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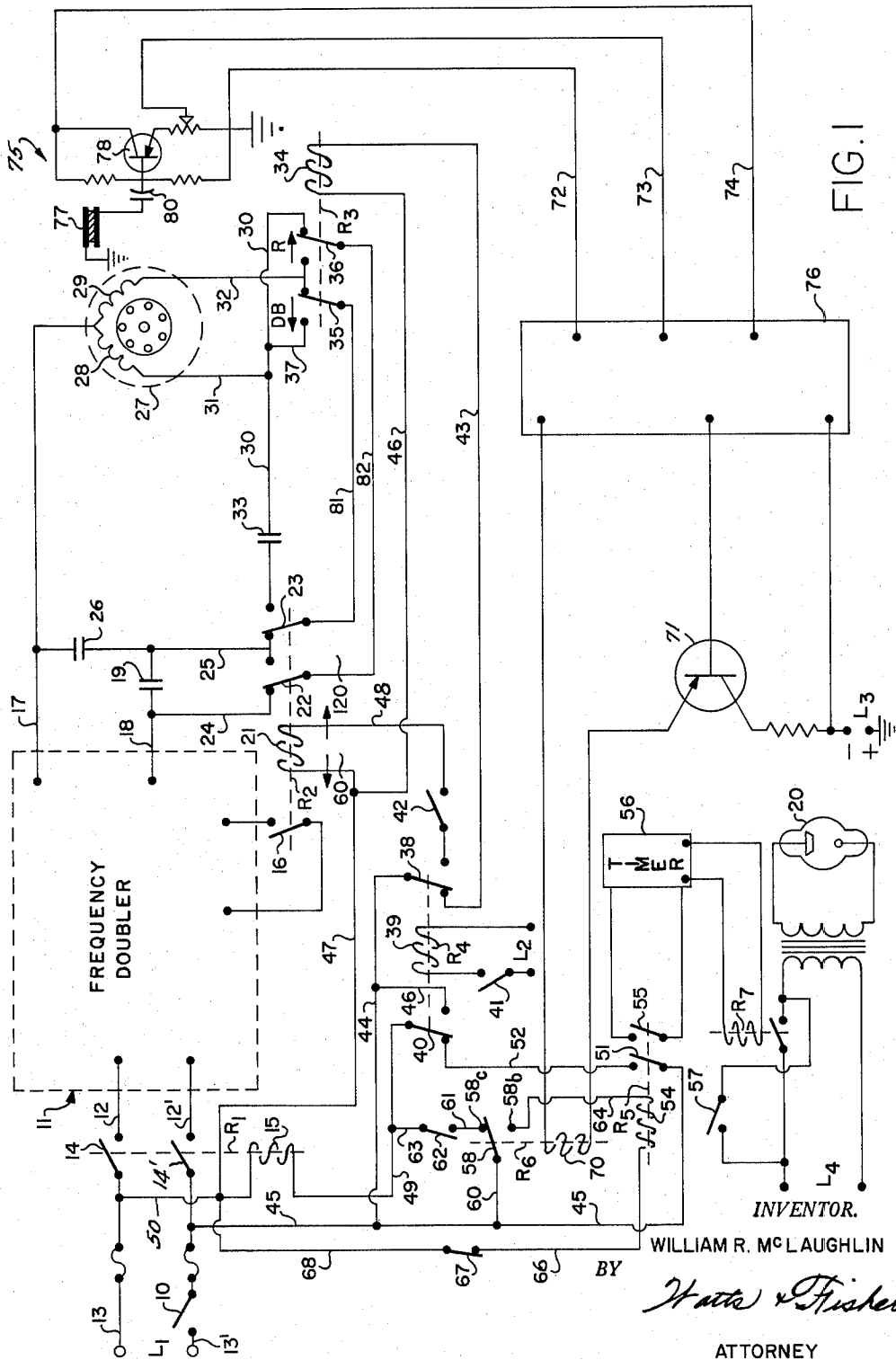
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X-RAY TUBE STARTER

Filed Aug. 14, 1962

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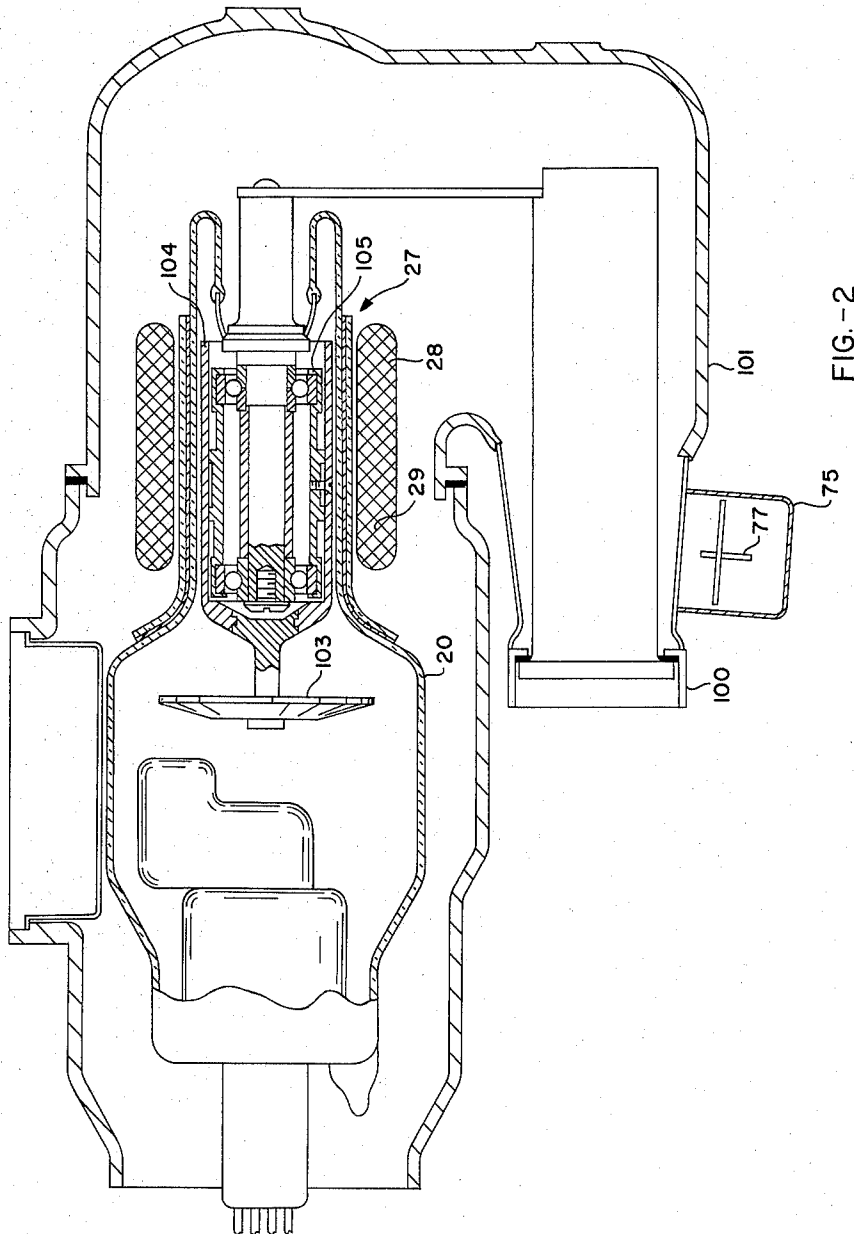


FIG. -2

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X-RAY TUBE STARTER

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The present invention relates generally to X-ray apparatus and more specifically to a new and improved control mechanism for controlling the rotation is an anode in a rotating anode-type X-ray tube.

In the operation of an X-ray tube, the tube anode is bombarded by a stream of electrons emitted by the tube cathode. The bombardment of the anode causes it to emit a beam of X-rays. It also causes the target area on the anode to become extremely hot such that it may burn away if the tube is used for too long an interval.

To overcome this heat problem, X-ray tubes are now provided with rotating anodes. The rotating anodes normally have a target surface which is a disc. When the tube is placed in operation the target rotates and the stream of electrons is focused on only a small area of the rotating target, so that the target area under bombardment is constantly changing. As a point on the target passes from underneath the stream of electrons it dissipates the heat generated therein until it again comes under the bombardment of the electrons.

The rapid heat dissipation by the rotating anode type of X-ray tube permits longer exposures at higher levels of X-ray energy than were previously possible with the fixed anode type of X-ray tube. It is necessary, however, that the anode be rotating at a minimum acceptable level of rotation before it is bombarded by the electrons. If for some reason the anode is rotating too slowly, or not at all, energization of the X-ray tube will destroy the anode by burning away a portion of the target surface. It is desirable, therefore, that the X-ray tube control circuit not permit the X-ray tube to be energized unless the anode is rotating at a minimal acceptable rotational speed.

Another problem in X-ray tubes of the rotating type is that the rotating anodes tend to coast for long periods of time after they have been deenergized. As an X-ray tube is used most frequently for only short intervals the total deceleration period is often longer than the total length of time the tube is in use. Hence, it is desirable, for safety purposes, convenience and to save wear and tear on the X-ray tube apparatus, to brake the anode during deceleration.

An additional feature desirable in X-ray apparatus is that it is usable for both radiography and fluoroscopy. In using the X-ray apparatus for fluoroscopy only about 1 to 5 milliamperes is passed through the X-ray tube as compared to 200 milliamperes for radiography. Therefore, as less heat is generated during fluoroscopic examinations the rotational speed of the anode may be much less during radiographic exposures. A lower anode rotational speed not only saves wear and tear on the anode bearings, but would also increase the permissible exposure period for the X-ray tube. If the anode is caused to rotate at its maximum speed during fluoroscopy, a substantial portion of the heat generated in the X-ray tube would be due to the heat generated by the induction motor windings of the rotating anode assembly. This is especially true since the energy levels are relatively low with fluoroscopy but the periods during which studies are conducted are relatively long. A versatile control system should, therefore, provide a high level of anode rotation during radiography and maintain a low rotational speed during fluoroscopy.

In the control system of the present invention a frequency doubler is utilized to provide 200-volt, 120-cycle voltage to the stator windings of a rotating anode X-ray

tube assembly from a common 120-volt, 60-cycle source. This provides an anode rotation of approximately 7200 r.p.m. Although it is possible to further increase the anode rotational speed by further multiplying the line frequency, such has been found to produce little additional advantage considering the increased apparatus and cost necessary to do so. Although increasing the anode rotational speed theoretically increases the permissible current rating of the X-ray tube, this has not been found to be true as there is a point of a rapidly diminishing return. At anode speeds in excess of approximately 8,000 to 10,000 r.p.m. an increase in the anode rotational speed makes little difference in the permissible current which may be supplied to the X-ray tube. This is because at such higher speeds a point on the target is not out from underneath the stream of bombarding electrons for a period long enough to dissipate the heat stored therein.

A safety feature of the present invention prevents energization of the X-ray tube unless the anode is rotating above a minimum acceptable level. The safety circuit includes a pick-up device which is responsive to the sound level of the screech of the anode moving in its bearings. The bearing screech of a rotating anode type of X-ray tube have a characteristic frequency which is quite distinguishable from other ambient noises. The bearing screech is detectable from the very first moment the anode rotates and its sound level increases with increased rotation up to approximately 1,000 r.p.m. A further increase in the anode r.p.m. does not produce an appreciable change in the sound level of the bearing screech.

The pick-up device includes a piezo-electric ceramic reed which produces an electrical impulse proportional to the sound level of the bearing screech. The electrical impulse is amplified and actuates a relay as the anode passes through the 1,000 r.p.m. level. The relay initiates the timer circuit which in turn connects the X-ray tube to the high voltage source for the duration of the exposure period. If the anode does not reach the 1,000 r.p.m. level, then the acoustic relay is not energized. The control system, therefore, establishes that the anode is rotating above at least 1,000 r.p.m. This is satisfactory protection as it establishes first, that the anode bearings are not frozen or otherwise in a very poor condition, and second, that the control circuitry is not broken.

The dynamic braking provided by the control circuit of the present invention is especially important because of the high rotational anode speed provided by the frequency doubler. X-ray tubes generally have a critical speed range of approximately 4,000-5,000 r.p.m. where extreme vibrations are set up in the tube. These vibrations tend to break the glass seals of the X-ray tube. If the anode is permitted to coast through the 4,000-5,000 r.p.m. range the vibrations may even destroy the tube. High speed rotation also causes excessive bearing wear. In other words, one revolution at a higher speed causes more bearing wear than an equal revolution at a lower speed. For these reasons it is very important that the anode be braked to a standstill as rapidly as possible. The dynamic braking provided by the control system of the invention has been found to be extremely effective and is capable of stopping the rotating anode in one-half second.

Dynamic braking is provided by the control system of the invention by applying the 60 cycle line voltage to the stator windings of the rotating anode assembly in a reversed phase relation from that when the stator windings were energized by the 240-volt, 120-cycle output of the frequency doubler. The reversed phase relationship effectively jogs the rotating anode until it reaches substantially a standstill at which point the jogging voltage is disconnected before the motor commences rotating in an

opposite direction. This type of control is possible primarily because of the sensitivity of the ceramic reed to any movement of the anode in its bearings. The acoustic relay is preferably adjusted to drop out and disconnect the jogging voltage just as the anode reaches a standstill. The entire assembly of reed and amplifier is an acoustic relay.

When the control system of the invention is used for fluoroscopy the stator windings are only periodically pulsed with electrical energy to maintain rotation of the anode between certain limits, for example, 100-1,000 r.p.m. During fluoroscopy, the acoustic relay serves to disconnect the stator windings from their energizing voltage source when the anode reaches the 1,000 r.p.m. level. The anode is then permitted to coast until it reaches the 100 r.p.m. level where the acoustic relay then causes the stator windings to be reconnected to the voltage source. The periodic pulsing and resultant rapid acceleration and gradual deceleration of the rotating anode continues all during the fluoroscopic examination.

The use of the ceramic reed in controlling the operation of the acoustic relay is unique in fluoroscopy pulsing because the ceramic reed is able to detect any rotation of the anode from a standstill to above 1,000 r.p.m. No prior device is presently known which is able to give an accurate and reliable continuous indication of the anode r.p.m. The prior art vibration detectors for indicating armature rotation are no longer practicable for use with present day X-ray tubes as such tubes now operate substantially vibration-free. Moreover, such vibration detectors are susceptible to erroneous detections from the ambient noises of the building as well as from the other electrical or mechanical devices forming part of the X-ray apparatus, for example, the X-ray table motor. Although phototubes might possibly be used to detect actual rotation of the anode, they require a fixed focus and a great deal of auxiliary structure mounted on the outside of the X-ray tube. Thus, the invention provides for the first time a practical way of detecting the actual r.p.m. of the anode.

Accordingly, an object of the present invention is to provide a versatile electrical system for controlling the operation of a rotating anode, first by preventing energization of the X-ray tube for use in radiography unless the anode is rotating above a minimum acceptable level, second, by dynamically braking the rotating anode during deceleration periods, and third, by maintaining a low rotational speed of the anode when the X-ray tube is used for fluoroscopy.

Another object of the present invention is to provide a new and improved electrical system for controlling operation of a rotating anode type X-ray tube wherein energization of the X-ray tube is prevented until the anode is rotating above a minimum acceptable speed level determined by sensing the screech of the anode moving in its supporting bearing.

A further object of the present invention is to provide a new and improved X-ray apparatus having a rotating anode and a control system to dynamically brake the anode until it reaches any selected lower rotational speed right down to a standstill.

Still another object of the present invention is to provide a new and improved X-ray apparatus having a rotating anode type X-ray tube and a control system to dynamically brake the rotating anode by applying to the stator winding in a reverse phase relation a braking voltage of a frequency differing from the frequency of the energizing voltage.

An additional object of the present invention is to provide a new and improved X-ray apparatus having a rotating anode wherein during use of the apparatus for fluoroscopy the rotational speed of the anode is maintained between specified upper and lower limits by accurately sensing the actual rotational speed of the anode and electrically pulsing the stator windings when the anode speed is at

the lower limit and deenergizing the stator windings when the anode speed has reached the upper limit.

Yet another object of the present invention is to provide a new and improved X-ray apparatus having a rotating anode and a control system which senses the actual rotational speed of the anode by responding to the screech of the anode moving in its bearing to accurately control the speed of the anode during all of the X-ray functions performed by the X-ray apparatus.

Other objects and a fuller understanding of the invention may be had by referring to the following description and claims taken in conjunction with the accompanying drawings in which:

FIGURE 1 shows a schematic illustration of the control system of the invention.

FIGURE 2 is a cross-sectional view of a conventional X-ray tube and tube housing which is utilized in the X-ray system of the present invention.

The drawing shows the preferred form of the control system of the invention. The control system includes a frequency doubler indicated generally by the reference character 11. The details of construction of the frequency doubler 11 do not form a part of the present invention and any suitable frequency doubler may be used. Input terminals 12, 12' of the frequency doubler 11 are connected to terminals 13, 13' of a 120 volt, 60 cycle power source L₁ by a main hand switch 10, and normally open contacts 14, 14' of a main relay R₁. The main relay R₁ includes a coil 15.

The frequency doubler 11 includes a control switch 16, output circuit conductors 17, 18, and a direct current blocking capacitor 19. When the control switch 16 is closed the frequency doubler 11 is operating and a 240 volt, 120 cycle voltage appears across the conductors 17, 18. When the control switch 16 is open the frequency doubler 11 is inoperative and the 60 cycle voltage of the line source L₁ appears across the conductors 17, 18. The frequency doubler control switch 16 is actuated by a frequency shifting relay R₂. The relay R₂ includes a coil 21 and two single pole, double throw switches 22, 23. The switches 22, 23 are shown in their 60 cycle position. In this position the switch 22 is connected to the conductor 18 by a conductor 24. The switch 23 is connected to the conductor 17 by a conductor 25. A capacitor 26 is provided in the conductor 25 for power factor correction.

An induction motor portion of a rotating anode type X-ray tube assembly 20 is indicated generally by the reference character 27. The induction motor 27 is a split-phase motor and includes stator windings 28, 29. The stator windings 28, 29 are both connected at one end to the conductor 17. The other end of stator winding 28 is connected to a conductor 30 by a conductor 31. The other end of stator winding 29 is connected to a conductor 32. A phase splitting capacitor 33 is provided in the conductor 30 between switch 23 and the conductor 31.

A dynamic braking relay R₃ is provided and includes a coil 34 and a pair of single pole, double throw switches 35, 36. The dynamic braking relay R₃ cooperates with the frequency shifting relay R₂ to connect the stator windings 28, 29 to the output circuit conductors 17, 18 in one of two alternate phase-frequency relationships. When the dynamic braking switches 35, 36 are in their running position R, as shown in the drawings, and the frequency shifting switches 22, 23 are in their 120 cycle position, the stator windings 28, 29 are energized with a 240 volt, 120 cycle voltage. With the latter voltage energizing the stator windings the anode is induced to rotate at approximately 7200 r.p.m. for radiographic exposures. But when the dynamic braking switches 35, 36 are in their dynamic braking position DB and the frequency shifting switches 22, 23 are in their 60-cycle position, a 60-cycle voltage is supplied to the stator windings 28, 29 in a reverse phase relation to effectively plug the induction motor.

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The energization of relays R_2 and R_3 is controlled by a single pole, double throw switch 38 of an exposure control relay R_4 . The switch 38 is connected to one side of the coil 34 of the relay R_3 by a conductor 43. The switch 38 is also connected to the terminal 13' of the voltage source L_1 by a conductor 44 and a conductor 45. The other side of coil 34 is connected to the other terminal 13 of the voltage source L_1 by a conductor 46, a conductor 47 and a conductor 50. The relay R_4 also includes a coil 39 and a second single pole, double throw switch 40. An exposure switch 41 is provided to control energization of the coil 39 of relay R_4 from a voltage source L_2 . A hand switch 42 is provided to also control energization of relay R_2 . The hand switch 42 is closed to permit 120 cycle operation of the induction motor 27 and is opened for 60-cycle operation.

The switch 40 of the exposure control relay R_4 controls the energization of the main relay coil 15 by either of two circuits. During radiographic exposures an energizing circuit for the coil 15 is made by a conductor 49, the switch 40, the conductor 46, the conductor 44 and the conductor 45 which in connected to terminal 13' of the voltage source L_1 and by the conductor 50 which is connected to the terminal 13 of the voltage source L_1 .

A second energizing circuit for the main relay coil 15 is made during dynamic braking when contact 40 of relay R_4 in the position shown where it connects or side of the coil 15 to the terminal 13' via a conductor 52, a switch 51 of an auxiliary control relay R_5 and the conductor 45. The switch 51 is closed during dynamic braking of the rotating anode as is more fully explained below.

The auxiliary relay R_5 also includes a coil 54 and a normally open switch 55. The switch 55 controls the energization of an X-ray timer unit 56. The timer unit 56 actuates a tube voltage control relay R_7 which controls the energization of X-ray tube 20 from voltage source L_4 . A hand switch 57 is provided to energize the X-ray tube 20 during fluoroscopic examination.

The energization of coil 54 of relay R_5 is controlled by a single pole, double throw switch 58 of an acoustic R_6 . The switch 58 of relay R_6 is connected 45 by a conductor 60. A normally closed contact 58c or switch 58 is connected by a conductor 61, a fluoroscopy control switch 62, and a conductor 63 to the conductor 49. A normally open contact 58b is connected to the auxiliary control relay coil 54 by a conductor 64. The other side of the coil 54 is connected by a conductor 66, a normally closed fluoroscopy control switch 67, and a conductor 68 to the conductor 50.

The acoustic relay R_6 includes a coil 70. The energization of the acoustic relay coil 70 is provided from a voltage source L_3 and is controlled by a switching transistor 71. The transistor 71 is connected by conductors 72, 73, 74 to a speed responsive unit 75 and is biased to conduct in response to a predetermined electrical signal therefrom. A transistor amplifier unit 76 is provided to amplify the electrical signal from the speed responsive unit 75 and is connected in the conductors 72, 73 and 74.

The speed responsive unit 75 includes a piezo-electric reed 77 which is responsive to the sound level of the screech of the anode moving in its bearings. When the anode is rotating its bearings emit a screech having a characteristic frequency which is quite distinguishable from other ambient noise. The frequency of the bearing screech is fairly constant and is most often in the 3500-6500 c.p.s. range. The ceramic reed 77, which is essentially a transducer device, has a resonant frequency somewhere in the frequency range of the bearing screech and produces an electrical signal which is substantially proportional to the sound level of the bearing screech. The sound of the bearing screech is detectable from the very first moment the anode rotates and increases in magnitude with an increase in anode rotation up to approximately 1,000 r.p.m.

The speed responsive device 75 is normally mounted somewhere on the X-ray tube housing. For example, re-

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fering to FIGURE 2, the speed responsive unit 75 is shown clamped solidly to the anode cover 100 of an X-ray tube housing 101. The ceramic reed 77 is carried by the speed responsive unit 75 on the X-ray tube housing 101. The rotating anode type X-ray tube 20 is carried within the housing 101 as is conventional. The X-ray tube 20 includes a rotating anode 103 having a rotor portion 104 rotatably supported within the X-ray tube envelope by a bearing 105. Stator windings 28, 29 (indicated schematically) induce rotation of the rotating anode 103 in the bearing 105 in the manner of a conventional induction motor. The speed responsive device 75 also includes an amplifier transistor 78 connected to the ceramic reed 77 by a coupling capacitor 80. The transistor 78 amplifies the electrical signal provided by the ceramic reed 77. The electrical signal is conveyed by the conductors 72, 73, 74 to the amplifier unit 76. When the anode is rotating above approximately 1,000 r.p.m. the magnitude of the electrical signal produced by the ceramic reed 77 as amplified by amplifier unit 76 biases switching transistor 71 to conduction thereby energizing coil 70 to the acoustic relay R_6 .

OPERATION DURING RADIOGRAPHY

To set the control system for radiographic operation the hand switch 42 and the fluoroscopy switch 67 are closed and the fluoroscopy switch 62 is opened.

Closing the main switch 10 energizes the coil 34 of relay R_3 by a circuit traced from the terminal 13 of the voltage source L_1 via the conductors 50, 47, 46, the coil 34, the conductor 43, the switch 38 of relay R_4 , the conductor 44 and the conductor 45 to the terminal 13'. Thus energized, the coil 34 moves the switches 35, 36 to their dynamic braking position DB.

The X-ray exposure is started by closing hand switch 41 to energize the coil 39 from voltage source L_2 . The coil 39 then moves the switch 40 to place coil 15 of main relay R_1 across the voltage source L_1 via the conductors 45, 44, 46, the switch 40, the conductor 49, the coil 15, and the conductor 50. Thus energized, coil 15 closes the main contacts 14, 14' to energize the frequency doubler 11. The coil 39 also moves the switch 38 to break the circuit energizing coil 34 of relay R_3 and to connect relay R_2 across the line voltage source L_1 . The switches 35, 36 of relay R_3 return to their running position R. The coil 21 of the relay R_2 is placed across the voltage source L_1 by the conductor 45, the conductor 44, the switch 38, the hand switch 42, the conductor 48, the coil 21, the conductor 47 and the conductor 50.

Thus energized, the coil 21 of the relay R_2 closes the control switch 16 to energize the frequency doubler 11 so that a 240-volt, 120-cycle voltage appears across the conductors 17, 18. The coil 21 also moves the switches 22, 23 to their 120-cycle position. The stator winding 28 of the split phase induction motor 27 is now connected across the frequency doubler output conductors 17, 18 via the conductor 31, the conductor 30, the switch 36, the conductor 82, the switch 22, the conductor 25 and the capacitor 19. The stator winding 29 is connected in parallel to stator winding 28 in a leading current phase relation thereto via the conductor 32, the switch 35, the conductor 81, the switch 23, the conductor 30 which contains the phase splitting capacitor 33 and the conductor 31. The energized stator winding cause the anode to rotate. The anode will have a maximum rotational speed of approximately 7200 r.p.m.

As the anode commences rotating the ceramic reed transducer 77 produces an electrical pulse having a magnitude proportional to the anode speed. When the anode has passed the 1,000 r.p.m. level the electrical energy signal produced by the transducer 77 as amplified by the transistor amplifier unit 76, biases the transducer switch 71 to a state of conduction. The transistor switch 71 effectively places the acoustical relay coil 70 in circuit with the voltage source L_3 . Thus energized, coil 70 moves switch 58 to place the coil 54 of relay R_5 across

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the voltage source L_1 via the conductors 50, 63, the fluoroscopy switch 67, the conductor 66, the coil 54, the conductor 64, the switch 58 now engaging contact 58, the conductor 50, and the conductor 45. The energized coil 54 then closes switches 51 and 55. The closed switch 55 energizes the X-ray timer 56 to start the X-ray exposure period. The X-ray timer 56 energizes relay R_7 to connect the X-ray tube to the voltage source L_4 . The anode is rotating at a maximum speed all during the X-ray exposure and continues to rotate until the exposure switch 41 is opened to deenergize relay R_4 .

DYNAMIC BRAKING

Opening the exposure switch 41 deenergizes the relay R_4 . The contact switch 40 returns to its normal position in circuit with conductor 52 to maintain the coil 14 of the main relay R_1 across the voltage source L_1 . This holding circuit includes the conductor 50, the coil 14, the conductor 49, the switch 40, the conductor 52, the switch 51 which is now closed, and the conductor 45. The switch 38 also returns to its normal position to deenergize the coil 21 of the relay R_2 and to energize the coil 34 of the relay R_3 . The switch 16 of the relay R_2 opens to turn off the frequency doubler 11 so that only a 60-cycle voltage appears across the conductors 17, 18. The switches 22, 23 return to their 60-cycle position as shown in the drawing.

The now energized coil 30 of relay R_3 moves the switches 35, 36 to their dynamic braking position DB. The switch 36 connects the stator winding 29 across the output lines 17, 18 of the frequency doubler via the conductor 32, the switch 36, the conductor 82, the switch 22 and the conductor 25. The switch 35 connects the stator winding 28 in series with the blocking capacitor 19, which series combination is connected in parallel to the stator winding 29. This circuit comprises the conductor 31, the conductor 37, the switch 35, the conductor 81, switch 23, the conductor 25, the blocking capacitor 19, the conductor 18, the conductor 23, the switch 22, the conductor 82, switch 36 and the conductor 32. The current in the stator winding 29 is now in a lagging phase relationship to the current in the stator winding 28. The anode is now dynamically braked, or effectively jogged, with a 60-cycle voltage until the anode is approximately at a stand still. At this point the electrical signal produced by the ceramic reed 77 has proportionally decreased and the acoustical relay R_6 is effectively deenergized. The coil 70 of relay R_6 releases switch 58 thus deenergizing the coil 54 of the relay R_5 . The coil 54 releases switches 51, 55. The switch 51 opens the holding circuit for the main relay coil 15. The coil 15 releases the main contacts 14, 14' to deenergize the frequency doubler 11 and, in turn, the stator windings 26, 27 of the induction motor 27.

OPERATION DURING FLUOROSCOPY

The high voltage energization of the X-ray tube is generally manually performed during fluoroscopy by the switch 57 so that the timer 56 is not used. To set the control system for use during fluoroscopy the fluoroscopy control switch 67 is opened to prevent the coil 54 of the relay R_5 being energized. The fluoroscopy control switch 62 is closed to energize the coil 15 of the main relay R_1 via the conductor 50, the relay coil 15, the conductor 49, the conductor 63, the switch 62, the conductor 61, the switch 58, the conductor 60 and the conductor 45. The now energized coil 15 closes the contacts 14, 14' to connect the frequency doubler to the voltage source L_1 . The voltage appearing across the conductors 17, 18 energizes the stator windings 28, 29 to cause the anode to commence rotating.

When the anode has reached a rotational speed of approximately 1,000 r.p.m. the electrical signal from the speed responsive pick-up device 75, as amplified by the

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transistor amplifier unit 76, biases switching transistor 71 to conduct and thereby energizes the coil 70 of the acoustical relay R_6 from voltage source L_3 . The energized coil 70 moves contact switch 58 to open the energizing circuit for coil 15 of the main relay R_1 . The coil 15 releases contacts 14, 14' to disconnect the frequency doubler 11 from the voltage source L_1 and thereby deenergize the stator windings 28, 29. The anode coasts during deceleration and is not dynamically braked.

When the anode rotation is at a predetermined lower level, for example 100 r.p.m., the coil 70 of acoustical relay R_6 is set to release switch 58 to close the energizing circuit for the main relay R_1 to again energize coil 15. The coil 15 closes the main contacts 14, 14' to reconnect the frequency doubler 11 to the voltage source L_1 and thus energize stator windings 28, 29.

The reenergized stator windings 28, 29 again cause the anode to accelerate. When the anode reaches approximately 1,000 r.p.m. the acoustical relay R_6 again releases contact 58 to release the main relay R_1 and deenergize the stator windings 28, 29. The anode gradually decelerates to the lower, 100 r.p.m. setting where the acoustical relay once again closes the energizing circuit for the main relay to repeat the energization cycle. The control system continues to cycle in the above manner as long as the fluoroscopy control switch 62 remains closed. The effect of the cycling operation of the control system is to periodically pulse the stator windings 28, 29 so as to maintain rotation of the anode between the rotational speed levels as set by the acoustical relay R_6 .

Although the invention has been described in detail above it is believed to comprise essentially: an X-ray apparatus having a rotating anode type X-ray tube wherein the anode is supported in a bearing and a stator winding is provided to induce rotation of the anode; a transducer device responsive to the screech of the anode moving in its bearing; a safety circuit responsive to the transducer and permitting the X-ray tube to be connected to its voltage source only when the transducer device indicates that the anode is rotating above a minimum acceptable level; a dynamic braking circuit to rapidly decelerate the rotating anode at the end of the exposure period, the dynamic braking circuit being responsive to the transducer device and applying dynamic braking until the anode has decelerated to a preselected rotational speed level as indicated by the transducer device; and a fluoroscopy control circuit responsive to the transducer device to periodically electrically pulse the stator winding to maintain low speed rotation of the anode when the X-ray apparatus is used for fluoroscopic examinations. The invention also contemplates that the X-ray apparatus include a means for increasing the frequency of the energizing voltage supplied to the stator winding and that the anode be dynamically braked by supplying a braking voltage of a frequency differing from that of the energizing voltage to the stator winding in a reverse phase relation.

Although the invention has been described in its preferred form with a certain degree of particularity, it is understood that the present disclosure of the preferred form has been made only by way of example and that numerous changes in the details of construction and the combination and arrangement of parts may be resorted to without departing from the spirit and the scope of the invention as hereinafter claimed.

What is claimed is:

1. In an X-ray apparatus having a rotating anode type X-ray tube wherein the anode is rotatably supported in a bearing and a stator winding is provided to induce rotation of the anode in the bearing, the combination for controlling operation of the rotating anode, said combination comprising:

(a) an exposure control means having ON and OFF positions, said exposure control means in the ON

- position connecting the stator winding to a first voltage source;
- (b) transducer means responsive to the characteristic frequency of the screech of the anode moving in its bearing and producing an output signal directly related to the rotational speed of the anode;
 - (c) a safety circuit means connected to the transducer means and responsive to the output signal thereof, said safety circuit means connecting the X-ray tube to a second voltage source to begin a radiographic X-ray exposure only when said output signal indicates that the anode is rotating above a minimum acceptable level;
 - (d) a dynamic braking circuit means associated with said stator winding and connected to said exposure control means to rapidly decelerate the rotating anode at the end of the exposure period when said exposure control means is in the OFF position, the dynamic braking circuit means being connected to the transducer means and being responsive to the output signal of the transducer device means to apply dynamic braking until the anode has decelerated to a preselected rotational speed as indicated by such output signal;
 - (e) a fluoroscopy control circuit means functioning independent of said exposure control means for connecting said stator winding to the first voltage source, and said fluoroscopy control circuit means being connected to the transducer means and being responsive to the output signal of said transducer means to periodically connect the stator winding to the first voltage source to maintain low speed rotation of the anode during fluoroscopic examinations.
2. In an X-ray apparatus having a rotating anode type X-ray tube wherein the anode is rotatably supported in a bearing and a stator winding is provided to induce rotation of the anode in the bearing, the combination for controlling operation of the rotating anode, said combination comprising:
- (a) main switch means having open and closed positions connecting and disconnecting, respectively, the stator winding to a voltage source;
 - (b) control switch means having ON and OFF positions and being connected to said main switch means and placing said main switch means in its closed and open positions when said control switch means is in its ON and OFF positions respectively;
 - (c) transducer means responsive to the characteristic frequency of the screech of the anode moving in its bearing and producing an output signal in response thereto, a characteristic of the output signal being directly related to the rotational speed of the anode;
 - (d) auxiliary switch means connected to said transducer means and operating between first and second positions in response to said output signal, said first position corresponding to a level of anode rotation above a minimum acceptable level required for protection of the X-ray tube, said second position corresponding to a lower level of anode rotation preselected in the speed range from said minimum acceptable level to and including a standstill;
 - (e) safety circuit means connected to said auxiliary switch means and to an energization circuit for the X-ray tube, said safety circuit means permitting energization of said X-ray tube only when said auxiliary switch means is in said first position;
 - (f) dynamic braking means associated with said stator winding and connected to said control switch means and to said auxiliary switch means, said dynamic braking means dynamically braking the rotating anode when said auxiliary switch means is in the OFF position and as long as said auxiliary switch means is in its first position; and,
 - (g) fluoroscopy control circuit means including a normally open switch for connecting said main switch

- means to said auxiliary switch means whereby said main switch means is placed in the closed position when said auxiliary switch means is in the second position and said main switch means is placed in the open position when said auxiliary switch is in the second position.
3. In an X-ray apparatus having a rotating anode type X-ray tube wherein the anode is rotatably supported in a bearing and a stator winding is provided to induce rotation of the anode in the bearing, the combination for controlling operation of the rotating anode, said combination comprising:
- (a) an exposure control means having ON and OFF positions, said exposure control means in the ON position connecting the stator winding to a voltage source;
 - (b) a frequency increasing means connected between said stator winding and said voltage source, said frequency increasing means having a first operating position supplying an energizing voltage to the stator winding and a second operating position supplying a braking voltage to the stator winding in a reverse phase relation, the energizing voltage having a frequency greater than the voltage source frequency, the braking voltage having a frequency different from that of the energizing voltage;
 - (c) transducer means responsive to the characteristic frequency of the screech of the anode moving in its bearing and producing an output signal proportional to the rotational speed of the anode;
 - (d) a safety circuit means connected to said transducer means and responsive to the output signal of the transducer device, said safety circuit means permitting the X-ray tube to be connected to a second voltage source to begin a radiographic X-ray exposure only when said output signal indicates that the anode is rotating above a minimum acceptable level;
 - (e) a dynamic braking control circuit means connected to the frequency increasing means and to the exposure control means and placing the frequency increasing means in its second position when said exposure control means is in the OFF position to supply said braking voltage to the rotating anode, the dynamic braking circuit means being responsive to the transducer means output signal and maintaining such braking voltage until the anode has decelerated to a preselected rotational speed as indicated by said output signal;
 - (f) a fluoroscopy control circuit means functioning independent of said exposure control means for connecting said stator winding to the voltage source, and said fluoroscopy control circuit means being responsive to the output signal of said transducer means and being operable to periodically connect the stator winding to the voltage source to maintain low speed anode rotation between fixed limits of rotation as detected by said transducer means during fluoroscopic examinations.
4. In an X-ray apparatus having a rotating anode type of X-ray tube wherein stator windings are provided in the rotating anode assembly to cause rotation of the anode in its bearing, the combination for controlling operation of the rotating anode, said combination comprising:
- (a) a frequency multiplier having a switch for controlling operation of the frequency multiplier, an input circuit connected to a line voltage source, and an output circuit providing an energizing voltage of a frequency at least the second multiple of the line voltage source frequency when the frequency multiplier switch is closed, said output circuit providing a voltage of the line voltage source frequency when said frequency multiplier switch is open;
 - (b) a main relay including a coil and normally open contacts, said normally open contacts being in the frequency multiplier input circuit to render said fre-

- frequency multiplier normally disconnected from said line voltage source;
- (c) a direct current blocking capacitor in the frequency multiplier output circuit;
 - (d) a phase splitting capacitor;
 - (e) exposure control switch means having ON and OFF positions, said exposure control switch means closing and opening the frequency multiplier control switch when in the ON and OFF positions, respectively;
 - (f) control means responsive and connected to said exposure control switch means, said control means connecting said stator windings in parallel and to said frequency multiplier output circuit with said phase splitting capacitor in series with one of said windings when said exposure control switch means is in the ON position, said control means connecting said stator windings in parallel and to said frequency multiplier output circuit with said blocking capacitor in series with the other of said windings when said exposure control means is in the OFF position;
 - (g) circuit means responsive and connected to said exposure control switch means, said circuit means connecting said main relay coil to said line voltage source when said exposure control switch means is in the ON position, and said circuit means connecting said main relay coil to said line voltage source by a holding circuit when said exposure control switch means is in the OFF position;
 - (h) transducer means disposed adjacent the X-ray tube and responsive to the characteristic frequency of screech of the anode moving in its bearing, said transducer means producing an electrical signal of an amplitude proportional to the sound level of such bearing screech;
 - (i) an acoustical relay having a coil and a switch contact, said coil being connected to said transducer means, said switch contact having first and second positions, said acoustic relay operating said switch contact to the first position when the bearing screech is above a first predetermined sound level and releasing said switch contact to the second position when the bearing screech is below a second predetermined sound level;
 - (j) said switch contact closing and opening the holding circuit for the main relay when in its first and second positions, respectively;
 - (k) a control circuit connected to the switch contact of the acoustic relay and controlling energization of the X-ray tube, said control circuit permitting energization of said X-ray tube only when said switch contact is in the first position;
 - (l) an alternate energizing circuit connecting said main relay coil to said line voltage source, the switch contact of the acoustic relay opening and closing said alternate energizing circuit when the switch contact is in the first and second positions, respectively; and,
 - (m) a normally open fluoroscopy control switch connected in said alternate energizing circuit.
5. In an X-ray apparatus having a rotating anode type X-ray tube wherein the anode is rotatably supported in a bearing and a stator winding is provided to induce rotation of the anode in the bearing, the combination for controlling operation of the rotating anode, said combination comprising:
- (a) an exposure control means having ON and OFF positions, said exposure control means in the ON position connecting the stator winding to a voltage source;
 - (b) a frequency increasing means connected between said stator winding and said voltage source, said frequency increasing means having a first operating position applying an energizing voltage to the stator winding and a second operating position supplying a braking voltage to the stator winding in a reverse

- phase relation, the energizing voltage having a frequency greater than the voltage source frequency, the braking voltage having a frequency different from that of the energizing voltage;
- (c) a transducer means responsive to the characteristic frequency of the screech of the anode moving in its bearing and producing an output signal proportional to the rotational speed of the anode;
 - (d) a safety circuit means connected to said transducer means and responsive to the output signal of the transducer means to permit the X-ray tube to be connected to a second voltage source to begin a radiographic X-ray exposure only when said output signal indicates that the anode is rotating above a minimum acceptable level;
 - (e) a dynamic braking control circuit means connected to the frequency increasing means and to the exposure control means and placing the frequency increasing means in its second position when said exposure control means is in the OFF position to supply said braking voltage to the rotating anode, and the dynamic braking circuit means being responsive and connected to the transducer means and maintaining such braking voltage until the anode had decelerated to a preselected rotational speed as indicated by said output signal.
6. In an X-ray apparatus having a rotating anode type X-ray tube wherein stator windings are provided in the rotating anode assembly to cause rotation of the anode in its bearing, the combination for controlling operation of the rotating anode, said combination comprising:
- (a) a frequency multiplier having a switch for controlling operation of the frequency multiplier, an input circuit connected to a line voltage source, and an output circuit providing an energizing voltage of a frequency at least the second multiple of the line voltage source frequency when said switch is closed, said output circuit providing a voltage of the line voltage source frequency when said switch is open;
 - (b) a main relay including a coil and normally open contacts, said contacts being in the frequency multiplier input circuit to render said frequency multiplier normally disconnected from said line voltage source;
 - (c) a direct current blocking capacitor in the frequency multiplier output circuit;
 - (d) a phase splitting capacitor;
 - (e) exposure control switch means having ON and OFF positions, said exposure control switch means closing and opening the frequency multiplier control switch when in the ON and OFF positions, respectively;
 - (f) control means responsive and connected to said exposure control switch means, said control means connecting said stator windings in parallel and to said frequency multiplier output circuit with said phase splitting capacitor in series with one of said windings when said exposure control switch means is in the ON position, said control means connecting said stator windings in parallel and to said frequency multiplier output circuit with said blocking capacitor in series with the other of said windings when said exposure control means is in the OFF position;
 - (g) circuit means responsive and connected to said exposure control switch means, said circuit means connecting said main relay coil to said line voltage source when said exposure control switch means is in the ON position, and said circuit means connecting said main relay coil to said line voltage source by a holding circuit when said exposure control switch means is in the OFF position;
 - (h) transducer means disposed adjacent the X-ray tube and responsive to the characteristic frequency of the screech of the anode moving in its bearing, said transducer means producing an electrical signal

- of an amplitude proportional to the sound level of such bearing screech;
- (i) an acoustic relay having a coil connected to said transducer means and a switch contact, said switch contact having a first and second position, said acoustic relay operating said switch contact to the first position when the bearing screech is above a first predetermined sound level and releasing said switch contact to the second position when the bearing screech is below a second predetermined sound level;
 - (j) said switch contact closing and opening the holding circuit for the main relay when in its first and second positions, respectively;
 - (k) a control circuit connected to the switch contact of the acoustic relay and controlling energization of the X-ray tube, and said control circuit permitting energization of said X-ray tube only when said switch contact is in the first position.
7. In an X-ray apparatus having a rotating anode type X-ray tube wherein the anode is rotatably mounted in a bearing and is induced to rotate by an electromagnetic field generated by a stator winding, the combination for dynamically braking the rotating anode to the point of standstill, said combination comprising:
- (a) circuit means connecting said stator winding to a voltage source;
 - (b) dynamic braking means connected to said circuit means to reverse the phase connection of said stator winding;
 - (c) control means to actuate said dynamic braking means;
 - (d) speed responsive means responsive to the rotational speed of the anode and connected to said circuit means to maintain dynamic braking until the anode decelerates to the point of standstill, and the speed responsive means including a transducer disposed adjacent the X-ray tube and responding to the characteristic frequency of the screech of the anode moving in its bearing to detect anode rotation.
8. In an X-ray apparatus having a rotating anode type of X-ray tube including a bearing rotatably supporting the anode and a stator winding for inducing rotation of the anode in the bearing, the combination for controlling dynamic braking of the rotating anode, said combination comprising:
- (a) circuit means selectively connecting the stator winding to a voltage source,
 - (b) dynamic braking means for rapidly decelerating the rotating anode;
 - (c) switch means connected to said circuit means and to said dynamic braking means, said switch means having an ON position where said circuit means connects said stator windings to said voltage source to induce rotation of the anode, said switch means having an OFF position where the rotating anode is dynamically braked;
 - (d) transducer means disposed adjacent the X-ray tube and responsive to the characteristic frequency of the screech of the anode moving in its bearing, said transducer means connected to said dynamic braking means and releasing the dynamic braking at a particular preselected point during deceleration of the anode when the switch means is in the OFF position.
9. In an X-ray apparatus having a rotating anode type of X-ray tube including a bearing rotatably supporting the anode and a stator winding for inducing rotation of the anode in the bearing, the combination for controlling dynamic braking of the rotating anode, said combination comprising:
- (a) circuit means connecting said stator winding to a voltage source for energization of the windings and to thereby induce rotation of the anode;
 - (b) relay means in said circuit means to selectively

- control connection of said stator winding to said voltage source;
- (c) dynamic braking means connected to said circuit means for reversing the phase of said stator winding;
 - (d) switch means connected to said relay means and to said dynamic braking means, said switch means having an ON position actuating said relay means to connect said stator winding to the voltage source, said switch means having an OFF position releasing said relay means to disconnect said stator winding from the voltage source, said switch means in the OFF position operating said dynamic braking means to reverse the phase of the stator winding;
 - (e) transducer means disposed adjacent said X-ray tube and responsive to the characteristic frequency of the screech caused by the anode moving in its bearing, said transducer means being connected to said relay means so as to maintain said relay means in the actuated position connecting the stator winding to the voltage source to thereby dynamically brake the rotating anode until said transducer means releases said relay means at a preselected lower speed level of the rotating anode.
10. In an X-ray apparatus having a rotating anode type X-ray tube wherein the anode is rotatably supported in a bearing and a stator winding is provided to induce rotation of the anode in the bearing, the combination for controlling operation of the rotating anode, said combination comprising:
- (a) an exposure control means having ON and OFF positions, said exposure control means in the ON position connecting the stator winding to a voltage source;
 - (b) transducer means responsive to the characteristic frequency of the screech of the anode moving in its bearing and producing an output signal proportional to the rotational speed of the anode;
 - (c) a safety circuit means connected to said transducer means and responsive to the output signal of the transducer means to permit the X-ray tube to be connected to a second voltage source to begin a radiographic X-ray exposure only when the output signal indicates that the anode is rotating above a minimum acceptable level;
 - (d) a dynamic braking circuit means associated with said stator winding to rapidly decelerate the rotating anode at the end of the exposure period when said exposure control means is in the OFF position, and the dynamic braking circuit means connected to said transducer means and being responsive to the transducer means output signal to apply dynamic braking until the anode has decelerated to a preselected rotational speed as indicated by such output signal.
11. In an X-ray apparatus having a rotating anode type X-ray tube wherein stator windings are provided in the rotating anode assembly to cause rotation of the anode in its bearing, the combination for controlling operation of the rotating anode, said combination comprising:
- (a) main switch means having ON and OFF positions connecting and disconnecting, respectively, said stator winding to a voltage source;
 - (b) transducer means responsive to the characteristic frequency of the screech of the anode moving in its bearing and producing an output signal in response thereto, the amplitude of the output signal being proportional to the rotational speed of the anode;
 - (c) auxiliary switch means connected to said transducer means and operating between first and second positions in response to said output signal, the first position corresponding to a minimum acceptable level of anode rotation of the X-ray tube, said second position corresponding to a preselected level of anode rotation from said minimum acceptable level down to a standstill;
 - (d) safety circuit means connected to said auxiliary switch means and to an energization circuit for the X-ray tube, said safety circuit means permitting ener-

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gization of said X-ray tube only when said auxiliary switch means is in said first position;

- (e) dynamic braking means associated with said stator windings and connected to said main switch means and said auxiliary switch means, and said dynamic braking means dynamically braking the rotating anode when said main switch means is in the OFF position for as long as said auxiliary switch means is in the first position.

12. In an X-ray apparatus having a rotating anode type X-ray tube wherein the anode is rotatably mounted in a bearing and is induced to rotate by an electromagnetic field generated by a stator winding, the control system for preventing energization of the X-ray tube from a high voltage source unless the anode is rotating at a minimum rotational speed, said control system comprising:

- (a) circuit means connecting the stator winding to a voltage source;
- (b) switch means connecting the X-ray tube to the high voltage source;
- (c) means responsive to the rotational speed of the anode and connected to said switch means to prevent connection of the X-ray tube to the high voltage source unless the anode is rotating above a minimum acceptable level, and the speed responsive means including a transducer responsive to the characteristic frequency of the screech of the anode moving in its bearing.

13. The combination of claim 12 wherein the transducer is a ceramic piezo-electric pick-up having a resonant frequency which is substantially the frequency of the screech of the anode bearing when rotating.

14. In an X-ray apparatus having a rotating anode type X-ray tube wherein the anode is rotatably supported in a bearing and a stator winding is provided to induce rotation of the anode in the bearing, the combination for controlling operation of the rotating anode, said combination comprising:

- (a) an exposure control means having ON and OFF positions, said exposure control means in the ON position connecting the stator winding to a voltage source;
- (b) transducer means responsive to the characteristic frequency of the screech of the anode moving in its bearing and producing an output signal proportional to the rotational speed of the anode;
- (c) a safety circuit connected to said transducer means and responsive to the output signal of the transducer means, said safety circuit permitting the X-ray tube to be connected to a second voltage source to begin a radiographic X-ray exposure only when the output signal indicates that the anode is rotating above a minimum acceptable level;
- (d) a fluoroscopy control circuit means functioning independent of said exposure control means for connecting said stator winding to the voltage source, said fluoroscopy control circuit means connected to said transducer means and being responsive to the output signal of said transducer means, and said fluoroscopy control circuit means connecting the stator winding to its voltage source when the anode rotational speed is just above a standstill and disconnecting the stator winding from its voltage source when the anode rotational speed is approximately the minimum level acceptable for radiographic exposures.

15. In an X-ray apparatus having a rotating anode type X-ray tube wherein a stator winding is provided in the rotating anode assembly to cause rotation of the anode in its bearing, the combination for controlling operation of the rotating anode, said combination comprising:

- (a) an energizing circuit connecting said stator winding to a voltage source;
- (b) a main relay including a coil and normally open main contacts, said normally open main contacts

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being connected in said energizing circuit to render said stator winding normally disconnected from said voltage source;

- (c) exposure control switch means having ON and OFF positions;
- (d) circuit means connected and responsive to said exposure control switch means, said circuit means connecting said main relay coil to said line voltage source when said exposure control switch means is in the ON position, and said circuit means connecting said main relay coil to said line voltage source by a holding circuit when said exposure control switch means is in the OFF position;
- (e) transducer means disposed adjacent the X-ray tube and responsive to the characteristic frequency of the screech of the anode moving in its bearing, said transducer means producing an electrical signal of an amplitude proportional to the amplitude of the characteristic frequency of such bearing screech;
- (f) an acoustic relay having a coil connected to said transducer means and a switch contact, said switch contact having a first and second position, said acoustic relay operating said switch contact to the first position when the bearing screech is above a first predetermined sound level and releasing said switch contact to the second position when the bearing screech is below a second predetermined sound level;
- (g) said switch contact closing and opening the holding circuit for the main relay when in its first and second positions, respectively;
- (h) a control circuit means connected to the switch contact of the acoustic relay and controlling energization of the X-ray tube, and said control circuit means permitting energization of said X-ray tube only when said switch contact is in the first position.

16. A control circuit for periodically pulsing the stator winding of a rotating anode type X-ray tube to maintain continuous rotation of the anode in its bearing with a minimum of heat generated in the X-ray tube, comprising:

- (a) circuit means for selectively connecting the stator winding to a voltage source;
- (b) controller means connected to said circuit means, said controller means shifting said circuit means between a first position wherein the stator winding is connected to the voltage source and a second position wherein said stator winding is disconnected from the voltage source;
- (c) means responsive to the characteristic frequency of the rotational speed of the anode, said speed responsive means including a transducer responsive to the screech of the anode moving in its bearings; and,
- (d) means connecting the speed responsive means to the controller means so that said controller means shifts said circuit means to said first position when said anode is rotating below a first predetermined rotational speed and shifts said circuit means to said second position when said anode is rotating above a second predetermined rotational speed higher than said first rotational speed.

17. An X-ray apparatus comprising:

- (a) a rotating anode type X-ray tube including:
 - (i) a bearing rotatably supporting an X-ray tube anode; and,
 - (ii) a stator winding for inducing rotation of the anode in the bearing, said bearing making a screech having a characteristic frequency when the anode is rotating in the bearing;
- (b) transducer means positioned adjacent the X-ray tube, said transducer means being responsive to the characteristic frequency of the bearing screech made by the bearing when the anode is rotating in the bearing and producing an output signal representative of the speed of anode rotation; and,
- (c) indicating means connected to said transducer

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means and providing an indication of a predetermined speed of anode rotation in response to said output signal.

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