(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
19 January 2012 (19.01.2012)

PCT

(10) International Publication Number
WO 2012/007881 A2

(51) International Patent Classification:
G21K 1/10 (2006.01) *H01J 35/00* (2006.01)
H05G 1/02 (2006.01)

(21) International Application Number:
PCT/IB2011/053012

(22) International Filing Date:
7 July 2011 (07.07.2011)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
10169443.8 13 July 2010 (13.07.2010) EP

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(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

(54) **Title:** X-RAY TUBE ARRANGEMENT WITH TOROIDAL ROTATABLE FILTER ARRANGEMENT AND COMPUTED TOMOGRAPHY DEVICE COMPRISING SAME

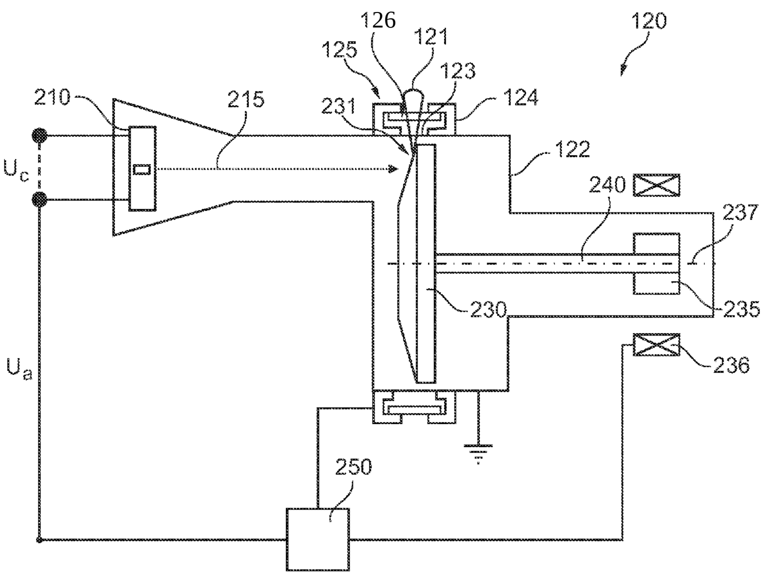

FIG. 2

(57) **Abstract:** An X-ray tube arrangement (120) for dual energy operation is proposed. The arrangement comprises an electron source (210) for emitting an electron beam (215) and a disk-shaped anode (230). Furthermore, a rotatable filter arrangement (125) is provided comprising a toroidal filter (126) with a filter pattern comprising an X-ray absorption portion arranged along a circumference of the toroidal filter (126). The rotatable filter arrangement (125) is adapted to rotate the toroidal filter around a rotation axis (237) orthogonal to the disk-shaped anode (230). The filter arrangement (125) may be attached to the tube housing (122) such that the toroidal filter (126) is held by a bearing (124). Alternatively, the toroidal filter (126) may be attached to the anode (230). Gyroscopic forces resulting upon filter (126) rotation may be reduced especially when applied in a rotating gantry of a CT device.

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X-RAY TUBE ARRANGEMENT WITH TOROIDAL ROTATABLE FILTER ARRANGEMENT AND COMPUTED TOMOGRAPHY DEVICE COMPRISING SAME

FIELD OF THE INVENTION

The present invention relates to an X-ray tube arrangement comprising a specific filter arrangement for selectively filtering X-rays. The X-ray tube arrangement may be specifically adapted for dual-energy operation. Furthermore, the present invention relates to a computed tomography device comprising such X-ray tube arrangement.

BACKGROUND OF THE INVENTION

X-ray systems such as computed tomography devices are widely used in clinical imaging and diagnosis. Several types of X-ray imaging methodologies may be employed to image different anatomical areas or to provide different diagnostic tools. One such X-ray imaging methodology is dual energy (DE) imaging. It is known that additional information can be obtained when DE imaging is used.

Dual energy is a clinical application wherein two X-ray images are acquired at different X-ray energies. The two X-ray images may then be combined to provide tissue-subtracted images, e.g. soft tissue and bone images. One clinical application of DE is diagnosis of plaque in the coronary arteries with X-ray. In practice, the soft tissue image may improve sensitivity by removing the structured noise due to bones, and the bone image may improve specificity by showing if an artery is vulnerable to plaque.

With flat panel X-ray detector technology, two X-ray images are typically successively acquired with two separate X-ray exposures at different X-ray energies. In order to minimize patient motion artefacts between the two X-ray images, the time between successive X-ray pulses for acquiring the different image types may be typically minimized to an order of a few milliseconds.

WO 2007/017773 A2 discloses a conventional system and method for dual energy dynamic X-ray imaging.

SUMMARY OF THE INVENTION AND EMBODIMENTS THEREOF

There may be a need for an improved solution for an X-ray tube for dual energy (DE) image acquisition in pulsed mode. Particularly, there may be a need for a computed tomography (CT) device comprising such X-ray tube.

Such need may be met by the subject-matter of the independent claims. Embodiments are defined in the dependent claims.

The present invention may be understood as being derived based on the present insight: Current X-ray tubes and high voltage (h/v) generators may allow for proper alternation of the high voltage and the primary X-ray spectrum. However, an additional X-ray filter may be needed for X-ray pulses with high h/v levels to further increase the mean photon energy and reduce excessive photon flux down to a desired level.

Conventionally, an alternating filter may be located in a beam collimator of the X-ray source. Such alternating filter may be disk-shaped and placed on a rotating tray.

However, it has been found that an achievable speed of movement of such disk-shaped filter arrangement may be too small, especially if the pulse time and frequencies are in an order of integration periods of a computer tomography system which may be in a range of sub-milliseconds.

Furthermore, particularly when the X-ray tube is applied in moving X-ray systems such as in a computed tomography device in which the X-ray tube moves along a circular gantry, the axes of rotation of the rotating tray may be perpendicular to an axis of rotation of the CT gantry. In such cases, gyroscopic forces may limit the achievable velocity of rotation. Therefore, transient times to move the filter across an X-ray fan-beam may be large.

According to an aspect of the present invention, an X-ray tube arrangement is proposed which comprises an electron source, a disk-shaped anode and a rotatable filter arrangement. The rotatable filter arrangement comprises a toroidal filter with a filter pattern comprising at least one X-ray absorption portion arranged along a circumference of the toroidal filter. Furthermore, the rotatable filter arrangement is adapted to rotate the toroidal filter around a rotation axis orthogonal to a center X-ray beam emitted from the anode upon impact of electrons from the electron source. In other words, the rotatable filter arrangement may be adapted to rotate the toroidal filter around a rotation axis substantially orthogonal to a main surface of the disk-shaped anode, i.e., in case of a rotating anode, around an axis of rotation which is substantially parallel to the axis of rotation of the disk-shaped anode. Thus, implemented in a CT system, the rotation axis may be substantially parallel to the axis of rotation of the gantry of the computed tomography system.

Due to the toroidal shape of the filter comprised in the rotatable filter arrangement and, furthermore, due to the orientation of the rotation axis of this toroidal filter being orthogonal to the disk-shaped anode, advantageous load conditions may be achieved, especially when the filter arrangement is rotated at high rotation velocities. Particularly, when the proposed X-ray tube is arranged on a gantry of a CT device and the rotatable filter arrangement is adapted to rotate the toroidal filter around a rotation axis parallel to the gantry axis, gyroscopic forces due to the movement of the rotating filter within the X-ray tube moving along the gantry may be prevented or kept low.

The proposed X-ray tube arrangement may further comprise a tube housing enclosing the electron source and the anode. Such housing may mechanically support the toroidal filter via a bearing. Thus, the tube housing may bear centrifugal expansion forces occurring upon rotation of the toroidal filter supported by the tube housing. Therein, the toroidal filter may be arranged inside or outside the tube housing. The toroidal filter may be attached to the tube housing for example by a magnetic bearing or a hydro-dynamic bearing such as an air bearing or a liquid bearing. Such bearings may be adapted for high rotation speed operation.

In order to damp intrinsic mechanical resonances of the rotating filter arrangement, a suitable damping arrangement may be comprised in the X-ray tube arrangement. In the case of an air bearing supporting the rotatable toroidal filter, such damping arrangement may comprise elastomer pads. In case of a magnetic bearing supporting the filter, an active drive control may be provided for controlling magnetic radial bearings.

In a specific embodiment, the toroidal filter arrangement included in the proposed X-ray tube comprises a rotatable toroidal hollow reservoir arrangement, at least one hollow filter element adapted for forming an X-ray absorption portion of the filter arrangement and a fluid X-ray absorbent comprised in at least one of the reservoir arrangement and the filter element. Both, the reservoir arrangement and the filter element, are arranged along a circumference of the toroidal filter arrangement and are in fluid communication with each other. In such filter arrangement, X-ray filter characteristics of the filter elements forming the X-ray absorption portions may depend on the amount of fluid X-ray absorbent comprised in the filter element when the X-rays are transmitted therethrough. As the filter element is in fluid communication with the reservoir arrangement, the amount of fluid X-ray absorbent comprised in the filter element may depend on conditions which may be specifically controlled. Accordingly, the filter strength may be variable and selectable.

The fluid X-ray absorbent may comprise metallic components or consist of metallic components. E.g., the fluid X-ray absorbent may be a liquid metal. Then, the X-ray tube arrangement may further comprise a magnetic field generator adapted for generating a magnetic field within at least one of the reservoir arrangement and the filter element. During rotation of the toroidal filter arrangement, the magnetic field may be generated such as to be perpendicular to the toroidal structure of the filter arrangement. Such perpendicular magnetic field may interact with the metallic components of the X-ray absorbent and may thus reduce the speed of the fluid comprised e.g. in the reservoir arrangement. As a result, a hydro-dynamic, centrifugal pressure within the reservoir may drop and fluid absorbent may flow from the filter element to the reservoir due to the fluid communication provided there between. Accordingly, using the magnetic field generator, the filter strength provided by the X-ray absorbent included in the filter element may be selected solely by electrical control of the magnetic field generator. Sub-millisecond speed of filter change may be possible such that filtering pulsing at high frequencies may be enabled.

Alternatively, a variable mechanical break arrangement may be provided which break arrangement is adapted for reducing a rotation velocity of fluid absorbent comprised in the rotating reservoir arrangement. Again, by reducing the rotation velocity, the hydro-dynamic pressure within the rotating reservoir arrangement may drop and fluid from the filter element may escape towards the reservoir arrangement. Using such mechanical break, a fluid other than a liquid metal may be used as an X-ray absorbent. For example, a suspension of X-ray absorbing material in other fluids may be used such as a suspension of metal particles in oil.

The proposed X-ray tube arrangement may be provided with a rotatable anode which, during operation of the X-ray tube arrangement, rapidly rotates around an axis orthogonal to the disk-shaped anode. In such case, the toroidal filter arrangement may be fixedly attached to the rotatable anode. Thus, the toroidal filter arrangement is coupled to the rotatable anode such as to rotate together with the anode. Accordingly, no additional drive is needed to rotate the filter arrangement during operation of the X-ray tube arrangement. Furthermore, synchronization of the anode rotation and with it the toroidal filter rotation with the image acquisition of the computed tomography system may be achieved by monitoring the phases of rotation, e.g. by using a mark on the anode and triggering the control circuit when the passage of the mark is detected, and controlling the anode drive motor such that the desired relationship is provided and maintained. Accordingly, an effective mechanical design may be provided in which the anode has a dual function as a radiation source and as a filter carrier. Particularly in such embodiment, the filter arrangement may be close to the anode serving as an X-ray source thereby possibly reducing weight and minimizing a transition period.

The proposed X-ray tube arrangement may further comprise a control for controlling a high voltage (h/v) applied between the electron source and the anode. The control may be adapted for periodically varying the applied voltage. The rotatable filter arrangement and the control may then be adapted for synchronized operation of filter and computed tomography system. In other words, on the one hand, the energy and spectrum of the X-ray radiation emitted by the anode strongly depends on the high voltage applied between the electron source and the anode. On the other hand, the energy and spectrum of the X-ray radiation effectively emitted by the entire X-ray tube arrangement may furthermore depend on the X-ray absorption characteristics of the filter arrangement through which radiation emitted by the anode has to pass before being emitted to an environment. A time-pattern of the high voltage applied between the electron source and the anode may be controlled by the h/v control of the X-ray tube arrangement. A time-pattern of the X-ray absorption characteristics provided by the filter arrangement strongly depends on the filter pattern comprised in the toroidal filter and on the rotation velocity of the toroidal filter. In synchronized operation, both time-patterns may be selected such as to correspond to each other.

In the proposed X-ray tube arrangement, a plurality of rotatable filter arrangements may be provided. The filter arrangements may have different filter patterns. The filter arrangements may be arranged coaxially and adjacent to each other along an axial direction parallel to the rotation axis. In other words, several filter arrangements may be provided wherein each of the filter arrangements may have e.g. a same diameter and may be adapted for rotating around the same rotation axis. However, the various filter arrangements may have different filter patterns differing for example in a size of the X-ray absorption portion(s), a distance between neighboring X-ray absorption portion(s) and/or in an absorption degree of such X-ray absorption portion(s). Depending on a specific application, a desired one of the plural filter arrangements may be repositioned such as to be located within the X-ray beam emitted from the anode. Then, depending on the filter pattern of the selected filter arrangement and its rotation velocity, a time-pattern of the resulting X-ray absorption characteristics may be selected.

Furthermore, the filter pattern comprised in the filter arrangement may include a plurality of X-ray absorption portions having different X-ray absorption degrees. For example, the X-ray absorption portions may have different thicknesses which results, when assuming a homogeneous X-ray absorption material, in different X-ray absorption degrees. Alternatively, the X-ray absorption portions may comprise different X-ray absorption materials thereby resulting in different X-ray absorption degrees. The X-ray absorption degrees may vary continuously or discontinuously during rotation of the filter arrangement. Radiation may be pulsed at the desired moment in time by controlling the tube current, e.g. using a grid controlled electron source or switching the tube voltage. So, the filter strength can be selected by selecting the phase of rotation of the filter at which the radiation pulse is generated.

The rotatable filter arrangement may comprise synchronization marks for defining a phase of rotation of the filter arrangement. Such synchronization marks may be used for synchronizing the phase of the rotation of the filter arrangement with the time-pattern of the high voltage applied between electron source and anode and, possibly, the time-dependence of the image acquisition system, or vice versa. The synchronization marks may be replaced by a device, which detects characteristic alternations of the X-ray radiation pattern, which are indicative of the phase of rotation of the filter, e.g. detects the passage of a filter structure by sudden alterations of the X-ray flux. This may be provided by an arrangement of photo diodes and a computer system,

It has to be noted that aspects and embodiments of the present invention are described herein with reference to different subject-matters. In particular, some embodiments are described with reference to the X-ray tube arrangement whereas other embodiments are described with reference to the computed tomography device. However, a person skilled in the art will gather from the above and the following description that, unless other notified, in addition to any combination of features belonging to one type of subject-matter also any combination between features relating to different subject-matters is considered to be disclosed with this application.

BRIEF DESCRIPTION OF THE DRAWINGS

Features and advantages of the present invention will be further described with reference to specific embodiments as shown in the accompanying figures but to which the invention shall not be limited.

Fig. 1 shows a perspective view of a computed tomography device.

Fig. 2 shows a cross-sectional view of an X-ray tube arrangement according to an embodiment of the present invention.

Fig. 3 shows a perspective view onto a portion of an X-ray tube arrangement according to an embodiment of the present invention.

Fig. 4 schematically shows an anode and a rotatable filter arrangement in a non-filtering state for an X-ray tube arrangement according to an embodiment of the present invention.

Fig. 5 shows an anode and a rotatable filter arrangement in a filtering state for an X-ray tube arrangement according to an embodiment of the present invention.

Fig. 6 shows a top view of an anode and a rotatable filter arrangement for an X-ray tube arrangement according to an embodiment of the present invention.

Fig. 7 schematically illustrates a time-pattern of an X-ray beam emission via time-dependent high voltage application synchronized with a rotation of a filter arrangement for an X-ray tube arrangement in accordance with an embodiment of the present invention.

Fig. 8 shows a rotatable filter arrangement comprising a reservoir and filter elements filled with a fluid absorbent for an X-ray tube arrangement according to an embodiment of the present invention.

Fig. 9a,b show perpective and cross sectional views of a portion of the filter arrangement of Fig. 8 in a filtering state.

Fig. 10a,b show perpective and cross sectional views of a portion of the filter arrangement of Fig. 8 in a non-filtering state.

Fig. 11 schematically shows a top view onto an anode and a rotatable filter arrangement having a toroidal filter with varying thickness along a circumference for an X-ray tube arrangement according to an embodiment of the present invention.

All figures are only schematical and not to scale. Similar features are indicated with similar reference signs throughout the figures.

DETAILED DESCRIPTION OF EMBODIMENTS

Fig. 1 shows basic components of an exemplary X-ray imaging system in a form of a computed tomography device 100 as used in medical facilities. The CT device 100 may be embodied in accordance with the present invention and comprises an examination table 115 suitable for positioning an object, for example a patient, of which projection images are to be taken. The CT device 100 further comprises a rotatable gantry 105 suitable for rotation around the examination table 130 along a rotation axis 135 of the gantry. The CT device 100 further comprises an X-ray tube arrangement 120 and a detector arrangement 110. The X-ray tube arrangement 120 and the detector arrangement 110 are diametrically arranged on the gantry 105. During an image acquisition phase, the gantry 105 rotates around the gantry axis 135 while the X-ray tube arrangement 120 emits X-rays. The emitted X-rays interact with the object deposited on the examination table 115 and the interacting X-rays are then incident on the detector arrangement 110. The incident X-rays define a pattern of points of intensities which are digitally transformed into a corresponding pattern of pixels. The pattern of pixels is then available as the projection image of the object. The digital projection image can then be stored and/or post-processed by suitable software to be viewable on a monitor.

Fig. 2 shows a simplified cross-sectional view of an X-ray tube arrangement 120 according to an embodiment of the present invention. The X-ray tube arrangement 120 comprises a cathode 210 and an anode 230 which at the same time acts as a target. The anode 230 is disk-shaped. A motor comprises a rotor 235 and a stator 236 which may drive a shaft 240 in order to rotate the anode 230 about an axis 237 orthogonal to the anode surface. The cathode 210 and the anode 230 are enclosed in a tube housing 122. In the present embodiment, the tube housing 122 is on a same electrical potential as the anode 230. In operation, a cathode voltage U_c is applied to the cathode 210 causing the cathode 210 to heat up whereupon the cathode 210 releases electrons by thermionic emission. The electrons emitted at the cathode 210 being on negative potential are accelerated towards the grounded anode 230 due to the accelerator voltage U_a between the cathode 210 and the anode 230 or the housing 122 thus establishing an electron beam 215. The electron beam 215 is incident with a high energy on the anode target 230 at a predetermined focal point 231. Upon incidence on the target, the electrons are decelerated thereby causing a beam of X-rays 121 to be released as "Bremsstrahlung". The X-rays 121 may exit the tube housing 122 through a window 123 and may then be available for an actual image acquisition.

Attached to the tube housing 122, there is a bearing 124 mechanically supporting a toroidal filter arrangement 125. The toroidal filter arrangement 125 comprises a toroidal filter 126 which may be driven to rotate around a rotation axis which is substantially perpendicular to the direction of the X-ray beam 121 . In other words, the rotation axis of the rotating toroidal filter 126 coincides or is at least parallel to the rotation axis 237 of the anode 230. Accordingly, in case the X-ray tube is used in a CT device, the rotation axis 237 of the anode may be parallel to the gantry rotation axis 135.

The toroidal filter arrangement 125 as well as the acceleration voltage U_a and cathode voltage U_c may be controlled by a control 250. Therein, the control 250 may control a rotation velocity with which the toroidal filter 126 is rotated around the axis 237. As the toroidal filter 126 may comprise a filter pattern which is formed by X-ray absorption portions arranged along a circumference of the toroidal filter 126, the rotation velocity has a direct impact onto the time-pattern with which the X-ray beam 121 is transmitted through the toroidal filter 126. With increasing rotation velocity, a frequency of the time-pattern increases.

Furthermore, as described in further detail below, the control 250 may be adapted to control absorption properties of the toroidal filter arrangement. For example, in case a liquid metal is used within the toroidal filter 126, a distribution of the liquid metal within the toroidal filter 126 may be influenced by the presence of a magnetic field which may be controlled by the control 250.

Fig. 3 shows an X-ray tube arrangement 120 comprising a tube housing 122 to which a rotatable filter arrangement 125 is attached via a hydro-dynamic bearing 124' in the form of an air-bearing. Instead of a hydro-dynamic bearing 124', a magnetic bearing may be used. The bearing 124' mechanically supports toroidal filters 126 and attaches them to the tube housing 122.

In the embodiment shown in Fig. 3, a plurality of toroidal filters 126', 126" is shown. Each of the toroidal filters 126', 126" comprises a rotatable X-ray filter wheel rim 127, i.e. a cylindric arrangement, a rotation axis of which may coincide or may be parallel to a rotation axis 237 (shown in fig. 2) of the anode 230 and may be parallel to the gantry axis 135 (shown in fig. 1). The filter wheel rim 127 has a hollow physical center enclosing the tube housing 122 of the X-ray tube 120. The anode 230 may be placed within this hollow physical center such that the wheel rim may be arranged within the path of the X-ray beam 121 emitted by the anode 230 through the window 123.

In the embodiment shown in Fig. 3, the toroidal filter 126 comprises a plurality of separate filter arrangement 126', 126" each of which is formed by a filter wheel rim 127', 127" and being arranged adjacent to each other in an axial direction parallel to the rotation axis 237. The plurality of toroidal filters 126', 126" may be displaced in the axial direction as indicated by the arrow 128 shown in Fig. 3. Thereby, it may be determined which of the toroidal filters 126', 126" is arranged in front of the X-ray tube window 123 and therefore determines an X-ray emission emitted therethrough. Each of the filter wheel rims forming the toroidal filters 126', 126" comprises a specific filter pattern. The filter patterns of the respective filter rims may differ.

In the embodiment shown in Fig. 3, the filter pattern is provided by the filter rim 127 being made from an X-ray absorbing material and comprising openings 129', 129" having specific dimensions. Thus, the material of a respective filter rim may form an X-ray absorption portion 130 which, when placed in front of the X-ray tube window 123, may at least partially absorb X-rays emitted by the anode 230. Accordingly, the X-ray absorbing portions 130', 130" are arranged along a circumference of the toroidal filters 126', 126" and are separated from each other by the intervening openings 129', 129". Upon rotation of the rotatable filter arrangement 125 around the tube housing 122, X-ray absorbing portions 130', 130" and openings 129', 129" alternately cover and uncover the window 123 thereby establishing alternating X-ray absorption characteristics with a time-pattern depending on the dimensions of the X-ray absorption portions 130', 130" and the openings 129', 129" as well as on the rotation velocity of the filter arrangement 125.

In the embodiment shown in Fig. 3, synchronisation marks 131 are provided on the filter wheel rim 127. The synchronisation marks 131 may be detected and may be used to synchronize the operations of the rotation filter arrangement 126 and of the anode voltage. Furthermore, damping elements 132 are provided in order to suppress intrinsic mechanical resonances of the thin wheel rim 127. In the air bearing 124, the damping elements 132 may be elastomers. In a magnetic radial bearing, the damping elements may be implemented as an active control of the magnetic radial bearing.

Figs. 4 and 5 show a simplified illustration of an X-ray tube arrangement 120 according to an embodiment of the present invention in which for clarity purposes, only the rotating anode 230 and the toroidal filter 126 is shown. The toroidal filter 126 comprises X-ray absorption portions 130 and non-absorbing portions provided by the openings 129. The toroidal filter 126 is rotated around an axis orthogonal to the disk-shaped anode 230 as indicated by the arrow 131. Therein, the toroidal filter 126 may be rotated independently from the anode 230. The toroidal filter 126 may be part of a filter arrangement 125 installed inside or outside the tube housing 122 and possibly supported by the tube housing e.g. by attaching it thereto via a bearing. Alternatively, it may be advantageous to couple the rotation of the toroidal filter 126 with the rotation of the anode 230, e.g. by attaching it thereto.

As shown in Fig. 4, in a non-absorbing state, the non-absorbing portion of the opening 129 of the toroidal filter 126 is in front of an X-ray tube window (not shown in Fig. 4 and 5) such that a non-filtered X-ray beam as generated by the electron beam 215 upon impact onto the focal spot 231 may be emitted from the X-ray tube 120. This non-filtered beam 121 may have a spectrum as indicated in the graph 170. Therein, the wavelength-dependent X-ray intensity mainly depends on the energy of the electron beam 215, i.e. on the electron flux and the acceleration voltage U_a (tube voltage), the target material and the permanent filtration of the X-ray port of the tube.

Upon further rotation of the toroidal filter 126, the X-ray absorption portion 130 may be moved in front of the window 123 as shown in Fig. 5. In such absorbing state, the characteristics of the X-ray beam 121 emitted by the X-ray tube 120 not only depend on the characteristics of the electron beam 215 determining the characteristics of the X-ray beam emitted from the focal spot 231 but also depends on the X-ray absorption characteristics of the X-ray absorption portion 130. Accordingly, the frequency-dependent intensity spectrum of the emitted X-ray beam 121 may be modified as shown in the graph 171.

Fig. 6 shows a simplified top view of an alternative embodiment of an X-ray tube 120' in accordance with the present invention. In this embodiment, a rotatable filter arrangement 125' is arranged within the tube housing 122 together with a rotating anode 230. The toroidal filter arrangement 125 comprises a cylindrical wheel rim 127 made from an X-ray transparent material. Along a circumference of the wheel rim 127, X-ray transparent displacement elements 133 and X-ray absorbing filter elements 134 are alternately arranged. Depending on whether a displacement element 133 or a filter element 134 is arranged within the X-ray beam 121 emitted from the focal spot 231, the X-ray characteristics may be significantly modified as indicated by the graphs 170, 171. Fig. 7 illustrates a time-pattern of an X-ray beam emission via time-dependent high voltage (h/v) application synchronized with a rotation of a filter arrangement. The energy dependent X-ray flux is shown in different phases of the anode rotation. Line "A" shows X-ray characteristics of the primary beam, i.e. before filtering through the toroidal filter arrangement. As shown, the characteristics of the primary beam may be time-dependent and may be determined by suitably controlling the acceleration voltage applied to the electron beam 215. Line "B" illustrates an anode phase and indicates whether or not a filter element is placed within the X-ray beam path. Line "C" indicates characteristics of the finally emitted X-ray beam, i.e. after filtering through the filter arrangement. Line "D" provides an indication on the high voltage applied for acceleration of the electron beam 215.

As may be derived from lines "A", "B" and "D", the anode phase and the phase of the rotating filter arrangement which, in this case, is coupled to the anode, is synchronized with the primary beam emission controlled by the applied high voltage as illustrated in lines "A" and "D". Due to such synchronization, the X-ray characteristics of the used beam indicated in line "C" may alternate in a desired manner.

While during a first phase portion (i) of the anode rotation, an increased high voltage is applied to the cathode thereby providing an X-ray spectrum with an increased overall intensity as shown in line "A", the filter element arranged within the emitted primary beam at that phase of the anode rotation absorbs a portion of the primary beam particularly at a lower frequency spectrum. Thus, the finally emitted used beam not only has a reduced overall intensity compared to the primary beam but also its maximum intensity occurs at relatively high X-ray energies Ei.

In contrast hereto, in a second phase portion (ii) of the anode rotation, the primary beam is generated with a reduced high voltage and thereby shows a reduced overall intensity as shown in line "A". However, as in this phase of the anode rotation, no X-ray absorbing filter element is placed within the emitted primary beam, the finally emitted used beam corresponds to the primary beam. Thus, an overall X-ray intensity of the used beam may be similar as in the case of phase (i). However, the energy E;, where the photon flux density of such used beam peaks may occur at lower X-ray energies as shown in line "C". Using such alternating peak X-ray energies Ei, E,,, an X-ray tube for dual energy operation may be provided.

Figs. 8, 9a,b and 10a,b show a specific embodiment of a toroidal filter 126"' to be used in an X-ray tube arrangement according to the present invention. In this embodiment, a toroidal hollow reservoir arrangement 140 and a plurality of hollow filter arrangements are provided along a circumference of a toroidal filter wheel rim 127"'. The reservoir arrangement 140 and the filter elements 141 are in fluid communication with each other via bores 142. A fluid X-ray absorbent may flow within the reservoir arrangement 140 and towards the filter elements 141 via the bores 142. In other words, the filter arrangement may comprise a layer of fluid X-ray absorbent in a ring-shaped channel made e.g. from an X-ray transparent material like carbon. In such arrangement, the fluid absorbent may be held in place at an outer wall of the channel by centrifugal forces.

The toroidal filter 126" may be placed within the X-ray tube arrangement such that the channel forming the hollow reservoir arrangement 140 is located off the X-ray beam during operation of the X-ray tube and the filter elements 141 and the displacement elements 133 placed between adjacent filter elements 141 are situated within the X-ray beam. The fluid X-ray absorbent which may be for example a liquid metal may flow from the reservoir 140 through the bores 142 towards the filter elements 141 and vice versa. Advantageously, such toroidal filter 126'" may be attached to the anode and therefore rotate in conjunction with the anode.

During anode rotation, the radius of the fluid surface, is usually equal in both, the reservoir 140 and the filter elements 141 communicating therewith. To reduce the thickness of the fluid X-ray absorbent in the filter elements 141, a magnetic field may be applied perpendicular to the toroidal reservoir arrangement 140 as indicated in Fig. 8 by the arrow 143. Using for example liquid metal as X-ray absorbent, such magnetic field 143 may reduce the rotational speed of the liquid metal within the reservoir arrangement 140. As a result, a hydro-dynamic pressure due to centrifugal forces within the liquid metal may drop and liquid metal from the filter elements 141 may escape towards the reservoir arrangement 140. In this way, the X-ray absorption properties provided by the filter elements 141 due to the thickness of fluid X-ray absorbent comprised therein may be electro-magnetically controlled.

Fig. 9a,b show a state in which no magnetic field 143 is applied and a level of fluid absorbent 144 is same within the reservoir arrangement 140 and the filter elements 141.

Fig. 10a,b show a state in which a magnetic field 143 is applied perpendicularly to the circumference of the filter 126'". Due to the reduced fluid rotation velocity, all fluid absorbent 144 is captured within the reservoir arrangement 140. The filter elements 141 are empty.

While, in the ON-state shown in Fig. 9, an alternating filter pattern is provided with X-ray absorption portions corresponding to the area of the filter elements 141 filled with fluid X-ray absorbent and non-absorption portions corresponding to the non-absorbing displacement elements 133, in the OFF-state shown in Fig. 10, no alternating filter pattern is provided.

Again, as explained with reference to Fig. 7, the high voltage level and the passage of the filter elements 141 through an X-ray beam may be synchronized in order to obtain a suitable dual-energy mode of operation.

Fig. 11 schematically shows an embodiment of a toroidal filter 126"" forming a filter pattern in which X-ray absorption portions have different X-ray absorption degrees due to a varying thickness of an X-ray absorbing layer along the circumference of the filter.

It should be noted that the term "comprising" does not exclude other elements or steps and that the indefinite article "a" or "an" does not exclude the plural. Also elements described in association with different embodiments may be combined.lt should also be noted that reference signs in the claims shall not be construed as limiting the scope of the claims.

LIST OF REFERENCE SIGNS

100	CT device
105	Gantry
110	Detector
115	Table
120	X-ray tube arrangement
121	X-ray beam
122	Tube housing
123	Tube window
124	Bearing
125	Rotatable filter arrangement
126	Toroidal filter
127	Filter wheel rim
128	displacement direction
129	Opening/non-absorbing portion
130	X-ray absorption portion
131	synchromisation mark
132	damping element
133	displacement element
134	filter element
135	Rotation axis
143	Magnetic field
144	fluid absorbent
170	Graph of X-ray intensity
171	Graph of X-ray intensity
210	Cathode
215	Electron beam
230	Anode
231	Focal spot
235	Rotor
236	Stator
237	Rotation axis
240	Shaft

CLAIMS:

1. An X-ray tube arrangement comprising an electron source (210), a disc-shaped anode (230), a rotatable filter arrangement (125), wherein the rotatable filter arrangement (125) comprises a toroidal filter (126) with a filter pattern comprising an X-ray absorption portion arranged along a circumference of the toroidal filter and wherein the rotatable filter arrangement (125) is adapted to rotate the toroidal filter (126) around a rotation axis orthogonal to a center X-ray beam(121) emitted from the anode (230) upon impact of electrons from the electron source (210).

2. The X-ray tube arrangement of claim 1, further comprising a tube housing (122) enclosing the electron source (210) and the anode (230), wherein the toroidal filter (126) is mechanically supported by the tube housing (122) via a bearing (124).

3. The X-ray tube arrangement of claim 2, wherein the toroidal filter (126) is attached to the tube housing (122) via at least one of a magnetic bearing and a hydro-dynamic bearing.

4. The X-ray tube arrangement of claim 2 or 3, further comprising a damping arrangement adapted for damping intrinsic mechanical resonances of the rotating filter arrangement (125).

5. The X-ray tube arrangement of claim 1, wherein the toroidal filter arrangement (125) comprises

- a rotatable toroidal hollow reservoir arrangement (140),
- at least one hollow filter element (141) adapted for forming an X-ray absorption portion,
- a fluid X-ray absorbent (144) comprised in at least one of the reservoir arrangement (140) and the filter element (141),

wherein both, the reservoir arrangement (140) and the filter element (141), are arranged along a circumference of the toroidal filter arrangement (125) and are in fiuid communication with each other.

6. The X-ray tube arrangement of claim 5, wherein the fluid X-ray absorbent (144) comprises metallic components and wherein the X-ray tube arrangement further comprises a magnetic field generator adapted for generating a magnetic field within at least one of the reservoir arrangement (140) and the filter element (141).

7. The X-ray tube arrangement of claim 5 or 6, further comprising a variable mechanical brake arrangement adapted for reducing a rotation velocity of fluid absorbent (144) comprised in the rotating reservoir arrangement.

8. The X-ray tube arrangement of one of claims 1 to 7, wherein the anode is provided as a rotatable anode (230), and wherein the toroidal filter arrangement (125) is fixedly attached to the anode.

9. The X-ray tube arrangement of one of claims 1 to 8, further comprising a control (250) for controlling a high voltage applied between the electron source and the anode, wherein the control (250) is adapted for periodically varying the applied voltage, and wherein the rotatable filter arrangement (125) and the control (250) are adapted for synchronized operation.

10. The X-ray tube arrangement of one of claims 1 to 9, further comprising a plurality of toroidal filters (126', 126") having different filter patterns, wherein the plural filter arrangements are arranged coaxially and adjacent to each other in an axial direction parallel to the rotation axis.

11. The X-ray tube arrangement of one of claims 1 to 10, wherein the filter pattern comprises a plurality of X-ray absorption portions having different X-ray absorption degrees.

12. The X-ray tube arrangement of one of claims 1 to 11, wherein the rotatable filter arrangement comprises synchronization marks for defining a phase of rotation of the filter arrangement.

13. A radiographic imaging system comprising: an X-ray tube (120) according to one of claims 1 to 12, and a gantry (105).

14. The radiographic imaging system of claim 13, wherein the rotatable filter arrangement is adapted to rotate the toroidal filter around a rotation axis (237) which is substantially parallel to a gantry axis (135).

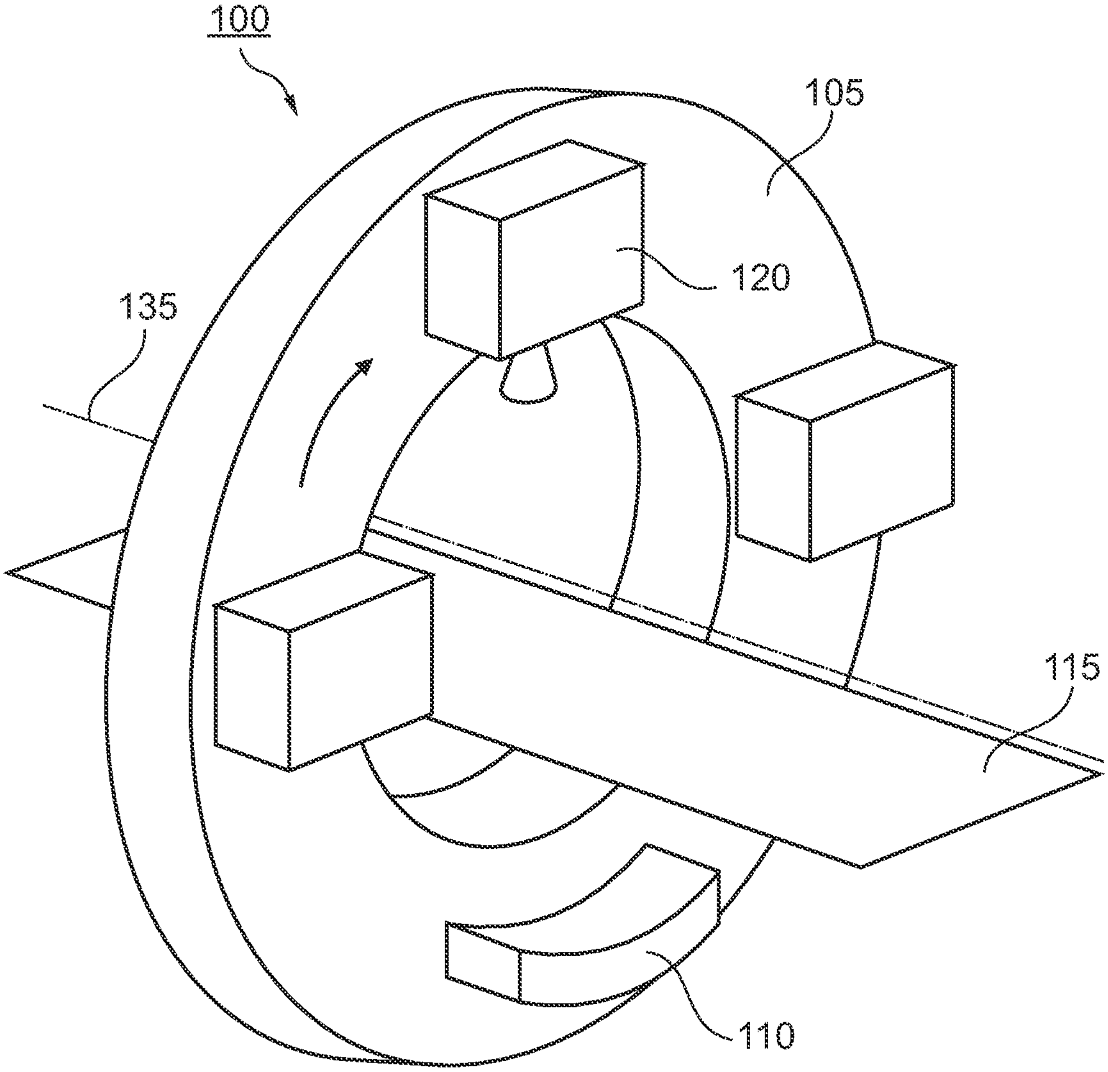

FIG. 1

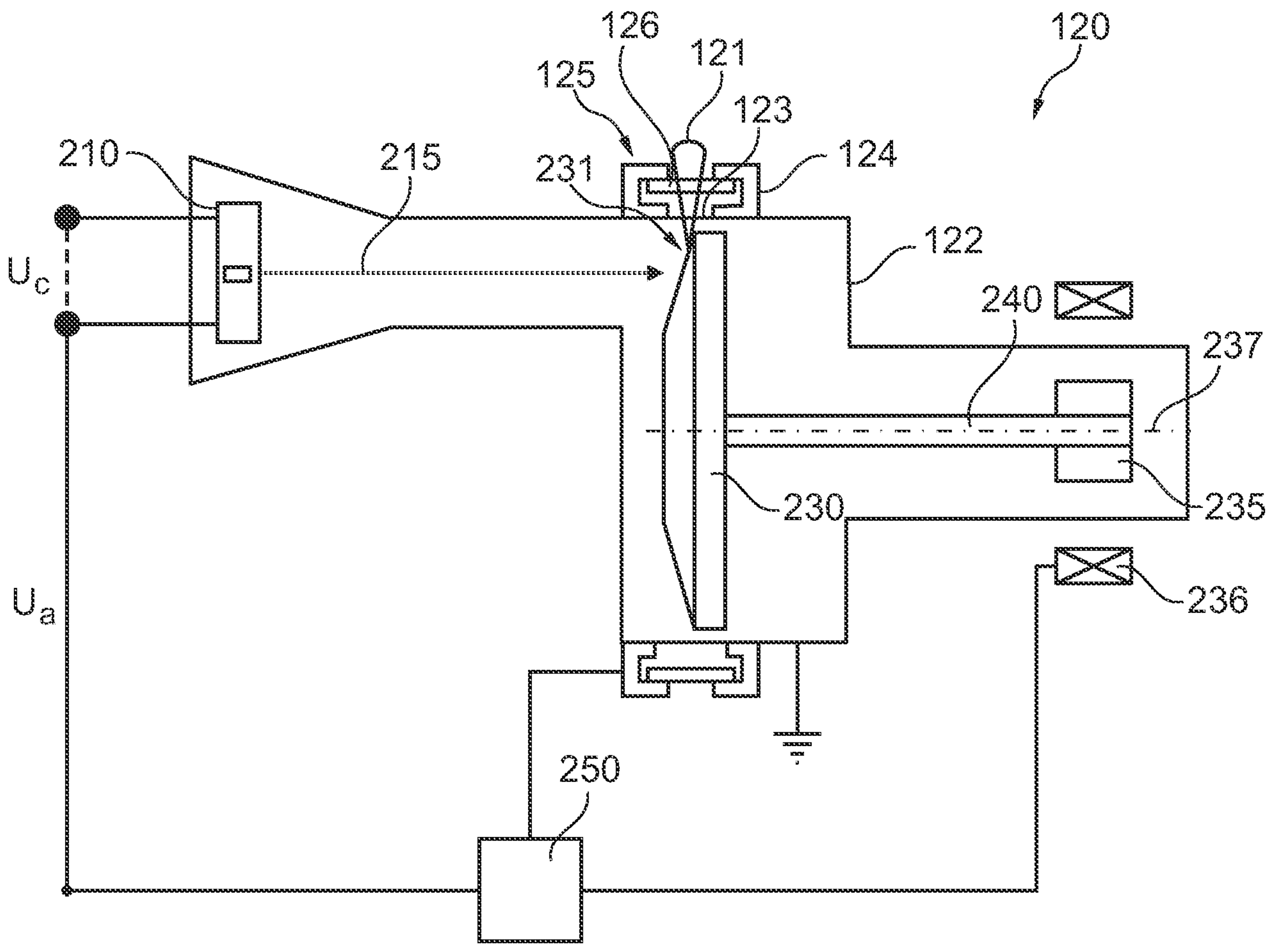
120
126
121
125
123
210
215
231
124
122
Uc
240
237
230
235
Ua
236
250

FIG. 2

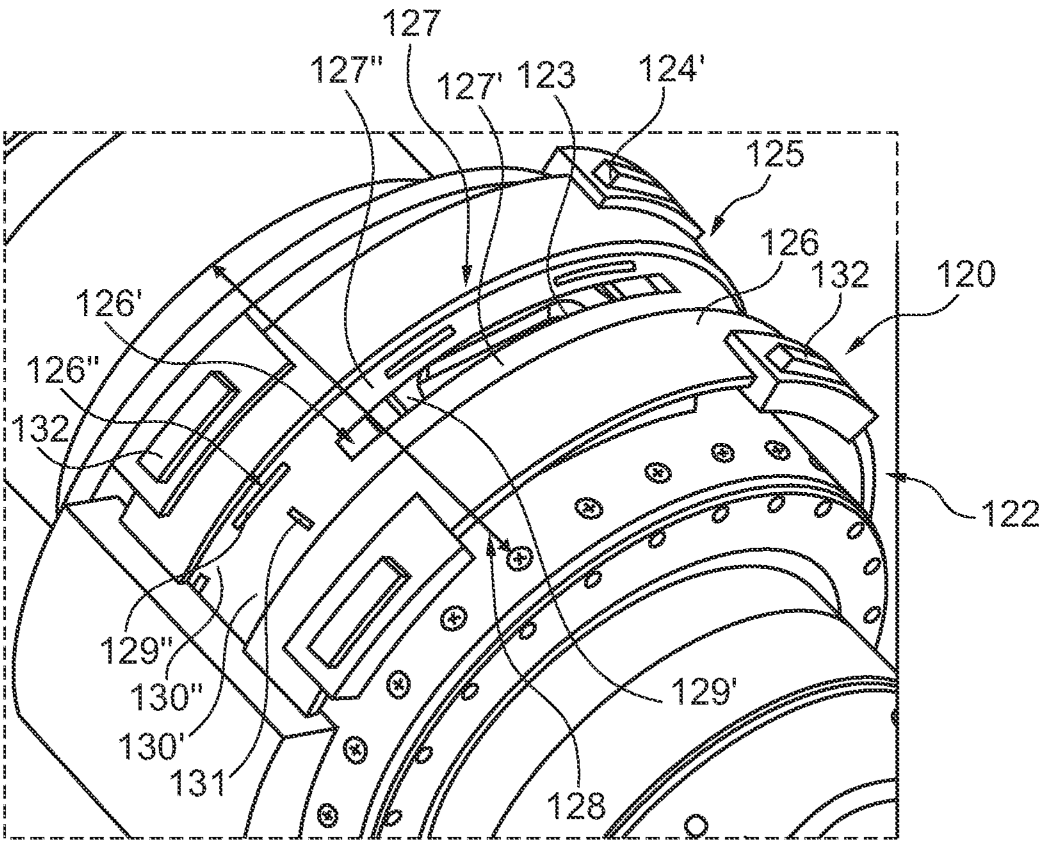
127
127''
127'
123
124'
125
126
132
120
126'
126''
132
122
129''
130''
130'
131
128
129'

FIG. 3

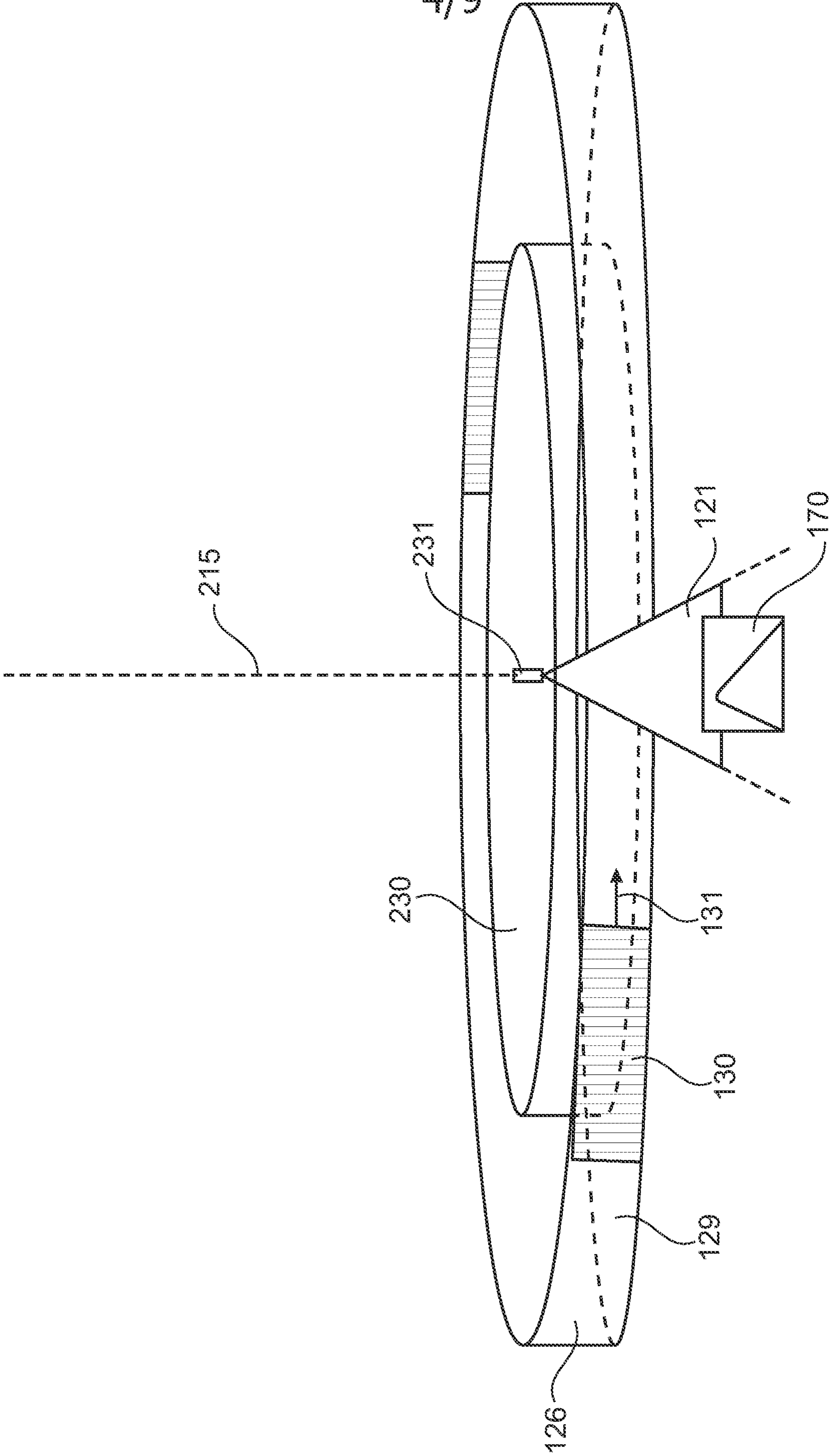

FIG. 4

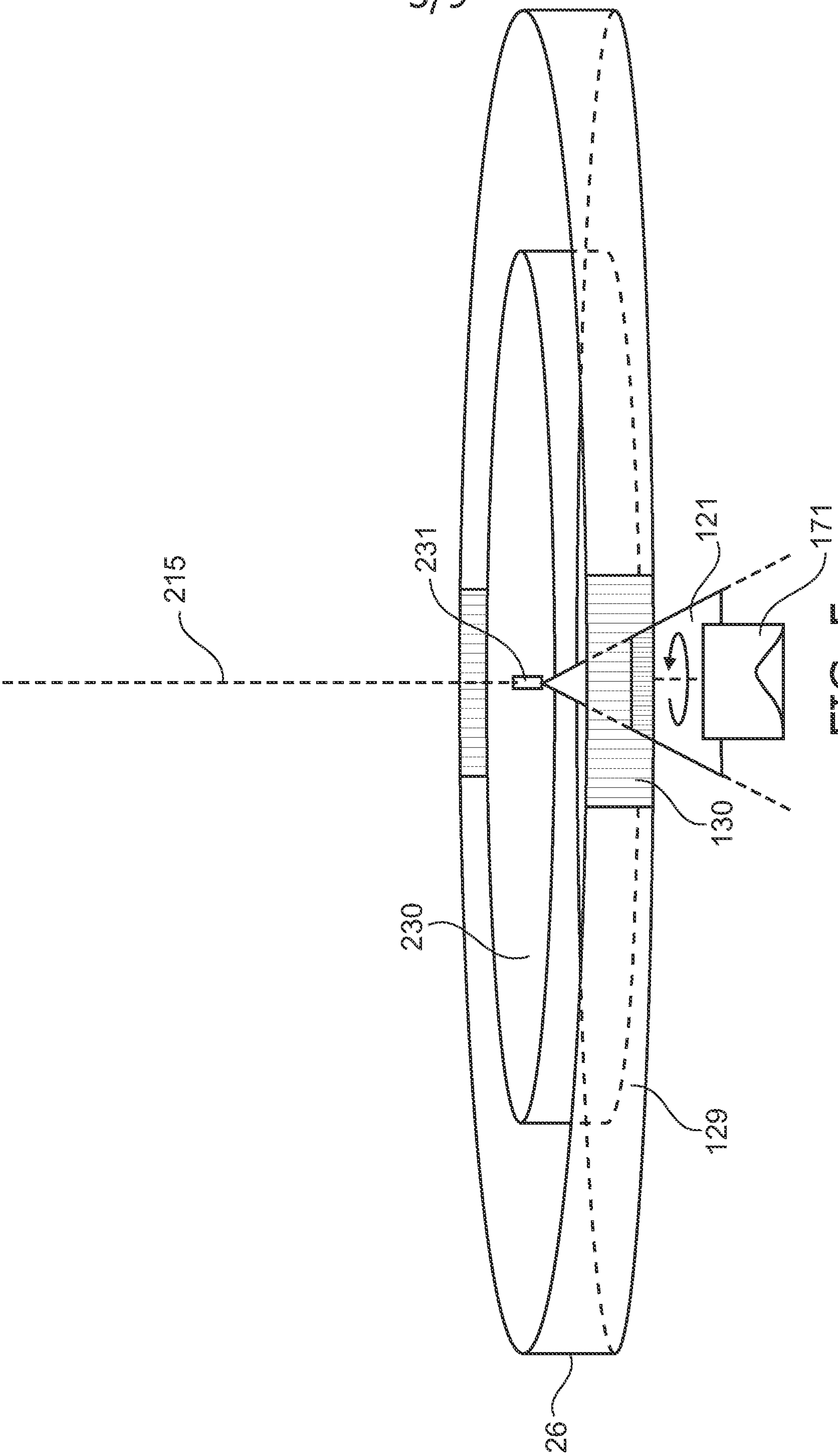

FIG. 5

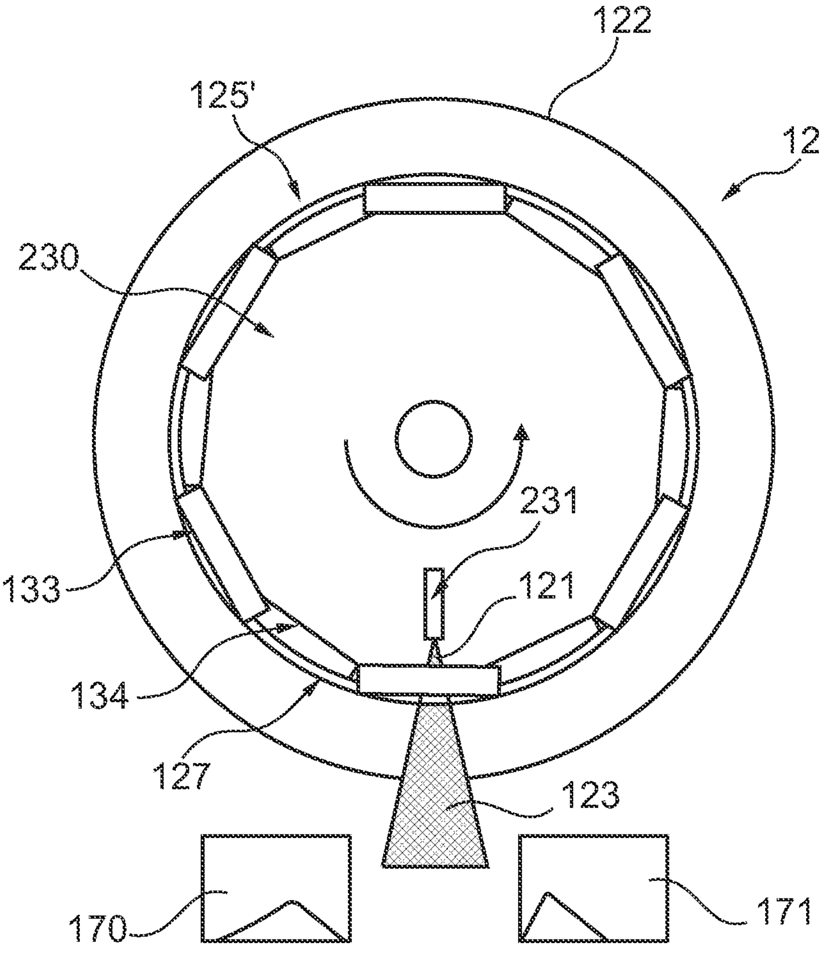

FIG. 6

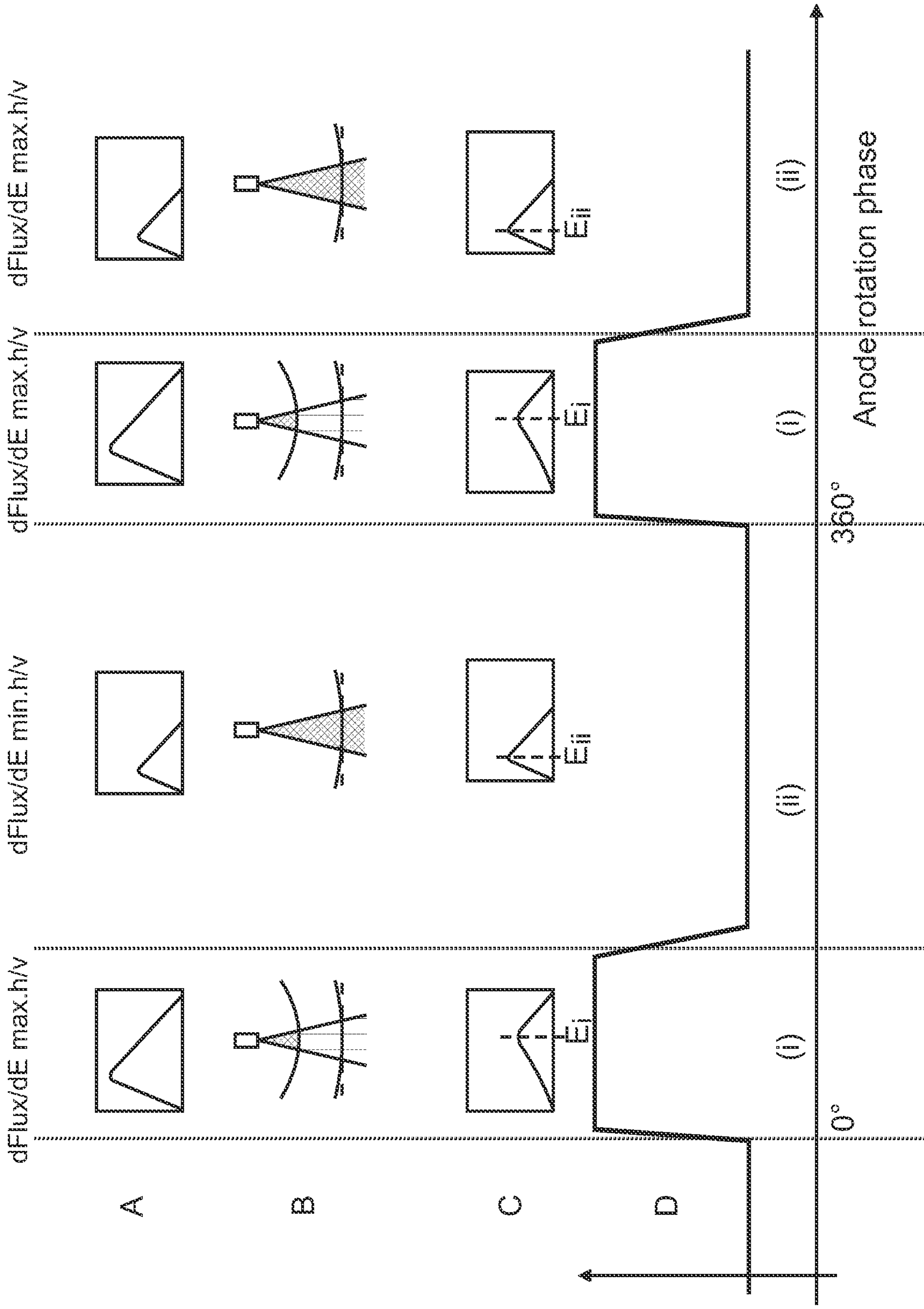
dFlux/dE max.h/v
dFlux/dE min.h/v
dFlux/dE max.h/v
dFlux/dE max.h/v
A
B
C
D
Ei
Eii
Ei
Eii
(i)
(ii)
(i)
(ii)
0°
360°
Anode rotation phase

FIG. 7

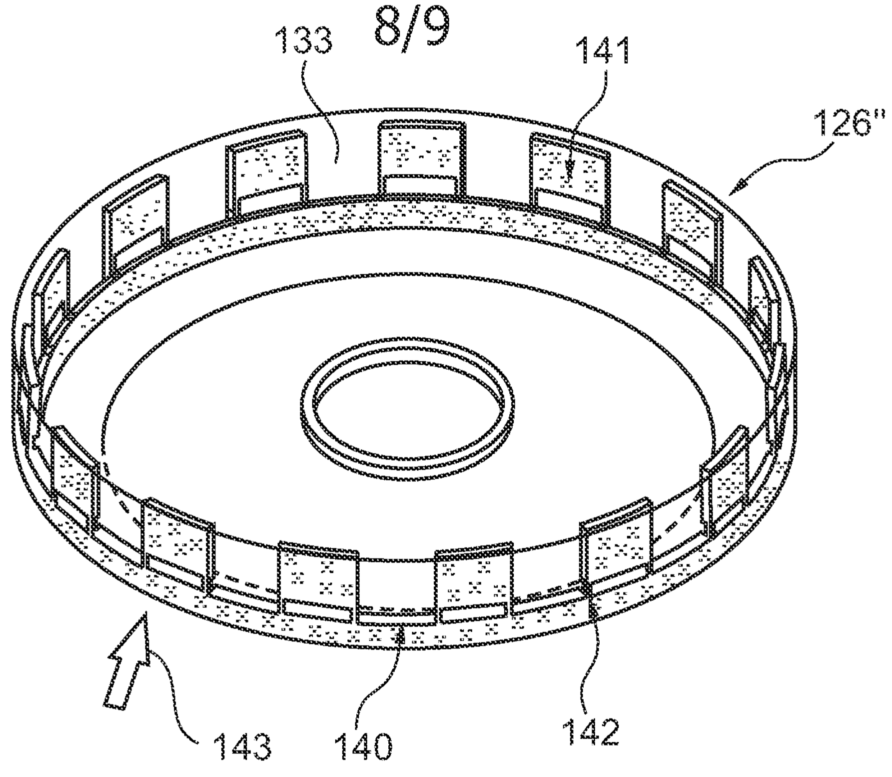

FIG. 8

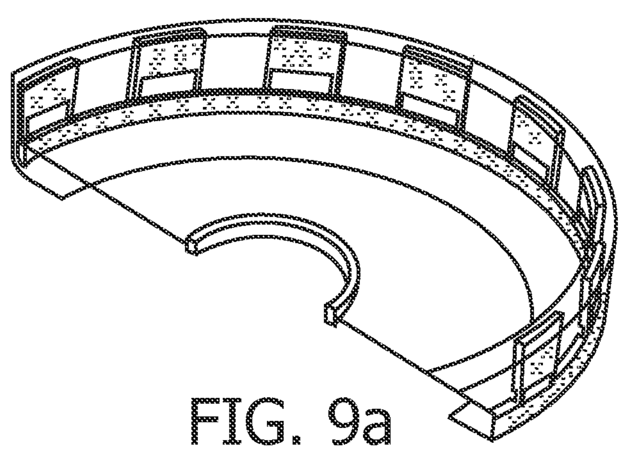

FIG. 9a

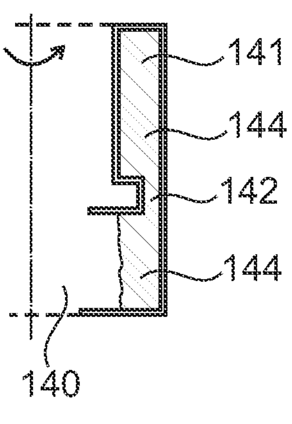

FIG. 9b

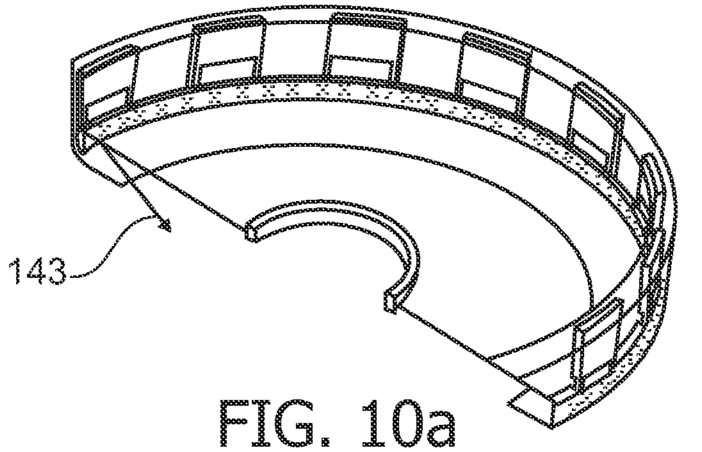

FIG. 10a

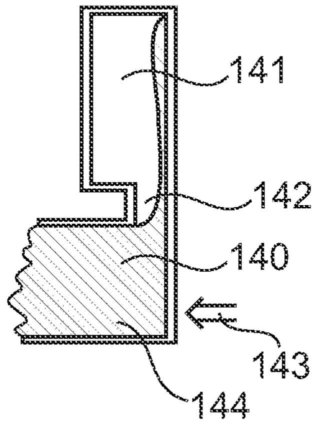

FIG. 10b

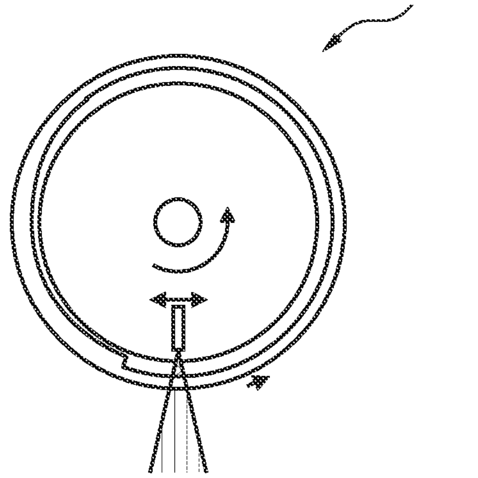

FIG. 11