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(54) X-RAY TUBE WITH ROTATING ANODE

(57) An X-ray tube (100) for X-ray imaging is described. The X-ray tube comprises an anode (10) configured to rotate around a rotational axis (12); a cathode (20) configured to generate an electron beam (14) impinging the anode; a rotational system (30) for rotating the anode around the rotational axis, wherein the rotational system comprises a bearing having a rotatable part and a stationary part. The rotatable part of the bearing is attached to the anode. The X-ray tube further includes a vacuum frame (40) enclosing the anode and the cathode, and a mechanical interface (50). The mechanical interface is positioned between the bearing and the vacuum frame, and is mechanically connecting the stationary part of the bearing and the vacuum frame. The mechanical interface comprises at least three elastic elements at different positions around the rotational axis, wherein each elastic element extends along the rotational axis to provide stiffness in an axial direction of the rotational axis, and wherein each elastic element is bendable in a radial direction of the anode.

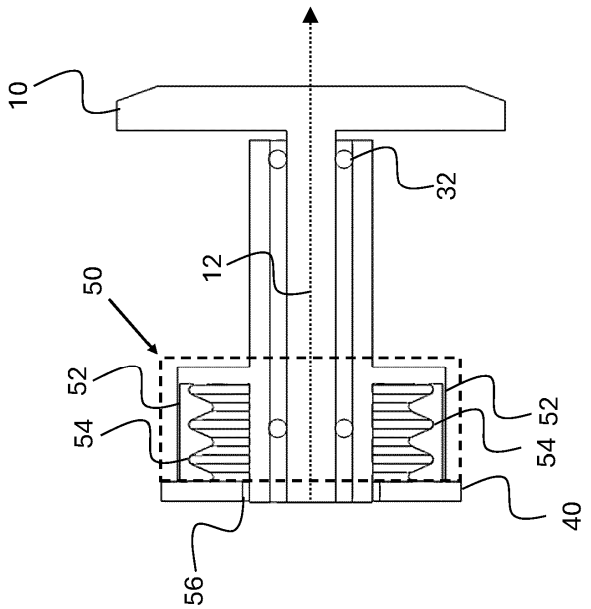


Fig. 4

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Description

FIELD OF THE INVENTION

[0001] The invention relates to an X-ray tube for X-ray imaging, and to an imaging system comprising the X-ray tube.

BACKGROUND OF THE INVENTION

[0002] An X-ray tube of an X-ray imaging system typically includes a cathode with a filament, and an anode. A filament current is applied to the filament, which current heats the filament, causing the filament to expel electrons (thermionic emission), creating a space charge a short distance away from the filament. A peak tube voltage is applied across the cathode and the anode and causes a beam of the electrons to accelerate from the cathode and impinge the anode. The X-ray tube current, or emission current, represents the number of electrons per second flowing from the cathode to the anode. Electrostatic or magnetic focusing with e.g. grid electrodes or quadrupoles can be applied to control a size of and steer the beam of electrons. An interaction of the electrons with the material of the anode produces heat and radiation, including X-rays, which pass through a tube window, into an examination region, to a detector.

[0003] A surface area of the anode that receives the beam of electrons is referred to as a focal spot. The size of the focal spot is one factor that affects the image quality of the X-ray image data. For example, the focal spot size affects the spatial resolution, where a smaller focal spot size results in a greater spatial resolution than a larger focal spot size, e.g., due to less focal spot blur from geometric magnification. The size and/or position of the focal spot may depend on the X-ray tube voltage, beam focusing voltage and tube current. With X-ray tubes having rotating anodes, the focal spot forms a so-called focal track on the anode due to the rotation. I.e., the focal track is a (circular) area on the anode where the focal spot moves on the anode due to the anode rotation.

[0004] During operation of such a rotating anode X-ray tube, vibrations occur. E.g., the anode may rotate with a frequency of 50-200Hz. Vibrations may be caused by small imbalances in the rotation system (anode, bearing, rotor). Vibrations during operation of the X-ray tube lead to noise and can negatively impact image quality.

[0005] JPS60105146A discloses a rotary anode X-ray tube device. The disclosure aims to reduce the noise and vibration caused by a supporting member which rotatably supports an anode member by connecting said supporting member to a tubular bulb, in which the anode member is installed and the internal atmosphere of which is maintained in a vacuum condition, through a bellows-like thin annular body.

SUMMARY OF THE INVENTION

[0006] There is a need to reduce the impact of vibrations on image quality when imaging with a rotary anode X-ray tube. In particular there is a need to reduce the impact of vibrations when imaging with a high resolution using a small focal spot, which is sensitive to disturbances. It is, inter alia, an object of the invention to provide an X-ray tube with improved resilience to disturbances on image quality caused by vibrations.

[0007] The invention is defined by the independent claims. Advantageous embodiments are defined in the dependent claims.

[0008] According to a first aspect of the invention, there is provided an X-ray tube for X-ray imaging. The X-ray tube comprises:

- an anode configured to rotate around a rotational axis;
- a cathode configured to generate an electron beam impinging the anode;
- a rotational system for rotating the anode around the rotational axis, wherein the rotational system comprises a bearing having a rotatable part and a stationary part, wherein the rotatable part of the bearing is attached to the anode;
- a vacuum frame enclosing the anode and the cathode; and
- a mechanical interface, wherein the mechanical interface is positioned between the bearing and the vacuum frame, and is mechanically connecting the stationary part of the bearing and the vacuum frame. According to the invention, the mechanical interface comprises at least three elastic elements at different positions around the rotational axis, wherein each elastic element extends along the rotational axis to provide stiffness in an axial direction of the rotational axis, and wherein each elastic element is bendable in a radial direction of the anode.

[0009] Due to tolerances in manufacturing, the rotational speed of the anode etc., some vibrations are likely to occur in any rotating anode X-ray tube assembly during use. By controlling the degrees of freedom of vibrations with the mechanical interface, particularly by preventing tilting of the rotational axis of the anode with respect to the electron beam, vacuum frame etc., during use of the X-ray tube, while allowing some movement in the radial direction, the negative influence of vibrations on e.g. focal spot size can be reduced.

[0010] The mechanical interface reduces vibrations of the rotational system and the anode in an axial direction of the rotational axis. By limiting tilting of the rotational anode as well as vibrations in the axial direction, while still allowing some vibrations in the radial direction, the negative influence on image quality from movement of the focal spot or focal track can be reduced.

[0011] Movement of the focal spot in the radial direc-

tion, i.e. in the rotational plane of the anode, has less negative impact on the focal spot size, and consequently on image quality, as compared to tilting of the anode. This is of particular relevance for applications with small focal spot sizes, e.g. smaller than 0.5 mm in diameter, such as for photon counting. Hence, imaging quality may be improved. Furthermore, the overall vibration amplitude and acoustic noise during operation may be reduced. The invention may be particularly beneficial for high anode rotation speeds.

[0012] In an embodiment, the mechanical interface comprises more than three, preferably at least five, elastic elements, wherein the elastic elements are distributed around the rotational axis.

[0013] In an embodiment, at least one of the elastic elements is a spring. The spring is configured to bend in the radial direction and to be stiff in the axial direction of the rotational axis. This provides an effective way to limit undesired movement as described above. The mechanical interface may comprise at least three springs, preferably at least five springs. The spring may comprise steel and/or titanium. These materials allow for the spring to maintain elasticity when brazed at high temperatures.

[0014] In an embodiment, the mechanical interface further comprises a bellow for providing fixation for radial and axial movement. The bellow may provide vacuum tight fixation. The fixation may be comparatively soft in the radial direction.

[0015] In an embodiment, the mechanical interface comprises a stopper for preventing overbending of the elastic elements. This is advantageous, since the stopper prevents damage to the mechanical interface, e.g. during transport conditions.

[0016] In an embodiment, the mechanical interface comprises an interface plate between the stationary part of the bearing and the vacuum frame. The interface plate provides for additional stability of the mechanical interface.

[0017] In an embodiment, the mechanical interface is configured to increase a stiffness of tilting of the rotational axis of the anode by a first factor, and to increase a stiffness in a radial direction of the rotational axis by a second factor, wherein the first factor is larger than the second factor.

[0018] In an embodiment, the first factor is at least 2, preferably at least 3, and more preferably at least 4. As compared to a situation without the mechanical interface according to the embodiment, the stiffness of tilting of the rotational axis may thus be increased with at least a factor 2, preferably a factor 3, and more preferably a factor 4 by the mechanical interface. At the same time, the corresponding increase in radial stiffness is proportionally lower, such as less than a factor 2 or preferably even lower. By increasing the tilt stiffness relatively more than the radial stiffness, vibrations will primarily occur in the radial direction of the rotation axis and tilting of the anode, and hence negative impact on the image quality, may be reduced.

[0019] In an embodiment, the bearing is a hydrodynamic bearing. The hydrodynamic bearing may be referred to as a liquid metal bearing. Such a bearing may be particularly suitable for high anode rotation speeds, while generating less vibration and noise as compared to ball bearings.

[0020] According to a second aspect of the invention, there is provided an X-ray imaging system comprising the X-ray tube according to the first aspect. The X-ray imaging system may be e.g. a computed tomography system, a radiography system, a fluoroscopy system, a luggage screening system etc.

[0021] These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022]

Fig. 1: Schematic drawing illustrating tilting of a rotating anode.

Fig. 2: Schematic drawing illustrating radial movement of a rotating anode

Fig. 3: Schematic drawing illustrating an X-ray tube according to embodiments of the invention.

Fig. 4: Schematic drawing of mechanical structure according to embodiments of the invention.

DETAILED DESCRIPTION OF EMBODIMENTS

[0023] Fig. 1 illustrates a rotating anode 10 of an X-ray tube. On the left side of Fig. 1, the anode 10 is in a default position, rotating around a rotational axis 12. An electron beam 14 impinges the anode at a focal spot 16. Due to the rotation of the anode, the focal spot forms a focal track on the anode. At the focal spot 16, X-rays are generated from the interaction between the electron beam and the anode. The size and position of the focal spot will therefore be of great importance for the localization of generated X-rays. Hence, the properties of the focal spot have a major impact on image quality when the X-ray tube is used for imaging in an imaging system. The right side of Fig. 1 illustrates, in schematic fashion, the effect of tilting of the anode and its rotational axis 12 with respect to the electron beam. As can be seen when comparing the situation left and right, the size and position of the focal spot 16 changes due to the tilting. This will lead to blurring of the image, hence reducing image quality.

[0024] Fig. 2 illustrates, in a similar way to Fig. 1, a rotating anode 10 of an X-ray tube. On the left side of Fig. 2, the anode 10 is in a default position, rotating around a rotational axis 12. An electron beam 14 impinges the anode at a focal spot 16. Due to the rotation of the anode, the focal spot forms a focal track on the anode. At the focal spot 16, X-rays are generated from the interaction between the electron beam and the anode. The right-hand side of Fig. 2 illustrates the effect of a movement of

vibration in a radial direction of the rotation axis. Here, the anode has moved in the direction from bottom to top in the figure. As illustrated in this example, when the position of the anode is shifted transverse to the rotational axis the size of the focal spot 16 stays the same. Hence, such vibrations in radial direction have much less negative impact on image quality as compared to the situation with tilting illustrated in Fig. 1.

[0025] Vibrations of components of the X-ray tube during operation cannot be completely avoided. The inventors have found that by, compared to a known X-ray tube, increasing or maximizing the allowed vibrations in the radial direction of the rotating anode, while reducing or minimizing any tilting of the anode with respect to the electron beam, the X-ray tube can be compliant to withstand total vibrations during operation, while improving the image quality. Vibrations will still occur, but by directing them in the radial direction as opposed to tilting and/or axial direction, the negative influence by vibrations on performance of the X-ray tube can be reduced.

[0026] An example of an X-ray tube 100 according to embodiments of the present invention is illustrated in Fig. 3. The X-ray tube includes a rotating anode 10, and a cathode 20 for generating an electron beam 14. In use, the anode rotates around a rotational axis 12, and the electron beam impinges the anode at a focal spot 16, such that X-ray radiation 18 is generated. The anode is attached to a rotational system 30. The rotational system comprises a motor for rotating the anode. The rotational system includes at least one bearing. The bearing extends along the rotational axis of the anode. The bearing, in use, has a stationary part and a rotating part. The rotating part of the bearing is mechanically connected to the anode 10, such that the anode 10 can rotate around the rotational axis 12. The X-ray tube includes a vacuum frame 40 that surrounds the anode and the cathode, such that a vacuum can be maintained. The bearing may be a ball bearing or a hydrodynamic bearing, also known as liquid metal bearing. The X-ray tube further includes a mechanical interface 50. The mechanical interface 50 is positioned between the bearing and the vacuum frame. The mechanical interface is mechanically connecting the stationary part of the bearing and the vacuum frame. The mechanical interface comprises at least three elastic elements positioned around the rotational axis, wherein each elastic element extends along the rotational axis to provide stiffness in an axial direction of the rotational axis, and wherein each elastic element is bendable in a radial direction of the anode. The mechanical interface may hereby increase a stiffness of tilting of the rotational axis of the anode relatively more than it is increases a stiffness in a radial direction of the rotational axis. The mechanical interface 50 may prevent and/or minimize vibrations of the rotational system and the anode in an axial direction of the rotational axis.

[0027] A schematic drawing of a mechanical structure of an X-ray tube according to embodiments of the invention is shown in Fig. 4. The figure shows a rotating anode 10, and its bearing, here shown as a ball bearing 32. The bearing may alternatively, or additionally, be a hydrodynamic bearing. The stationary part of the bearing is mechanically connected to a vacuum frame 40 via a mechanical interface 50. In this example the mechanical interface 50 comprises springs 52 as elastic elements. For simplicity, only a top and a bottom spring 52 is illustrated in the figure but one or more additional elastic elements are positioned around the rotational axis. The mechanical interface also comprises bellows 54. The bellows have surfaces inclined to the rotational axis of the anode, which means that the bellows 54 may provide for vacuum tight but soft fixation for radial movement and axial movement. The springs 52, in the form of pillars, on the other hand provide for high stiffness, strong resistance to movement in the axial direction (left-right in the figure) and tilting direction of the rotational axis 12 of the anode, while at the same time the resistance to movement in a radial direction (e.g. up-down in the figure) is reduced to a lesser extent since. Preferably, at least five springs 52 are positioned around the bearing. In the example in Fig. 4, a mechanical stopper 56 prevents overbending of the springs by limiting the possible amplitude of movement. This may be of particular advantage to avoid damage to the mechanical interface when transporting the X-ray tube, i.e. when the X-ray tube is not in use and the anode is not rotating.

[0028] As an example, simulations indicate that a mechanical interface such as in Fig. 4, with e.g. six springs 52, may be designed to increase the tilt stiffness from 3.3E+03 Nm/rad to 1.4E+04 Nm/rad, i.e. with a factor of more than 4, whereas the radial stiffness at the same time is only increased from 3.4E+05 N/m to 6.7E+05 N/m, i.e. with less than a factor of 2. Herein, 3.3E+03 is a different notation for 3.3×10^3.

[0029] In Fig. 4, the springs are in the form of pillars that are stiff in the axial direction but may bend in a radial direction. Alternatively, or additionally, other springs or elastic elements may be used, which are designed and oriented as to provide large stiffness and resistance to movement in the axial and tilting direction, while being more flexible to move in the radial direction.

[0030] It should be noted that the above-mentioned embodiments illustrate rather than limit the invention, and that those skilled in the art will be able to design many alternative embodiments without departing from the scope of the appended claims. In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim. The word "comprising" does not exclude the presence of elements or steps other than those listed in a claim. The word "a" or "an" preceding an element does not exclude the presence of a plurality of such elements. The invention may be implemented by means of hardware comprising several distinct elements. In the device claim enumerating several means, several of these means may be embodied by one and the same item of hardware. Measures recited in mutually different dependent claims may advanta-

geously be used in combination.

Claims

1. An X-ray tube (100) for X-ray imaging, the X-ray tube comprising:

   - an anode (10) configured to rotate around a rotational axis (12);
   - a cathode (20) configured to generate an electron beam (14) impinging the anode;
   - a rotational system (30) for rotating the anode around the rotational axis, wherein the rotational system comprises a bearing having a rotatable part and a stationary part, wherein the rotatable part of the bearing is attached to the anode;
   - a vacuum frame (40) enclosing the anode and the cathode; and
   - a mechanical interface (50), wherein the mechanical interface is positioned between the bearing and the vacuum frame, and is mechanically connecting the stationary part of the bearing and the vacuum frame, and

   characterized in that the mechanical interface comprises at least three elastic elements at different positions around the rotational axis, wherein each elastic element extends along the rotational axis to provide stiffness in an axial direction of the rotational axis, and wherein each elastic element is bendable in a radial direction of the anode.

2. The X-ray tube according to claim 1, wherein the mechanical interface comprises more than three elastic elements, and wherein the elastic elements are distributed around the rotational axis.

3. The X-ray tube according to claim 1 or 2, wherein at least one of the elastic elements is a spring (52).

4. The X-ray tube according to claim 3, wherein the mechanical interface comprises at least three springs (52) around the rotational axis, preferably at least five springs (52) around the rotational axis.

5. The X-ray tube according to claim 3 or 4, wherein a material of at least one spring comprises at least one of steel or titanium.

6. The X-ray tube according to any of the preceding claims, wherein the mechanical interface further comprises a bellow (54) for providing fixation for radial and axial movement.

7. The X-ray tube according to any of the preceding claims, wherein the mechanical interface further comprises a stopper (56) for preventing overbending the elastic elements

8. The X-ray tube according to any of the preceding claims, wherein the mechanical interface comprises an interface plate between the stationary part of the bearing and the vacuum frame.

9. The X-ray tube according any of the preceding claims, wherein the mechanical interface is configured to increase a stiffness of tilting of the rotational axis of the anode by a first factor, and to increase a stiffness in a radial direction of the rotational axis by a second factor, wherein the first factor is larger than the second factor.

10. The X-ray tube according to claim 9, wherein the first factor is at least 2, preferably at least 3, and more preferably at least 4.

11. The X-ray tube according to claim 9 or 10, wherein the first factor is at least twice as large as the second factor.

12. The X-ray tube according to any of the preceding claims, wherein the bearing is a hydrodynamic bearing.

13. An X-ray imaging system comprising the X-ray tube according to any of the preceding claims.

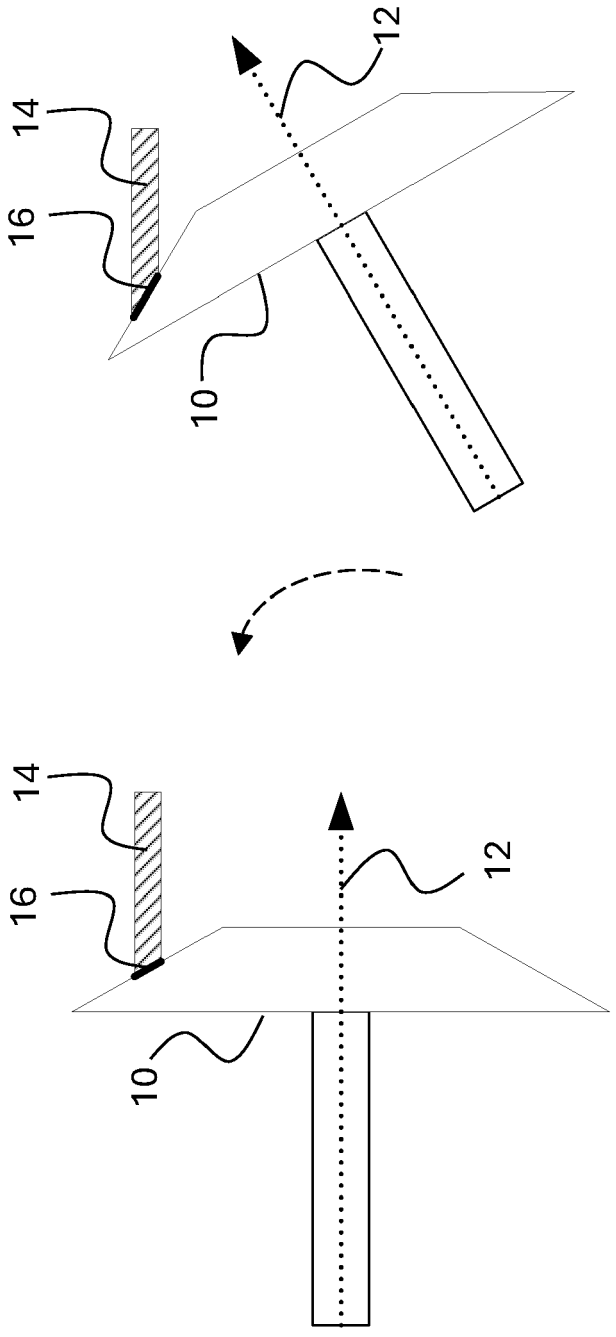


Fig. 1

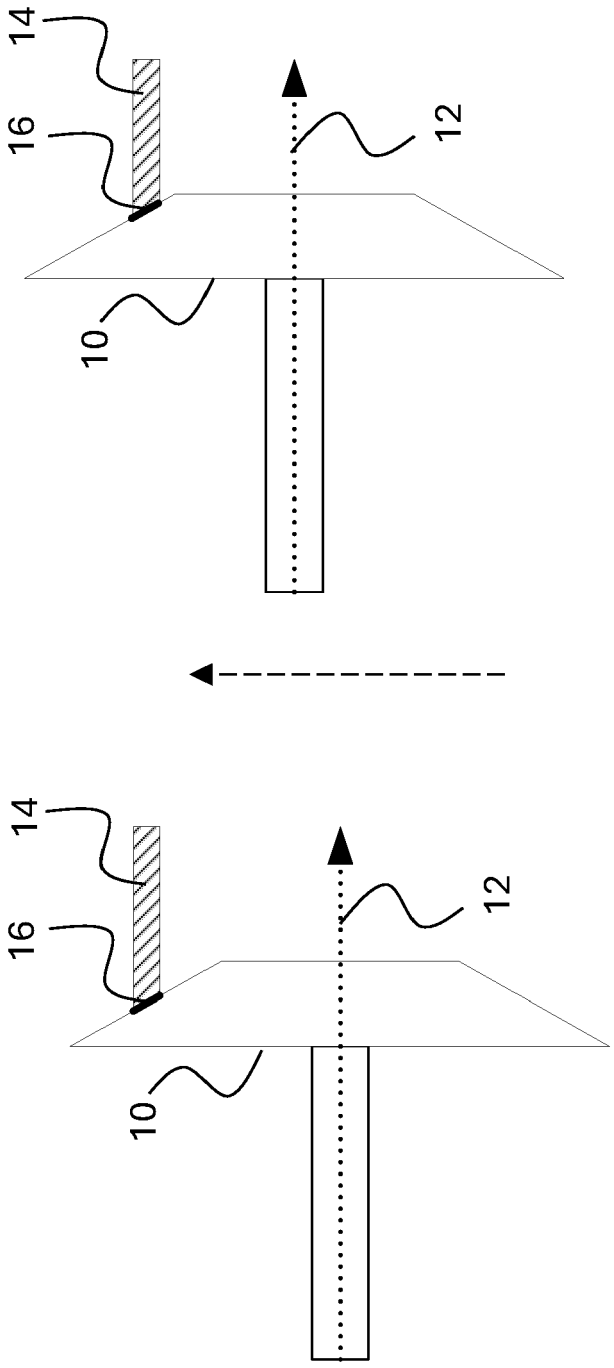


Fig. 2

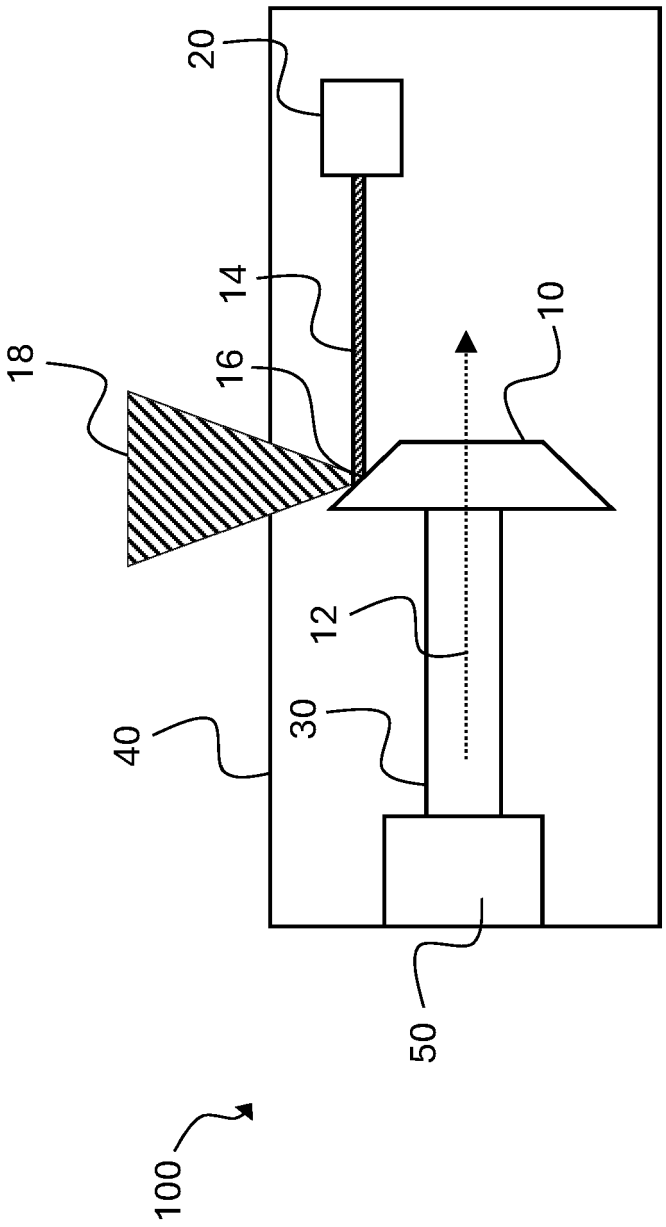


Fig. 3

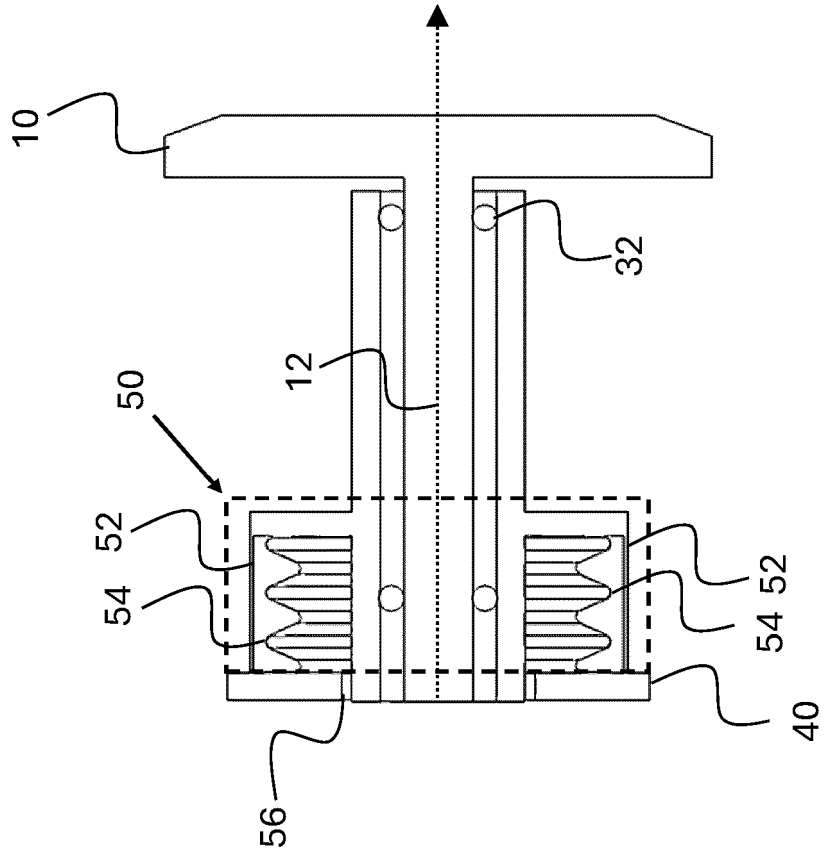


Fig. 4

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EUROPEAN SEARCH REPORT

Application Number
EP 25 16 7292

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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TECHNICAL FIELDS SEARCHED (IPC)

H01J

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	12 September 2025	Giovanardi, Chiara

CATEGORY OF CITED DOCUMENTS

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