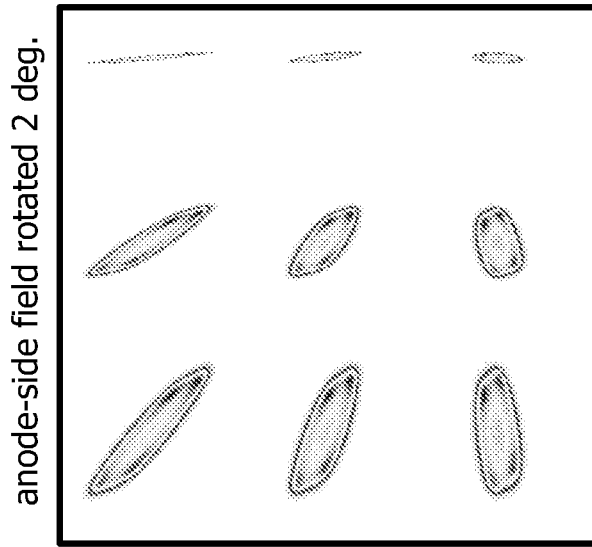
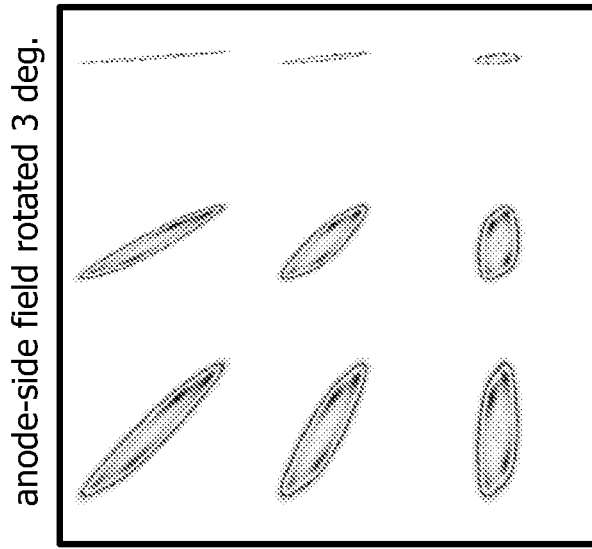


FIG. 10C

FIG. 10B

FIG. 10A

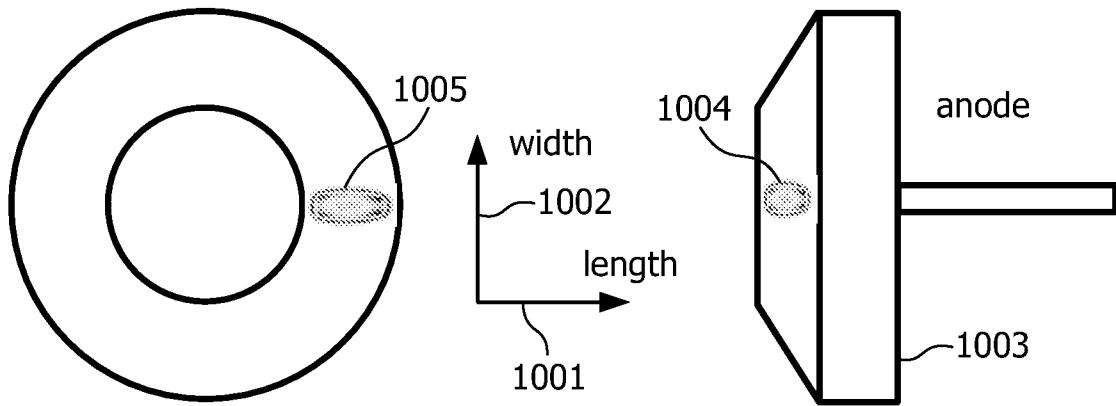


FIG. 10D

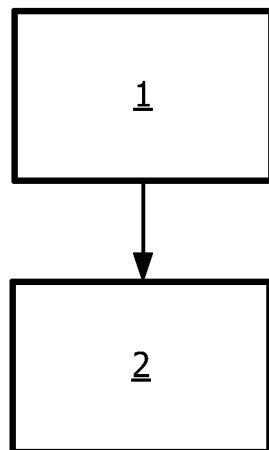


FIG. 11

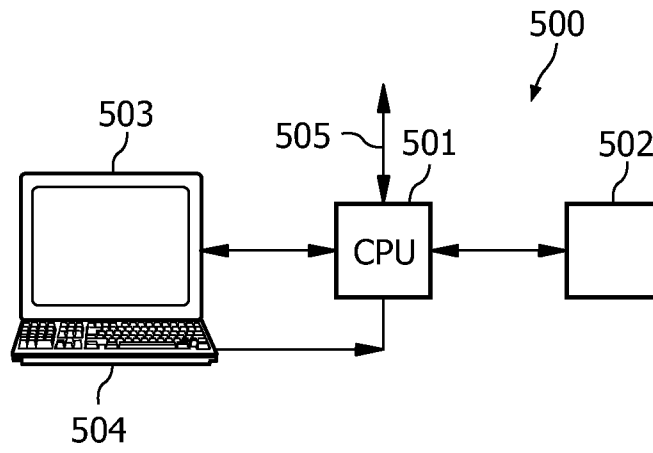


FIG. 12

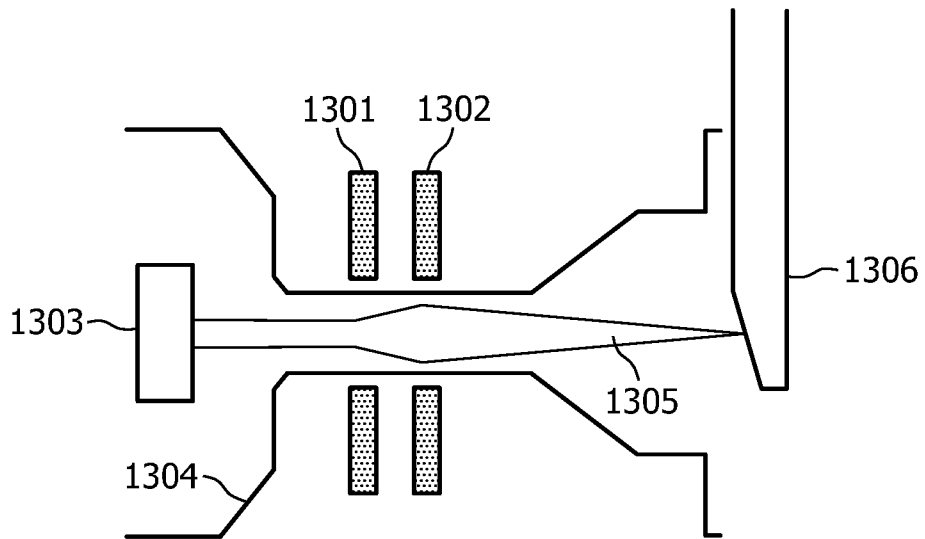


FIG. 13

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2008/052332

A. CLASSIFICATION OF SUBJECT MATTER
INV. G21K1/08 H01J35/14

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G21K H01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	SU 1 170 948 A1 (MO INZH FIZ INST [SU]) 15 February 1986 (1986-02-15) abstract figure 1 -& DATABASE WPI Week 198636 Thomson Scientific, London, GB; AN 1986-237118 XP002498190 & SU 1 170 948 A (MOSC ENG PHYS INST) 15 February 1986 (1986-02-15) abstract <div style="text-align: center; margin-top: 20px;">----- -/--</div>	1-7, 10-13

Further documents are listed in the continuation of Box C.

See patent family annex.

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- *O* document referring to an oral disclosure, use, exhibition or other means
- *P* document published prior to the international filing date but later than the priority date claimed

- *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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Date of the actual completion of the international search

2 October 2008

Date of mailing of the international search report

15/10/2008

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Authorized officer

Angloher, Godehard

INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2008/052332

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 429 229 A (GLUCKSTERN ROBERT L [US]) 31 January 1984 (1984-01-31) column 3, lines 9-15 column 4, lines 28,29 column 4, line 42 - column 5, line 14 column 6, line 65 - column 7, line 3 figures 3,4 -----	1-7, 10-13
X	US 2003/029999 A1 (HOSOKAWA FUMIO [JP]) 13 February 2003 (2003-02-13) paragraphs [0019], [0020] figure 1 -----	1,2,4,5, 10
X	GB 1 602 011 A (HAIMSEN J) 4 November 1981 (1981-11-04) page 1, lines 10-20 page 6, line 40 - page 7, line 54 page 16, lines 91-97 figures 1,5,6,11a-11e,12a-12e -----	1-13

INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2008/052332

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SU 1170948	A	15-02-1986	NONE
US 4429229	A	31-01-1984	CA 1194540 A1 01-10-1985
US 2003029999	A1	13-02-2003	NONE
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