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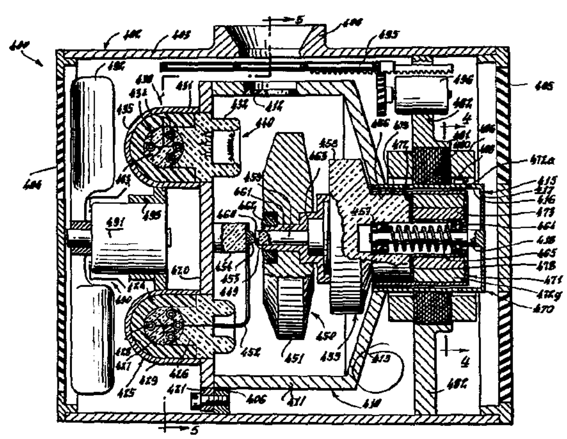
(71) Applicant: **LITTON INDUSTRIAL PRODUCTS, INC., P.O. Box 9461, Minneapolis, MN 55440 (US)**

(72) Inventor: **Klostermann, Heinrich F., 469 Dayton Road, Trumbull Connecticut 06611 (US)**

(74) Representative: **Patentanwälte TER MEER - MÜLLER - STEINMEISTER, Triftstrasse 4, D-8000 München 22 (DE)**

(54) **Rotating anode X-ray tube.**

(57) An x-ray tube comprises a generally cylindrical evacuated metal tube envelope (410) having an anode (451) rotatably mounted therein. The tube envelope wall (525) includes ferrous segments (526a–526f) which minimize the gap in the magnetic coupling while permitting a thick and strong tube envelope wall. Drive means (230) includes a DC stator (240) external of the tube envelope acting on an internal rotor (235) mounted to rotate with the anode. Anode drive means also includes a DC stator (480) operating on a rotor (471) having encapsulated rare earth magnets (472a–472h), and an AC stator (570) operating on a squirrel cage rotor (550) through a laminated segmented tube wall (525).



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TER MEER-MÜLLER-STEINMEISTER
PATENTANWÄLTE – EUROPEAN PATENT ATTORNEYS

Dipl.-Chem. Dr. N. ter Meer
Dipl.-Ing. F. E. Müller
Triftstrasse 4,
D-8000 MÜNCHEN 22

Dipl.-Ing. H. Steinmeister
Artur-Ladebeck-Strasse 51
D-4800 BIELEFELD 1

0081755

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Mü/b

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LITTON INDUSTRIAL PRODUCTS, INC.
P.O. Box 9461
MINNEAPOLIS, MN 55440

ROTATING ANODE X-RAY TUBE

BACKGROUND OF THE INVENTION

This invention relates to improved x-ray tubes in general and more particularly to x-ray tubes with efficient rotation drives for the anode, and with a compact metal tube envelope.

Present rotating anode x-ray tubes have a cathode consisting of one or two filaments with corresponding focus cups, and a rotating anode assembly. These are mounted inside an all glass or a metal/glass evacuated tube envelope and the envelope is mounted inside an x-ray tube housing. The housing is filled with insulating oil, includes a heat expansion system and also incorporates the stator of an AC squirrel cage anode drive motor. The stator is generally concentric about the rotor of the anode drive motor, the rotor being part of the rotating anode assembly inside the vacuum tube envelope. Thus, the stator is spaced from the rotor by the thickness of the tube wall plus necessary clearances, which makes the squirrel cage motor inefficient and heat-producing.

SUMMARY OF THE INVENTION

An x-ray tube according to the invention herein has an anode rotatably mounted within a tube envelope, the anode being connected to an internal rotor which is magnetically coupled to external drive means for rotating the anode. The internal rotor is positioned closely adjacent the interior of the tube envelope and the tube envelope is provided with ferrous segments which form a part of flux loops coupling the internal rotor with the external drive means. Thus, the tube envelope may be relatively thick and structurally sound, and yet gaps in the magnetically-coupling flux loops are minimized.

The internal rotor may also be driven by the field of stator mounted outside the tube envelope surrounding the rotor portion of the anode/rotor assembly. In one such embodiment, the stator is a multiple pole DC stator having its pole shoes surrounding a cup portion of the tube envelope in which the rotor is closely received. The rotor comprises a plurality of bar magnets, preferably of the rare earth type, which extend outwardly from the surface of a ferrous sleeve and are separated by non-ferrous spacers. The rare earth magnets and sleeve are sealed in a non-ferrous casing to prevent the rare earth magnets from contaminating the vacuum in the tube envelope. The axial length of the permanent magnets is greater than that of the pole shoes, which biases the anode/rotor toward a structural stop at the cathode end of the tube to achieve stable cathode-anode spacing, and also provides for mounting a Hall device over the extending permanent magnets for switching current to the stator. The cup portion of the tube envelope between the rotor and stator may be either entirely non-ferrous or may comprise ferrous segments with non-ferrous spacers.

In another such embodiment, the stator and rotor comprise a brushless AC induction motor, also known as a squirrel cage motor. The stator pole shoes are deployed surrounding a cup portion of the tube envelope, the cup wall having ferrous segments separated by non-ferrous spacers to reduce the effective gap between the stator and rotor. The stator, rotor and ferrous wall segments are all preferably laminated to reduce eddy currents, and the wall has a thin sleeve to prevent vacuum leaks between the laminations. The rotor is fabricated and mounted to a ceramic insulator (which mounts the anode) by a copper casting process, in which the ferrous laminations of the rotor are aligned on the end of a ceramic insulator and liquid copper is flowed into open spaces in the laminations to form the longitudinal non-ferrous bars of the rotor and is also flowed over the exterior of the rotor and the adjacent portion of the ceramic insulator to form a sleeve which secures the rotor to the ceramic insulator. The ceramic insulator is preferably configured so that the sleeve surrounds flat surfaces and grooves to achieve a strong connection. The rotor also preferably incorporates a cam having ferrous lobes which close a flux loop through an externally mounted magnet and Hall device, providing a speed monitor.

At least the main portion of the tube envelope surrounding the rotating anode is generally cylindrical and made of metal, preferably copper, which may be lined with ceramic insulating material. The end of the tube envelope opposite the anode target surface is not lined with ceramic for good transfer of heat from the anode, and the exterior of the tube envelope end may be finned to dissipate heat rapidly. The tube envelope may be mounted in a surrounding housing, and is air cooled.

Other features of the x-ray tube according to the invention herein include embedding the cathode supply leads (both filament and grid) in the ceramic tube lining, whereby both the cathode and anode cables may enter the tube envelope generally opposite the x-ray window area, making the tube easy to mount and utilize in x-ray apparatus. Power to the anode is provided through a coupling separate and distinct from the bearings on which the anode is mounted, prolonging the life of the bearings. Improved cable terminations are also provided.

All of the foregoing features combine to provide a vastly improved x-ray tube. Other and more specific features and objects of the invention herein will in part be obvious to those skilled in the art and will in part appear from the following description of the preferred embodiments and the claims, taken together with the drawings.

DRAWINGS

Figure 1 is a longitudinal sectional view, partially cut away, of an x-ray tube according to the invention herein;

Figure 2 is a sectional view of the x-ray tube of Figure 1 taken along the lines 15-15 of Figure 1;

Figure 3 is a longitudinal sectional view of another x-ray tube according to the invention herein;

Figure 4 is a sectional view of the motor drive of the x-ray tube of Figure 3, taken along the lines 17-17 of Figure 3;

Figure 5 is a sectional view of the x-ray tube of Figure 3, taken along the lines 18-18 of Figure 3;

Figure 6 is a fragmented longitudinal sectional view of another x-ray tube according to the invention herein, particularly the motor drive portion thereof;

Figure 7 is a sectional view of the motor drive portion of the x-ray tube of Figure 6, taken along the lines 20-20 of Figure 6;

Figure 8 is a sectional view of the motor drive portion of the x-ray tube of Figure 6 taken along the lines 21-21 of Figure 6;

Figure 9 is a sectional view of the x-ray tube of Figure 6 taken along the lines 22-22 thereof;

Figure 10 is a schematic view illustrating an assembly step in fabricating the x-ray tube of Figure 6; and

Figure 11 is a schematic view also illustrating an assembly step in fabricating the x-ray tube of Figure 6.

The same reference numerals refer to the same elements throughout the various Figures.

DESCRIPTION OF PREFERRED EMBODIMENTS

With reference to Figures 1 and 2, an x-ray tube 220 according to the invention herein is shown. More particularly, in Figure 1, the anode drive 230 for the x-ray tube 220 is shown, and the remaining portions of the x-ray tube 220 including the cathode, anode assembly, remainder of the tube envelope, etc. may be the same as any of the previously described x-ray tubes.

In Figure 1, the shaft 45 of the anode assembly is supported in and extends through bearings 46 which are mounted in the disc 38 of the tube envelope 20. The shaft 45 is also mounted in bearings 221 set in the end wall of cup 223 extending from the tube envelope 20.

The anode drive 230 is characterized by a permanent magnet rotor 235 which is driven by a stationary external DC stator 240 coupled to the rotor through the cylindrical wall 224 of the cup 223. The permanent magnet rotor 235 is mounted to shaft 45 and is positioned in the cup 223. The north pole 236 and the south pole 237 of the permanent magnet rotor 235 are diametrically opposed and lie closely adjacent the interior of the cylindrical wall 224, with a minimum air gap therebetween. The stator 240 surrounds the cylindrical wall 224, and has diametrically opposed ferrous pole pieces 241 and 242 havng pole shoes 243 and 244, respectively, lying closely adjacent the exterior of the cylindrical wall 224. The pole pieces 241 and 242 have coils 245 and 246, respectively, wound thereabout for creating a magnetic field which drives the permanent magnet rotor 235. The pole pieces 241 and 242 are connected by a ferrous cylindrical outer wall 247, which provides a flux path connecting the pole pieces.

The cylindrical wall 224 of the tube envelope cup 223 includes ferrous segments 225 and 226, the ferrous segment 225 lying adjacent the pole shoe 243 of the pole 241 and the ferrous segment 226 lying adjacent the pole shoe 244 of the pole 242. The other portions of the cylindrical wall 224 are non-ferrous, and may be aluminum or preferably glass. It should be noted that the pole shoes 243 and 244, the ferrous wall segments 225 and 226 and the permanent magnet rotor ends 236 and 237 are of the same size and particularly the same width, whereby they are coterminus when aligned.

The rotor 235 is driven by energizing the coils 245 and 246, respectively, surrounding the pole pieces 241 and 242, thereby establishing a magnetic field which repulses or attracts the rotor 235 depending upon its position and the direction of the magnetic field, as is well known in motor technology. For instance, with reference to Figure 2, the rotor 235 is shown rotating in a clockwise direction, and the coils 245 and 246 are energized to establish pole piece 241 as a north pole and pole piece 242 as a south pole. Thus, the north pole 236 of the rotor is repelled from the pole piece 241 of the stator, and the south pole 237 is also repelled from the pole piece 242 of the stator, continuing to drive the rotor in the clockwise direction. As the rotor completes 180° of rotation, the direction of the current in coils 245 and 246 is reversed to continue to drive the rotor and hence the anode via shaft 45.

A sensor 250 mounted through the end wall of the cup 223 determines the passage of a passive sensor target 251 mounted to the rotor 235. The sensor may be a magnetic sensor, an optical and particularly a fiber optical sensor, or even a mechanical sensor, as desired. The output of the sensor 250 is processed through a signal generator 252, which signals a position indicator 253 and a speed indicator 254. Speed control circuitry 255 receives the output of a speed selector and control 256 as well as the output from the speed indicator 254 and, in conjunction with pulse generator and timing circuitry 257, receiving the output of the position indicator 253, provides appropriate pulses for energizing the coils 245 and 246 to drive the rotor 235 and hence the anode. The pulses are timed with respect to the rotation of the rotor such that maximum torque is exerted until the rotor and anode are at the desired speed, and then sufficient driving force is provided to maintain that speed. Braking is accomplished by appropriate reversing of the fields to slow and stop the rotor. An external cooling fan (not shown) may be provided with the x-ray tube 220, inasmuch as there are no moving external parts for creating a flow of cooling air. It will be appreciated that the rotor 235 may have multiple pole pieces and the stator may also have multiple pole pieces, whereby the strength of the drive is increased. The embodiment shown has two pole pieces for sake of simplicity.

A further and preferred embodiment of the invention herein is found in the x-ray tube 400 of Figures 3-5. The x-ray tube 400 generally comprises a tube envelope 410 having an anode assembly 450 rotationally mounted therein, the anode assembly including an anode 451 and the rotor portion of a motor drive 470. The tube envelope 410 is received in a housing 402, which mounts the stator of the motor drive. The tube envelope includes cable terminations, and is cooled by a fan which circulates air through the housing surrounding the tube envelope.

The tube envelope 410 includes a cylindrical sidewall 411 surrounding the anode, and is provided with a radiolucent window 412 for emitting the x-rays. An annular end wall 413 joins the sidewall 411 with a cup 415. The cup 415 protrudes outwardly and includes its cylindrical sidewall 416 and an end wall 417. An axially-disposed stud 418 protrudes from the end wall 417 into the interior of the tube envelope for supporting the rotating anode assembly 450, as more fully discussed below. The opposite end of the tube envelope 410 is closed by an end wall 420 secured to the cylindrical sidewall 411 of the tube envelope, which mounts terminals 425 and 430, more fully discussed below. The sidewall 411 and end wall 420 are preferably fabricated of copper, and the cup 415 is preferably fabricated of .304 steel, Monel steel or other similar non-ferromagnetic steel.

The anode assembly 450 is rotationally mounted in the tube envelope 410 on the stud 418 of the cup 415. The anode assembly 450 generally comprises the anode 451, a ceramic insulator 455, and the rotor 471 of the motor drive 470 for the rotating anode assembly. The insulator, which is fabricated of ceramic, includes a cylindrical shank 456 which extends into the cup 415 of the tube envelope. Thus, the shank surrounds the stud 418, and a bearing 457 is provided between the stud and interior of the shank. The ceramic insulator 455 further comprises a disc 458 which extends radially outwardly from the shank along the tube envelope end wall 413, and shields the interior of the cup 415 from radiant heat transfer from the anode. A stud 459, which may be stepped as shown, extends from the disc 458 opposite the shank 456, and has a metal contact and bearing plate 460 mounted at its free end. A metal sleeve 461 is fitted around and secured to the stud 459, and the anode 451 is slipped over the metal sleeve and secured by a nut 462. A portion of the metal sleeve 461, indicated at 463, forms a key which engages with a slot in the anode 451 to ensure rotation of the anode with the ceramic insulator 455.

The motor drive 470 is characterized by a rotor 471 incorporating a plurality of permanent magnets, preferably of the rare earth type, which results in a motor drive capable of high torque despite the gap extant between the stator and the rotor. The rotor structure seals the rare earth magnets to prevent them from contaminating the evacuated interior of the tube envelope 410.

More particularly, the rotor 471 comprises eight generally rectilinear rare earth permanent magnets 472a-472h, deployed spaced apart and extending outwardly from an octagonal steel ring 473, which serves to close the flux loop between the magnets. As best seen in Figure 4, the permanent magnets 472 are separated by spacers of non-ferrous material 474. A casing of non-ferrous material surrounds and encloses the permanent magnets, the casing including an outer sleeve 475 which extends over and is secured to the shank 456 of the ceramic insulator by brazing or the like to mount the rotor 471 thereto. The casing further includes an inner sleeve 476 concentric with the stud 418. End walls 477 and 478 connect the inner and outer sleeves to complete the encapsulation of the permanent magnets and steel ring. The outer surface of the steel ring is octagonal, whereby the eight permanent magnets 472a-472h lie flat against the eight outwardly facing surfaces of the steel ring. The permanent magnets are deployed with alternating polarities, e.g., permanent magnet 472a has its north pole on its outer surface and its south pole adjacent the steel ring, and permanent magnet 472b has its north pole adjacent the steel ring and its south pole on its outer surface.

The rotor 471 may be fabricated by a copper cast process, and in particular, the steel ring 473 and the magnets may be placed in a form or mold into which liquid copper is poured to form the end walls 477 and 478, spacers 474, and inner casing sleeve 476. This subassembly may be milled to round the outer surfaces of the magnets and spacers, and the diameter of the inner casing sleeve may be finished to desired tolerances. The resulting subassembly may be dropped into the outer casing sleeve 475, and appropriate welding or brazing is carried out to seal the structure and encapsulate the permanent magnets. The extending portion of the outer sleeve is brazed to the shank of the ceramic insulator to mount the rotor thereto. Alternatively, the magnets can be pre-rounded on their outer surfaces, and the entire casing and spacers can be cast in one operation. As a further alternative, the spacers can be fabricated in pieces, and the rotor structure can be fabricated from welding up end walls and sleeves to encapsulate the steel ring, magnets and spacers. In short, there are several ways of making the sealed rotor, and the primary characteristic is that the permanent magnets are encapsulated so as not to contaminate the evacuated interior of the x-ray tube envelope.

A second bearing 464 is mounted between the interior of the rotor and the stud 418, and the two spaced apart bearings serve to rotationally mount the anode assembly 450. It will be noted that the second bearing butts against a shoulder of the stud 418, the first bearing butts against a shoulder of the opening in the shank of the ceramic insulator, and a spring 465 is placed between the two bearings. This arrangement biases the rotating anode assembly away from the cup end of the tube, and structurally "grounds" it as further discussed below.

The stator 480 of the motor drive 470 for the x-ray tube 400 surrounds the cup 415 of the tube envelope 410. The stator itself is mounted in a ring 481 supported on struts 482 extending from the housing 402. The cup 415 of the tube envelope slides in and out of the stator for replacing the tube envelope, and the stator supports and positions the tube envelope within the housing.

With particular reference to Figure 4, the stator 480 comprises a plurality of pole pieces 483 terminating in pole shoes 484 which surround the cylindrical sidewall 416 of the cup 415. The pole pieces are connected at the outer portion of the stator by a ring. The space between the cores accommodate the windings, not shown in detail but shown generally at 486 in Figure 3. The stator is preferably comprised of a stack of laminations, as also indicated in Figure 3, which reduces eddy currents in the stator. Winding is accomplished in accordance with known motor technology, given the specific number of magnets and number of pole pieces. In the embodiment shown, there are twenty-four pole pieces and eight magnets, but it will be appreciated that a different number of both pole pieces and magnets could be utilized and with the stator wound accordingly.

A Hall device 488 is mounted on the exterior of the cup wall 316 adjacent the stator 480. It will be noted that the permanent magnets 472 have an axial length greater than that of the pole shoes, and thereby extend beyond the pole pieces. This allows the Hall device to be positioned adjacent the pole pieces and be activated by the permanent magnets as the rotor rotates, and also biases the rotating anode assembly away from the cup end of the tube envelope toward a structural stop.

It should be noted that the gap between the cup wall 416 and the exterior of the rotor is exaggerated in Figure 4 for purposes of clarity. The motor drive is quite strong and capable of producing high torque for quick starts. Although a specific motor control is not shown, it can be similar to that described above with respect to x-ray tube 220, with the Hall device providing switching signals.

The x-ray tube 400 further comprises a cathode 440 mounted to the end wall 420 opposite the anode 451, and receiving its power via cable 441 through terminal 430. Terminal 430 comprises a ceramic or glass stud 431 sealed to and extending through the end plate 420 of the tube envelope. The ceramic stud 431 has a cup portion 432 extending into the tube, and which mounts one or more filaments and the grid comprising the cathode 440 of the x-ray tube 400. With reference to Figures 3 and 5, the outside end of the ceramic or glass stud 431 has a flat, sideways facing surface 433 in which plug receptacles 434 are fitted. Wires are embedded in the stud to connect the plug receptacles with the filaments and grid, as appropriate. A metal shield 435 is secured to the end plate 420 and has a curved closed end portion 436 generally surrounding the protruding stud and an elongated portion 437, U-shaped in section, extending along the end plate 420. Plastic insulation 438 is positioned between the metal shield 435 and stud 431, and defines an opening therein for receiving the terminal end 442 of the cathode supply cable 441. The terminal end 442 of the cathode supply cable has a plurality of plugs 443, such that it may be inserted into the opening in the plastic insulation 438 and plugged into the plug receptacles 434 on the stud 431. The terminal end 442 is shaped for this purose, and includes a flange 444 which may be secured to the metal shield for retaining the cable. A narrow air channel 439 is provided from the interface of the cable terminal end and the stud, the air channel 439 leading through the plastic insulation and metal shield, such that air may be pushed out of the opening in the plastic cover as the cable's terminal end is inserted.

The anode supply cable 445 is terminated at the tube envelope in a similar manner. The terminal 425 also comprises a ceramic or glass stud 426 extending through and sealed to the end plate 420, the stud 426 having a flat, sideways facing surface 427 in which plug receptacles 428 are formed. A metal shield 429 is secured to the end plate 420, and has a plastic insulation 424 fitted therein for receiving a terminal end 446 of the anode supply cable 445, which plugs into the plug receptacles 428. The plug receptacles 428 are connected to a wire lead 452 which extends into the x-ray tube envelope and has an end terminal 453 supported on a ceramic stud 454 mounted to the end plate and extending toward the anode, with the metal plate 460 on the rotating anode assembly in contact therewith. A wire lead 449 from the metal plate to the metal sleeve 461 completes the electrical circuit to the rotating anode.

It will be noted that the rotating anode assembly 450 is biased against the terminal 453 supported by the ceramic stud 454, which thereby axially positions the anode 451 within the tube envelope. This is advantageous and in that anode and cathode both have their reference position with respect to the end plate 420, and the distance between the cathode and anode remains constant within close tolerances despite heat expansion of the tube envelope.

The entire tube envelope 410 is mounted in the housing 402, which basically comprises a cylindrical outer wall 403 and end covers 404 and 405. The tube envelope is supported within the housing by sliding the end cup 415 within the stator 480 which in turn is mounted to the cylindrical wall of the tube housing by struts 482. At the terminal end of the tube envelope several lugs 421 extend radially outwardly and are fastened to complementary positioned lugs 406 extending from the tube housing, as best seen in Figure 5. The housing wall 403 is slotted at 407 (Figure 5) to accommodate the anode and cathode supply cables 441 and 445.

A fan assembly 490, including a fan motor 491 driving fan blades 492, is mounted within the tube housing for air cooling the x-ray tube 400. The fan assembly is preferably mounted at the cathode end of the tube, and in the preferred embodiment shown a bracket 493 is provided extending from the terminal shields 429 and 435 for supporting the fan motor. The end covers 404 and 405 at the ends of the tube housing are slotted to provide air flow. When the fan is operated, it blows on the end wall 420 and pushes air along the sides of the tube envelope and out the opposite end of the housing. End wall 420 can be provided with cooling fins, if desired.

The tube housing sidewall 403 is provided with a collimator 408 which is in registration with the window opening 412 of the tube envelope for emitting the x-rays. It is convenient to mount a sliding filter 495 powered by a motor 496 within the tube housing adjacent the tube envelope wherein the filter is slidably adjustably positioned over the window opening 412. The cylindrical tube housing is readily adaptable to the trunnion mounts generally used in x-ray tube equipment.

The x-ray tube 400 operates in the usual manner, i.e. a high voltage potential is applied to the anode 451 via the anode cable 445, anode terminal 425, lead wire 452 and terminal 453. The cathode is heated and grid voltage applied, and the motor drive 470 is operated to rotate the anode while x-rays are being produced. It will be appreciated that the copper tube envelope acts as an effective shield for stray x-rays, and also has excellent heat conductivity for transferring the heat from the interior to the exterior of the tube. The fan assembly provides cooling air to maintain the tube in a relatively cool condition during operation. The ceramic insulator 455, and particularly the cylindrical disc portion 458 thereof, helps to maintain the temperature in the cup 415 at relatively low level. Thus, the rare earth magnets of the rotor 471 are able to maintain their magnetic properties over a substantial period of time.

With reference to Figures 6-9, another x-ray tube 500 according to the invention herein is illustrated. The x-ray tube 500 is characterized by the use of rotating field induction motor drive, commonly referred to as the squirrel cage motor drive, operating through a laminated segmented portion of the tube envelope wall disposed between the stator and rotor. A further feature of the x-ray tube 500 is a cam activated Hall device speed monitor, which can be used in a feedback mode to control the motor speed. Figures 6-9 are fragmentary views of the x-ray tube 500, illustrating the cup portion 520 of tube envelope 510, a portion of the rotating anode assembly 540 including the rotor 550 of the motor drive, and the stator 570 of the motor drive surrounding the cup 520. It will be appreciated that the remaining elements of the x-ray tube 500 may be the same as those found in the x-ray tube 400 described above, and that the motor drive of the x-ray tube 500 can also be used with other configurations of x-ray tubes described above in place of the specific motor drives disclosed in connection therewith.

The end cup 520 of the x-ray tube 500 comprises a cylindrical sidewall 525, an end plate 535, and a stud 538 for mounting the rotating anode assembly 540. The cylindrical sidewall 525 of the cup has a plurality of laminated ferrous segments 526a-526f disposed between the rotor and stator of the motor drive, the segments extending axially along the wall in the area between the rotor and the stator and being interrupted along the circumference of the cylindrical wall by narrow non-ferrous segments 530, best seen in Figure 7. The stator 570, comprising pole pieces 571 and pole shoes 572, surrounds the cup 520, whereby the ferrous segments 526a-526f in effect become extensions of the pole shoes 572 of the stator 570, thereby reducing the effective gap between the stator and the rotor. The gap is exaggerated in the drawings for purposes of clarity, and is actually on the order of .005 inch.

The segments 526a-526f are preferably laminated to reduce eddy current effects; however, the laminated segments are not vacuum tight. Therefore the cylindrical wall of the cup 520 further comprises a thin preferably non-ferrous cylindrical sleeve 528 which prevents loss of vacuum through the laminated segments.

But even a ferrous sleeve 528 will perform satisfactorily results in preventing losses of vacuum through the laminated segments if thin enough to avoid magnetic circuit disruption. Also other materials which are neither ferrous nor non-ferrous such as glass or ceramic may be appropriate for this cylindrical sleeve 528.

With reference to Figures 10 and 11, a process for making the end cup 520 with its laminated segments is illustrated. A plurality of annular laminations 524 are fabricated, including spaced apart openings 523. At this point, the laminations are of greater diameter than the diameter of the finished wall, and correspond to the lower right hand portion of Figure 11. A cylindrical cup portion 521 is provided with openings positioned correspondingly to the openings in the laminations, and non-ferrous pins 530 are inserted into these openings. The laminations are inserted over the pins, and a second portion 522 of the cup comprising the end wall and stud and a portion of the cylindrical sidewall is press fit on to the pins, thereby sandwiching the laminations between the two solid portions of the cup. As schematically shown in Figure 11, the partially completed cup is milled to a lesser diameter,

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exposing the non-ferrous pins on the exterior surface. It will be noted that the pins were already exposed on the interor surface by virtue of the position of the openings in the laminations. Thus, the annular laminations are separated into the laminated ferrous segments 526a-526f between the non-ferrous pins 530.

The rotor 550 is mounted to the end of a ceramic insulator 545 of the rotating anode assembly, generally opposite the anode (not shown) and is positioned within the cup 520 surrounded by the stator 570. The rotor 550 comprises a stack of ferrous laminations 551 which, in their outer portions, have longitudinal openings filled with non-ferrous material indicated at 552, in typical squirrel cage configuration. Again, laminations are used to reduce eddy currents; however, it is difficult to completely clean the laminations and, therefore, the laminations of the rotor are sealed in a casing 555 to prevent contamination of the tube envelope. More particularly, the laminations are encased by a cylindrical outer sleeve 556, a cylindrical inner sleeve 557 and end walls 558 and 559, with the cylindrical outer sleeve extending over a portion of the shank 546 of the ceramic insulator 545 to attach the rotor thereto. The rotor is formed by copper casting the non-ferrous bars 552 and casing 555, which also permits providing a good mechanical connection to the shank 546 of the ceramic insulator. As seen in Figure 9, the shank 546 of the insulator is formed with flat surfaces 547 and a circumferential groove 548. Thus, when the outer sleeve 556 is copper cast, the copper mates with the flats and grooves of the shank for securely attaching the rotor in both axial and rotational modes.

The rotor also incorporates a cam 561, best seen in Figures 6 and 8, which forms a part of a speed monitoring assembly 560 of the x-ray tube 500. The speed monitoring assembly 560 also comprises two spaced-apart ferrous segments 562 and 563 extending through the cylindrical wall 525 of the cup 520 (although they do not extend through the inner sleeve 528). A magnet 564 is positioned over one of the segments, and a Hall device 565 is positioned over the other, with a ferrous bar 566 bridging the magnet and Hall device. The cam 561 has ferrous lobes 568 which, when they pass the ferrous segments 562 and 563, close a flux loop through the Hall device 565. Thus, the signals from the Hall device indicate the speed at which the anode is rotating. The cam 561 is conveniently positioned adjacent the rotor, and may be incorporated into the rotating anode assembly structure by copper casting it with the rotor. It will be appreciated that the cam may comprise any ferrous element mounted on or near the exterior of the rotating anode assembly and positioned and sized to make and break the flux loop through the Hall device.

The rotating anode assembly 540 is mounted on stud 538 by bearings 542 and 543 and is biased toward the cathode end of the tube by spring 544, similar to the description above with respect to x-ray tube 400.

The stator 570 of the motor drive is as described above, and has windings 571 in accordance with known motor technology, e.g. it can be wound for two or three-phase operation. The motor drive can be run from AC current at standard frequencies, but is preferably powered by a variable frequency motor control, not a part of the invention herein.

The x-ray tube 500 can be efficiently driven, primarily because of the small effective gap between the stator and rotor, achieved through the use of the segmented wall.

It will be appreciated that the x-ray tubes illustrated and described herein are preferred embodiments and that changes may be made by those skilled in the art without departing from the spirit and scope of the invention. As a very basic example, the various drive means may be used in combination with the rotating cathode feature or with the fixed grounded cathode feature, or even with tube envelopes of prior art x-ray tubes which have been appropriately modified to accept the drive means according to the invention herein. Similarly, structural changes in the tube envelopes illustrated, terminals, bearing positions, and the like, may also be made. Accordingly, the invention herein is limited only by the following claims.

CLAIMS

1. An x-ray tube comprising:

A. An evacuated tube envelope (410) having a window (412) for passing x-rays from the interior thereof;

B. a cathode mounted in the tube envelope (410);

C. an anode (451) rotatably mounted in the tube envelope (410); and

D. electrical means connected to the anode and cathode for producing x-rays;

characterized by

E. variable speed anode drive means (230) for rotating the anode, the variable speed drive means including

1. an internal rotor (235) mounted within the tube envelope (410) and adjacent a wall of the tube envelope, the internal rotor being mounted to rotate with the anode as a rotating anode assembly, the internal rotor comprising at least one permanent magnet (472a to 472h) having at least two poles,

2. a stator (480) positioned on the exterior of the tube envelope surrounding the rotor and

3. means to create a magnetic field driving the internal rotor and thereby rotating the anode,

whereby the anode is rotated while the x-ray tube is operated to produce x-rays, thereby preventing rapid deterioration of the anode.

2. An x-ray tube as defined in claim 1, wherein the stator is a DC stator and having a number of pole pieces equal to or greater than the number of poles of the permanent magnet of the internal rotor and said magnetic field creating means are means pulsing the DC stator.

3. An x-ray tube as defined in claim 1, wherein

- the internal rotor comprises a squirrel cage rotor having alternating ferrous and non-ferrous longitudinal segments;
- the stator is an AC stator,
- the magnetic field creating means are supplied by an AC current, and wherein

the portion of the tube envelope positioned between the stator and the rotor comprises ferrous segments separated from each other by non-ferrous spacers, the ferrous spacers acting as extensions of the stator and thereby reducing the effective air gap between the rotor and the stator.

4. An x-ray tube as defined in claim 2, wherein the permanent magnet is a rare earth magnet encapsulated in a non-ferrous casing whereby the rare earth magnet does not contaminate the interior of the evacuated tube envelope.

5. An x-ray tube as defined in claim 3, wherein at least one permanent magnet comprises an even number of permanent magnets longitudinally deployed on the outwardly facing surfaces of a polygonal ferrous sleeve presenting alternating north and south poles at the exterior surface of the rotor with the ferrous sleeve providing a flux path between the magnets, with non-ferrous spacers deployed about the sleeve between adjacent magnets.

6. An x-ray tube as defined in claim 5 wherein the spacers and at least a portion of the casing are integrally formed of copper by a copper casting process.

7. An x-ray tube as defined in claim 4 wherein the anode is mounted to a ceramic insulator having a shank protruding opposite the anode, and the rotor casing includes an outer cylindrical sleeve which extends over at least a portion of the shank and is secured thereto to mount the rotor with the anode.

8. An x-ray tube as defined in claim 5 wherein the anode is mounted to a ceramic insulator having a shank protruding opposite the anode, and the rotor casing includes an outer cylindrical sleeve which extends over at least a portion of the shank and is secured thereto to mount the rotor with the anode.

9. An x-ray tube as defined in claim 2 wherein the axial length of the rotor magnet is greater than the axial length of the stator with the rotor magnet extending beyond the rotor opposite the anode, whereby the rotating anode assembly is biased into abutting contact with a structural stop which positions the anode relative to the cathode.

10. An x-ray tube as defined in claim 8 wherein the tube envelope comprises an end wall facing the anode, the end wall mounting the cathode and the structural stop against which the anode is biased.

11. An x-ray tube as defined in claim 10 wherein the structural stop comprises an insulated stud extending from the tube envelope end wall and having a conductive terminal at the free end thereof connected to an anode supply cable, and the portion of the rotor/anode assembly biased into contact with the terminal is a conductive plate electrically connected to the anode.

12. An x-ray tube as defined in claim 11 wherein the rotor is received in a cup portion of the tube envelope including a stud extending axially into an axial opening in the rotor, and the rotating anode assembly is rotationally mounted on the stud by spaced apart bearings.

13. An x-ray tube as defined in claim 2 and further comprising a sensor for sensing the position and/or speed of the rotating anode assembly, whereby the output of the sensor can be used to control the timing of pulses to the DC stator for controlling the speed at which the anode rotates and/or to confirm anode rotation at the desired speed.

14. An x-ray tube as defined in claim 13 wherein the axial length of the rotor magnet is greater than the axial length of the stator, and the sensor is a Hall device positioned outside the tube envelope in the path of the rotor magnet.

15. An x-ray tube as defined in claim 2 wherein the tube envelope is fabricated of non-ferrous metal.

16. An x-ray tube as defined in claim 15 wherein the tube envelope includes a cup having relatively thin wall portions for closely receiving the rotor and surrounded by the stator, and the remainder of the tube envelope is fabricated of copper.

17. An x-ray tube as defined in claim 16 wherein the cup is fabricated of a non-ferromagnetic material.

18. An x-ray tube as defined in claim 2 wherein the portion of the tube envelope wall between the rotor and the stator is fabricated of alternating ferrous and non-ferrous segments, the ferrous segments acting as extensions of the stator to reduce the effective air gap between the stator and rotor.

19 An x-ray tube as defined in claim 2 wherein the tube envelope is fabricated of metal and is mounted in a tube housing including a generally cylindrical sidewall spaced apart from the tube envelope, and further comprising a fan mounted to flow air through the tube housing for cooling the tube envelope.

20. An x-ray tube as defined in claim 19 wherein the fan is mounted to flow air on the portion of the tube envelope opposite the anode, whereby cooling is maximized on the portion of the tube envelope receiving radiant heat from the anode.

21. An x-ray tube as defined in claim 19 and further comprising a filter mounted within the tube housing for sliding movement into position over the window of the tube envelope.

22. An x-ray tube as defined in claim 3 wherein the ferrous segments are laminated to reduce eddy currents, and the tube envelope further comprises a thin sleeve covering the laminated ferrous segments to preserve the integrity of the vacuum in the tube envelope.

23. An x-ray tube as defined in claim 22 wherein said sleeve is fabricated of non-ferromagnetic material.

24. An x-ray tube as defined in claim 20 wherein the non-ferrous spacers comprise pins inserted through openings in annular laminations to align the laminations during fabrication of the wall, wherein the laminations are reduced in radial width to expose the non-ferrous pins in the finished wall.

25. An x-ray tube as defined in claim 22 wherein the rotor comprises a plurality of laminations and the rotor is encapsulated in a non-ferrous casing to prevent contamination of the evacuated tube envelope.

26. An x-ray tube as defined in claim 25 wherein the anode is mounted to a ceramic insulator having a shank protruding opposite the anode, and the rotor casing includes an outer cylindrical sleeve which extends over at least a portion of the shank and is secured thereto to mount the rotor with the anode.

27 An x-ray tube as defined in claim 26 wherein the rotor casing including the sleeve and the non-ferrous longitudinal segments of the rotor are integrally formed of copper by a copper cast process.

28. An x-ray tube as defined in claim 27 wherein the shank of the insulator is non-cylindrical and thereby interlocks with the copper sleeve for a good structural connection between the shank and the rotor.

29. An x-ray tube as defined in claim 3 and further comprising a speed sensor system including:

1. Two spaced apart ferrous segments deployed in the tube envelope wall adjacent the rotor,
2. a permanent magnet having one pole positioned on one of the segments,
3. a Hall device positioned on the other of the segments,
4. a ferrous bar connecting the other pole of the magnet with the Hall device, and
5. a ferrous rotor segment deployed to pass adjacent the two ferrous wall segments and close a flux loop through the Hall device.

30. An x-ray tube as defined in claim 29 wherein the ferrous rotor segment comprises a cam having ferrous lobes.

31. An x-ray tube as defined in claim 3 wherein the rotor is received in a cup portion of the tube envelope including a stud extending axially into an axial opening in the rotor, and the rotating anode assembly is rotationally mounted on the stud by spaced apart bearings having spring means deployed therebetween, whereby the rotating anode assembly is biased into abutting contact with a structural stop which positions the anode relative to the cathode.

32. An x-ray tube as defined in claim 31 wherein the tube envelope comprises an end wall facing the anode, the end wall mounting the cathode and the structural stop against which the anode is biased.

33. An x-ray tube as defined in claim 32 wherein the structural stop comprises an insulated stud extending from the tube envelope end wall and having a conductive terminal at the free end thereof connected to an anode supply cable, and the portion of the rotor/anode assembly biased into contact with the terminal is a conductive plate electrically connected to the anode.

34. An x-ray tube as defined in claim 3 wherein the tube envelope is fabricated of metal and is mounted in a tube housing including a generally cylindrical sidewall spaced apart from the tube envelope, and further comprising a fan mounted to flow air through the tube housing for cooling the tube envelope.

35. An x-ray tube as defined in claim 34 wherein the fan is mounted to flow air on the portion of the tube envelope opposite the anode, whereby cooling is maximized on the portion of the tube envelope receiving radiant heat from the anode.

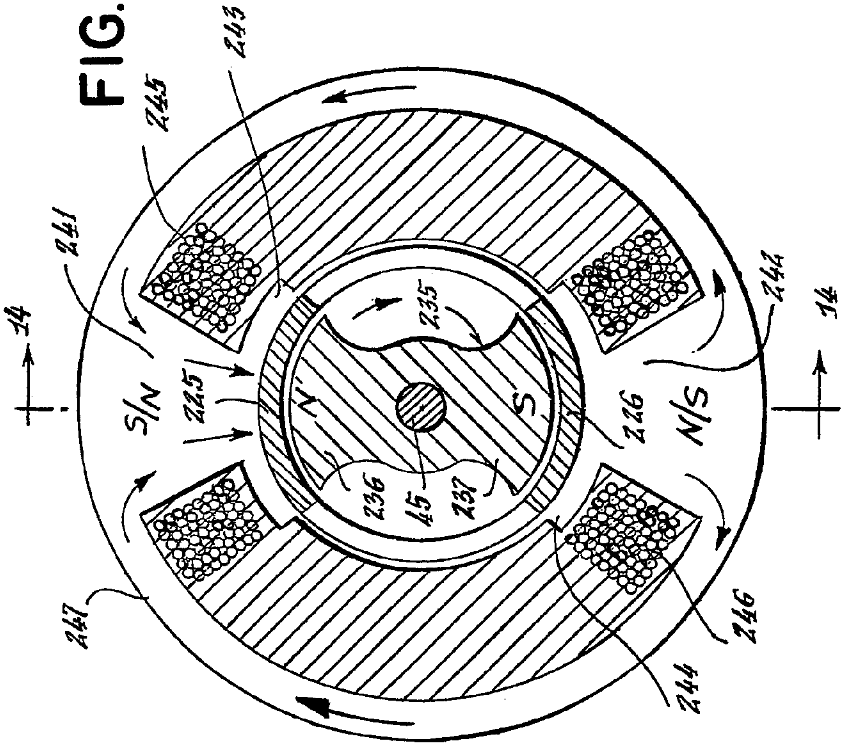
36. An x-ray tube as defined in claim 34 and further comprising a filter mounted within the tube housing for sliding movement into position over the window of the tube envelope.

37. An x-ray tube as claimed in at least one of the preceeding claims comprising a metal tube envelope and terminal means for connecting power supply cables to the anode and cathode, including:

A. An insulating stud sealed to and extending through the generally flat end wall of the tube envelope, the insulating stud having a flat surface perpendicular to the end wall on the outside of the tube envelope;
B. plug receptacles mounted in the flat surface of the stud, and wire means embedded in the stud and extending from the plug receptacles to the interior of the tube for connection with the anode or cathode;
C.. metal shield means secured to the tube end wall, the metal shield having a first end surrounding the protruding stud and a second open end spaced apart therefrom;
D. insulating material within the metal shield and defining an opening extending from the flat surface of the insulating stud to the open end of the metal shield; and
E. a terminal end fitting receiving the supply cable and including pins extending from the end thereof, the terminal end being sized to fit into the opening in the insulating material with the pins received in the plug receptacles.

38. An improvement in x-ray tubes as defined in claim 37 wherein a small air path is defined leading from the flat face of the stud to the exterior of the metal shield, whereby air escapes from the opening in the insulating material as the terminal end fitting is inserted therein.

FIG. 2



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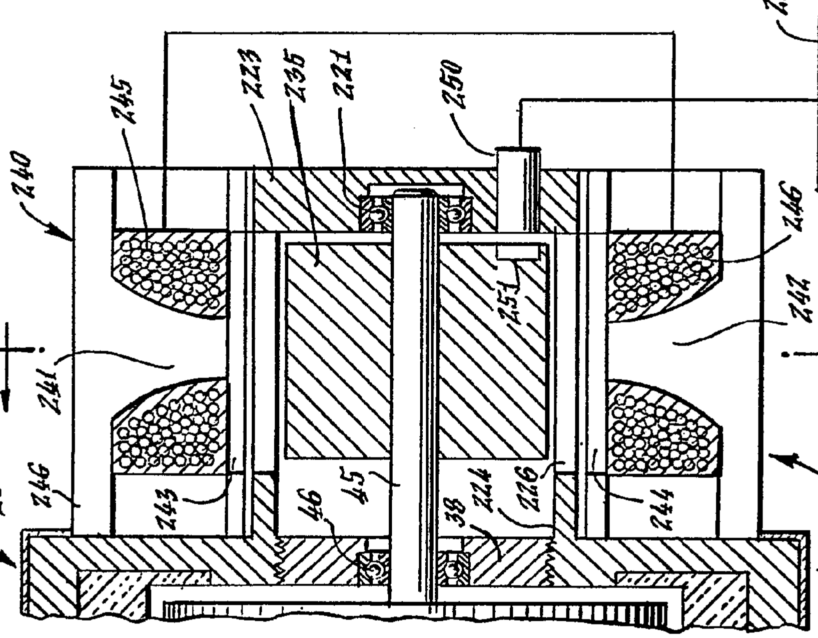

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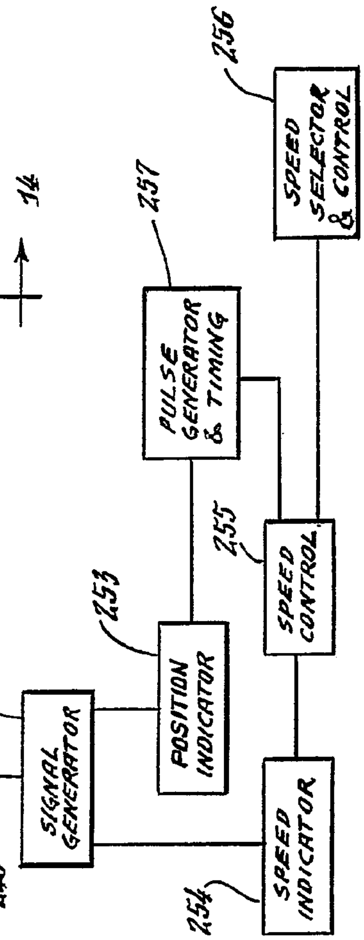

SIGNAL GENERATOR
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SPEED INDICATOR
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SPEED CONTROL
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PULSE GENERATOR & TIMING
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SPEED SELECTOR & CONTROL
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FIG. 1

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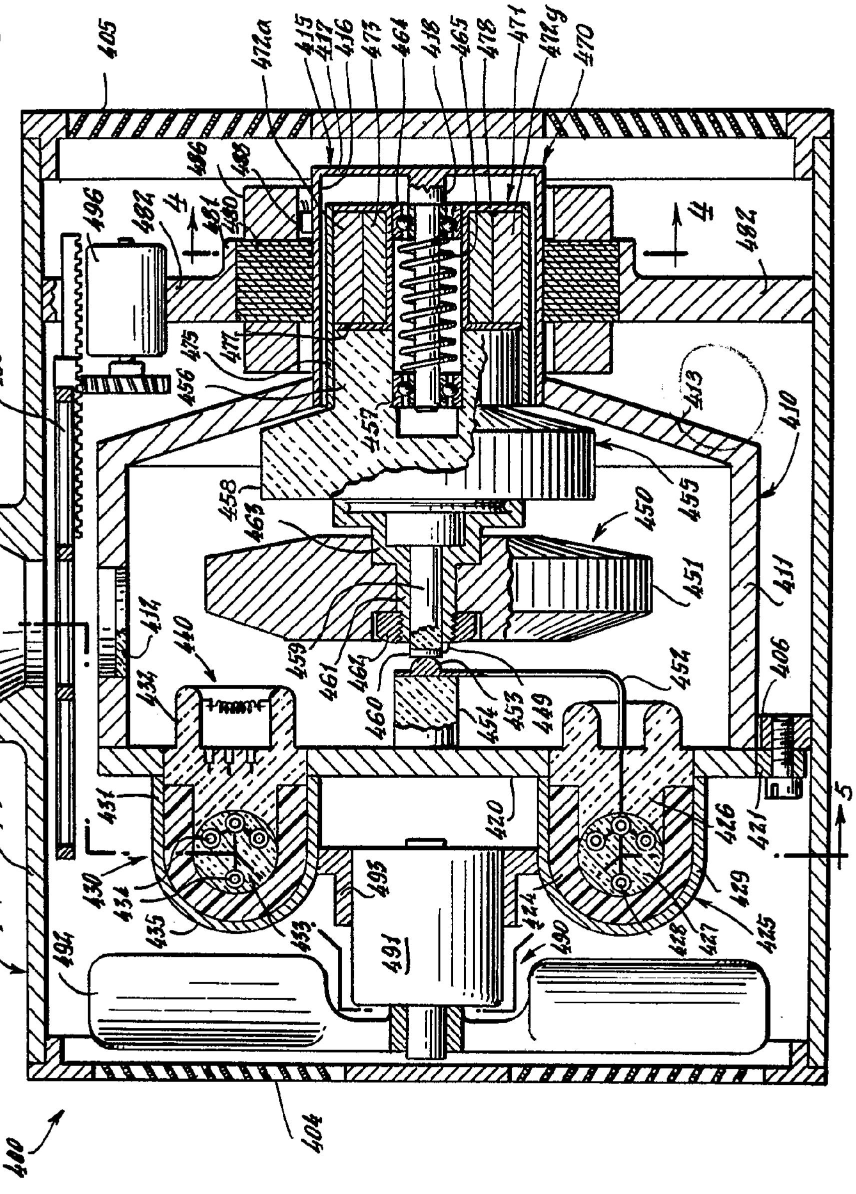

FIG. 3

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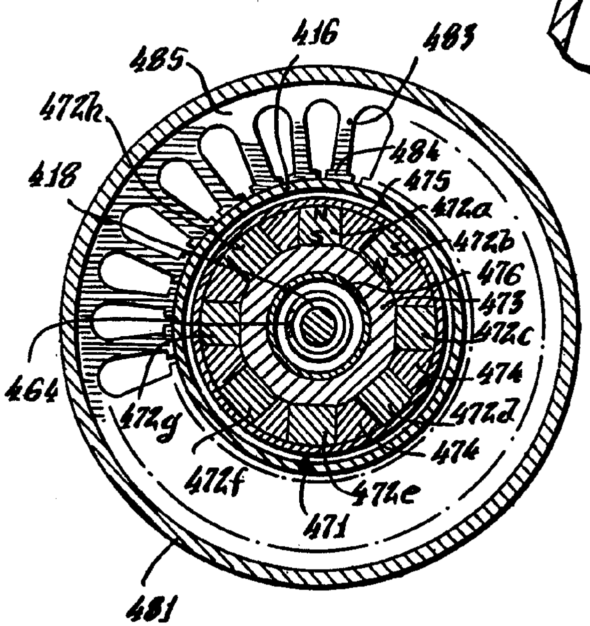
FIG. 4



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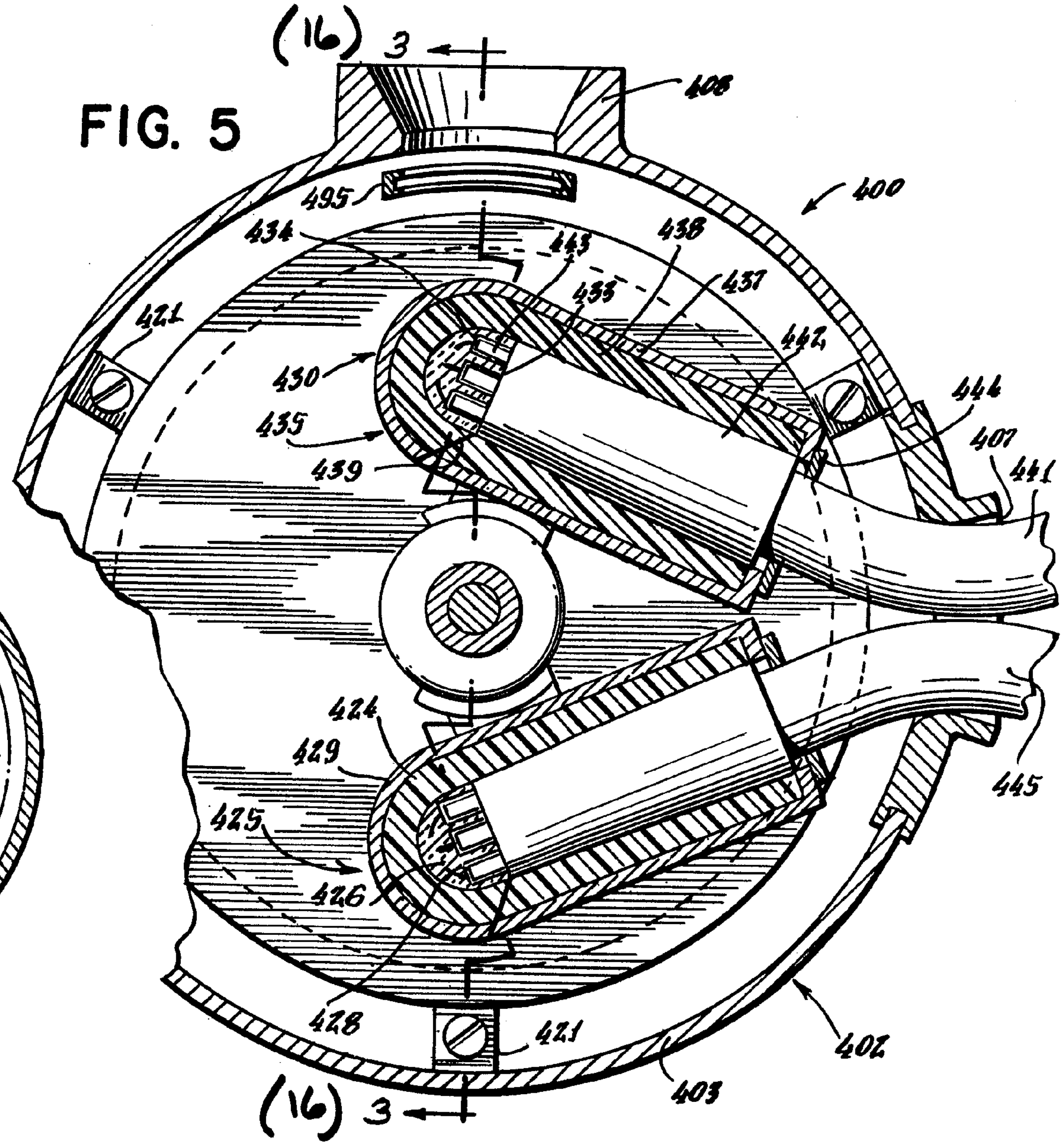

FIG. 7

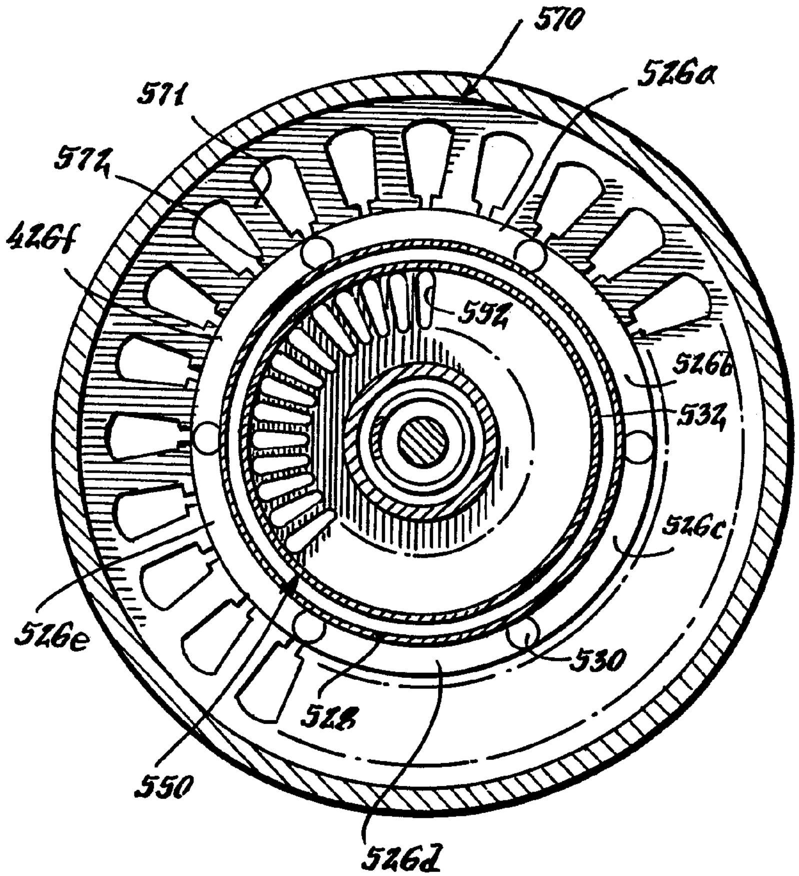
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FIG. 6

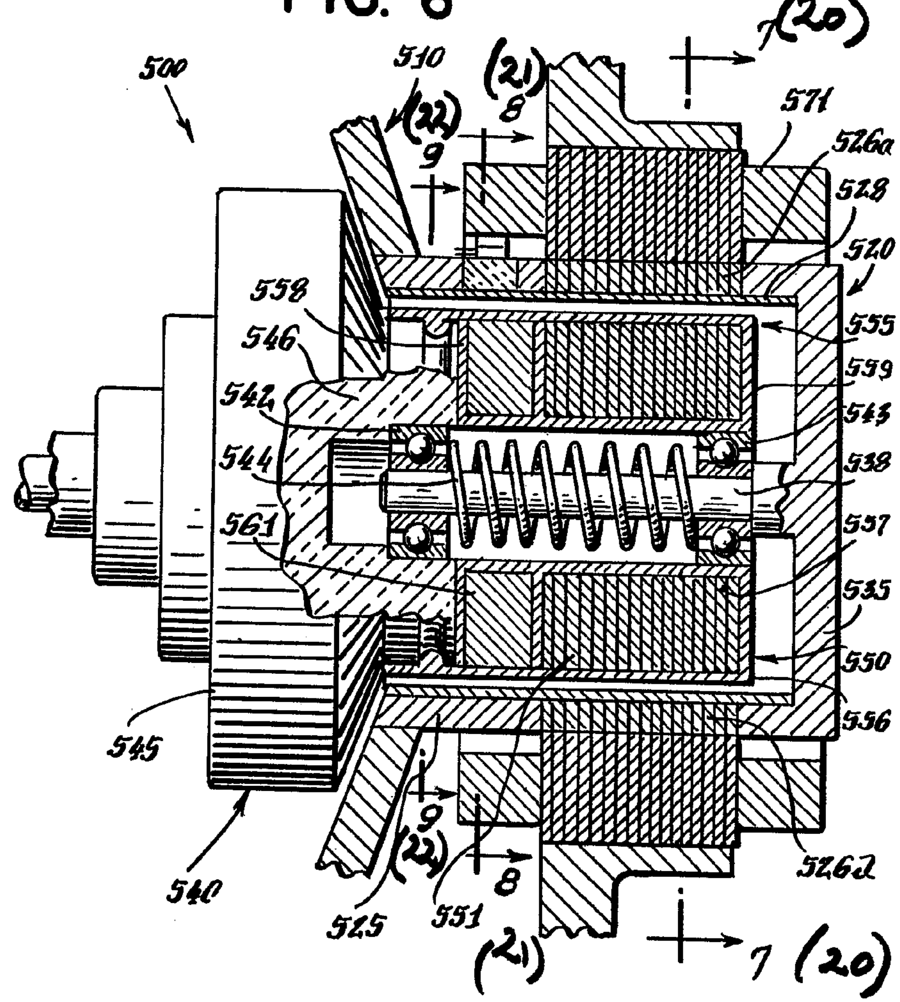
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FIG. 9

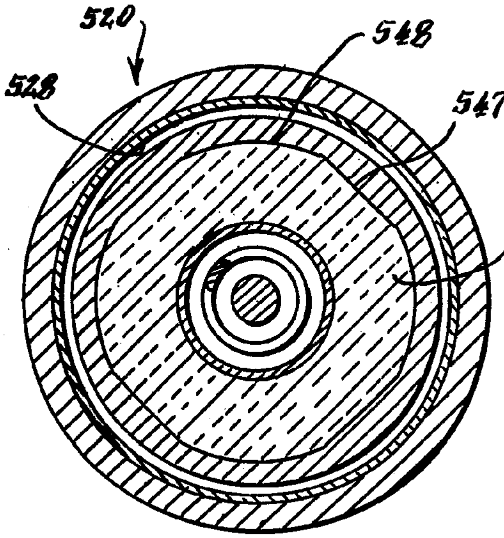
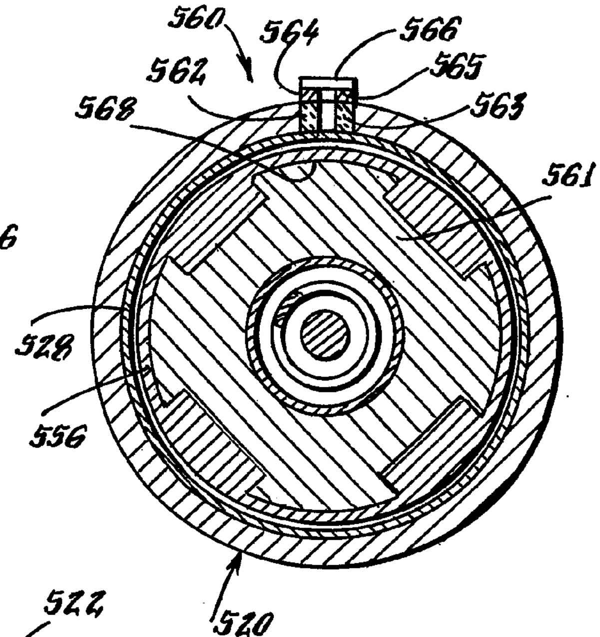


FIG. 8



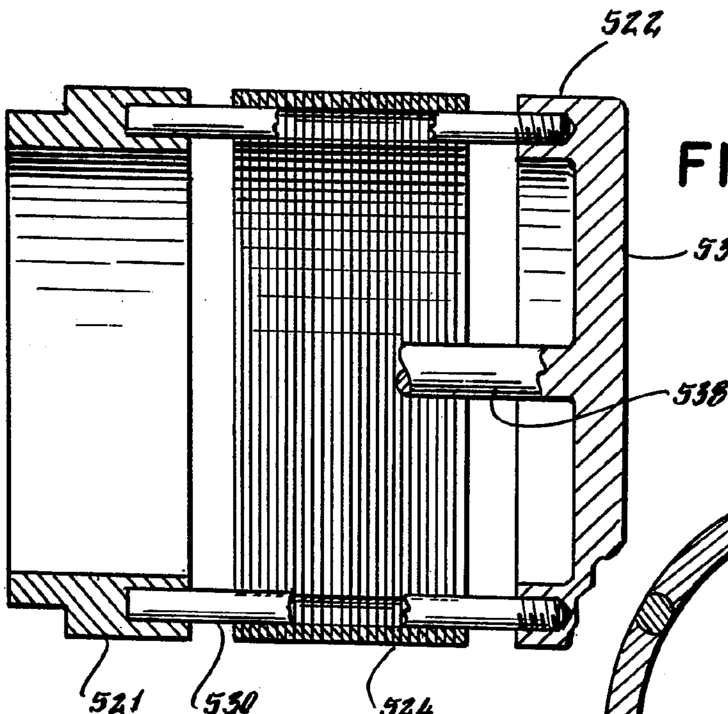


FIG. 10

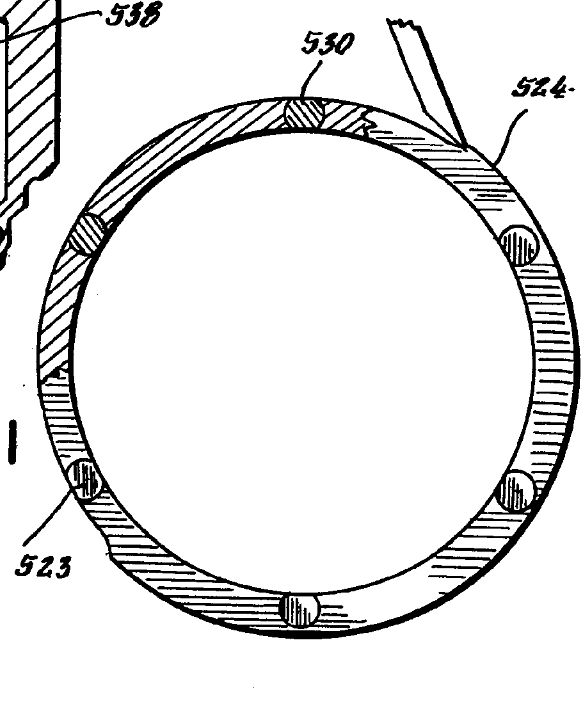


FIG. 11