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X-RAY TUBE PROTECTION MECHANISM

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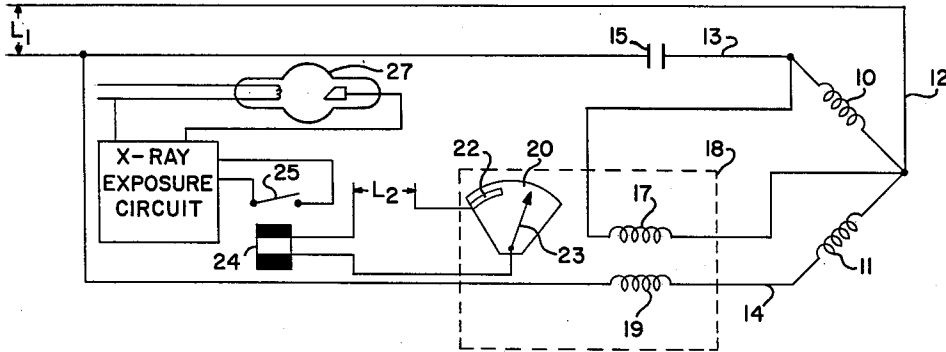


FIG. -1

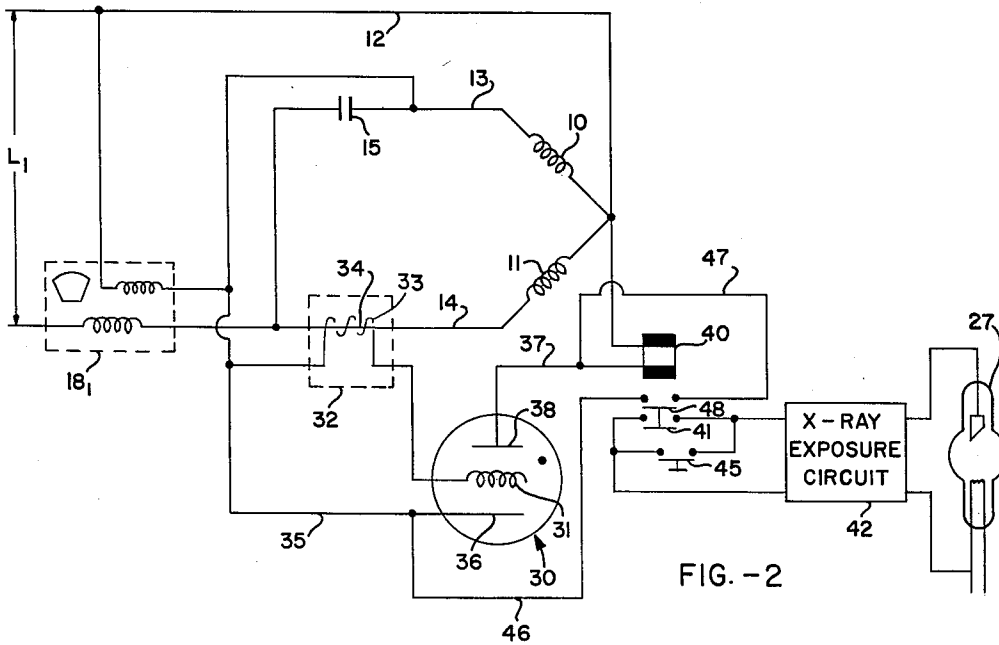


FIG. -2

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1

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X-RAY TUBE PROTECTION MECHANISM

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This invention pertains to X-ray apparatus and more particularly to a novel and improved mechanism for preventing the energizing operation of a rotating anode type X-ray tube when the anode is not rotating properly.

When an X-ray tube is in operation, a target area on the anode is struck by a bombarding flow of electrons emitted by the tube filament or cathode. This bombarding of the target area causes a beam of X-rays to be emitted. It also causes the target area to become extremely hot.

The use of X-ray tubes equipped with rotatable anodes has now become a well established practice. These rotatable anodes have ring-like targets. The anode is caused to rotate when the tube is in use in order that the target area is a constantly changing area. The bombarding electrons will strike each portion of the ring-like target of the anode once each revolution of the anode. Through this technique the heat generated by the bombardment of the anode is widely dissipated. This heat dissipation permits higher levels of X-ray energy and longer exposure than can be obtained with a fixed target.

Inherently, the anode must be rotating, and at its designed speed or close to it, or the heat dissipation benefits will be partially or totally lost. If the anode is, for some reason, not rotating at all, energization of the tube for an exposure will destroy the anode by burning out a portion of the target ring. For these reasons it is important that the anode be rotating at a minimum acceptable speed level before the X-ray exposure circuit is energized.

In the past a number of proposals have been set forward for protecting against the energization of rotating anode type X-ray tubes in situations where an X-ray tube anode is not rotating at a safe speed. Most of these prior proposals have not been fully acceptable for a number of reasons, the usual being that they are too delicate to provide the dependable reliability required. Most, while operating satisfactorily on what might be generally referred to as a laboratory scale, are too delicate to withstand the rigors of day-to-day use.

Probably the best of the prior art proposals is that disclosed and claimed in United States Letters Patent application Serial No. 270, filed by Edward B. Graves on January 4, 1960, for "Protection Device for Rotating Anode X-Ray Tube" which issued as Letters Patent No. 3,043,957 on July 10, 1962. With the structure of that invention, one of two energizing windings which cause the anode to rotate is disconnected from its energizing circuit. If the tube is functioning properly, there will be generated electricity flowing in this disconnected winding. This generated electricity is known as back electromotive force or simply back E.M.F. After the winding is disconnected from the energizing circuit, it is then connected to a sensing solenoid. If the back E.M.F. generated in the disconnected winding is above a predetermined level the sensing solenoid will close a switch and permit an X-ray exposure to be made.

With this described mechanism, the power of the disconnected one of the windings is obviously lost and rotation of the anode is maintained solely by the remaining winding. The anode operates as a single phase motor during the time when one of the windings is disconnected and the back E.M.F. is measured. This inherently re-

2

sults in a decrease of speed which is quite acceptable and permissible if exposures are relatively short. Inherently, however, the advantage of a rotating anode type tube is partly lost.

To obtain the full advantage of the rotating anode type tube, particularly where relatively long exposures have to be made, the commercial practice has been to reconnect the disconnected winding after the sensing solenoid has closed the exposure circuit. Thus, the winding is temporarily disconnected and the sensing solenoid is energized if rotation is at, or in excess of, an acceptable minimal level. Subsequently, the winding is reconnected for use during an exposure period. This arrangement provides some minimal amount of risk since there is some remote chance that the anode may cease to rotate properly while the exposure is in progress.

From the preceding discussion it will be seen that the best of the prior art proposals for protecting the anode of a rotating anode type tube has had some inherent disadvantages. The present invention overcomes all of these disadvantages and also provides additional advantages. The present invention utilizes a very simple and dependable mechanism which will permit the commencement of an X-ray exposure only if the tube is operating at a speed above a predetermined minimum acceptable level. Further, this mechanism may be constructed to prevent the completion of the exposure if, but only if, the anode continues to rotate above a minimum acceptable speed level. The mechanism utilizes a simple and dependable arrangement which is easy to manufacture, easy to maintain and which can readily provide a visible indicia of the anode condition to the operator.

According to the present invention, the voltage from one of the anode windings and the amperage from the other is utilized. These windings are maintained 90° out of phase by a phase shifting capacitor when the anode is at rest. When the anode commences to rotate, the generated back E.M.F. will change the phase angle from its "at rest" angle of 90°. With the two windings 90° out of phase, the voltage from one and amperage from the other will produce a wattage which is 0. As the anode commences to rotate, the phase angle will change and a wattage will be produced. Once the wattage reaches a predetermined minimum level, a mechanism responsive to this wattage is utilized to permit an X-ray exposure to be made.

In its simplest form, the mechanism utilizing the concept of the present invention may simply be a wattmeter with contacts on the indicating needle and dial. These contacts close an electric circuit when the wattage reaches a predetermined minimum level, say 50 watts. When closed, the contacts close an energizing solenoid which permits an X-ray exposure circuit to be closed.

The mechanism then is one in which there is utter simplicity but yet all possible variables affecting the operating conditions of the rotating anode tube are reflected. For example, the wattage will reflect both the temperature of the tube and the speed of rotation. This is true because the change of phase angle is controlled by the amount of back E.M.F. generated. This back E.M.F. is a voltage induced in the windings by the current flowing in the armature of the rotating anode. Now, the amount of back E.M.F. induced is a function of both the speed of rotation and the amount of current flowing in the armature. The amount of current flowing in the armature will decrease as the resistance increases. A temperature rise in the armature will cause an increase in resistance and with it a drop in back E.M.F. A reduction in rotational speed will also reduce the amount of back E.M.F.

The utilization of a system reflecting change in phase angle produces another outstanding advantage in the present invention. Since the induced back E.M.F. de-

creases as the temperature of the armature increases, a safe minimum speed of anode rotation when a tube is cold will be slower than a safe minimum speed of rotation when a tube has been heated by long use. This mechanism inherently will permit an exposure in a hot tube only if the minimum speed is faster than the minimum acceptable speed in a cold tube.

This latter described variation in minimum speed lends itself to use with one presently standard X-ray tube construction in which the bearings are designed to become looser providing less friction as the tube heats up. Thus, with one of the well known present commercial types of X-ray tubes that is functioning properly, the speed of rotation in a cold tube is less than that in a hot tube.

In the preferred construction of this invention, a vacuum tube responsive to the amount of wattage induced by the two windings in the manner described above is used. When this tube has a predetermined minimum of energization it fires energizing and closing a solenoid. In this manner, an X-ray exposure is permitted.

Accordingly, one of the principal objects of this invention is to provide a novel and improved mechanism for protecting a rotating anode of an X-ray tube which mechanism includes a means responsive to the wattage induced by the voltage of one field winding for inducing anode rotation and the amperage of another such field winding and in which this means is used to close an X-ray exposure circuit.

Another object of the invention is to utilize the changing phase angle of two parallel connected field windings for causing rotation of a rotating anode in an X-ray tube to selectively close an X-ray exposure circuit.

A more general object of the invention is to provide a novel and improved, simple, dependable mechanism for preventing exposure energization of a rotating anode X-ray tube when the anode is rotating at a speed below a predetermined acceptable minimum level.

A further object of the invention is to provide a novel and improved rotating anode type X-ray tube protection mechanism which can be constructed to prevent the continuance of an X-ray exposure if the speed of anode rotation drops below a safe minimum level.

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

FIGURE 1 is a schematic wiring diagram demonstrating the principle of this invention; and,

FIGURE 2 is a wiring diagram showing a preferred arrangement for obtaining the advantages of this invention.

Referring now to the drawings, a pair of parallel connected field windings 10, 11 are provided. These field windings 10, 11 are the windings of a two-phase induction motor used to cause the anode of a rotating anode type X-ray tube to rotate. The field windings 10, 11 are connected by a conductor 12 to one side of a source of alternating current L_1 . The field windings 10, 11 are connected respectively to the other side of the source L_1 by conductors 13, 14.

A phase shifting capacitor 15 is in series with the field winding 10 and included in the line 13. This phase shifting capacitor 15 maintains the field windings 10, 11 out of phase, by 90° when the device is at rest. As rotation commences, back E.M.F. induced in the field windings causes a change in this phase angle. It is this change in phase angle which is utilized in the present invention in a manner which will be described in greater detail below.

In FIGURE 1, a mechanism which demonstrates the principle of this invention is shown. Here a voltage winding 17 of a wattmeter 18 is connected in parallel with the field winding 10. An amperage winding 19 of the wattmeter 18 is connected in the line 14 to place it in series with the field winding 11. The wattage indicated on the

dial 20 of the meter 18, will be a function of the voltage in the field winding 10 and the amperage in the field winding 11.

The wattage so produced can be computed by the usual formula of wattage equals voltage times amperage times the cosign theta, ($W=EI \cos \theta$) where theta is the phase angle. Since the phase angle is 90° when the device is at rest, the cosign of this angle is 0 and therefore the wattage is 0. As the anode arrives at full speed of rotation, this phase angle will reduce to approximately 45° so that cosign theta will, at its maximum, equal about 0.5. At this point, the wattage will achieve its maximum which may be in the neighborhood of 200 watts.

An elongated contact 22 is mounted on the face of the wattmeter dial 20. This elongated contact is sized to form an electrical connection with a contact on an indicator needle 23. This connection will be obtained during a selected wattage range of perhaps 50 to 200 watts. The contact 22 on the dial and the contact on the needle 23 may be connected to an exposure solenoid 24. When the circuit is closed by connecting these contacts, electric energy supplied by a source L_2 will energize the solenoid 24. Energizing the solenoid 24 closes a switch 25 to complete an X-ray exposure circuit and provide exposure energization for the tube shown schematically at 27.

In FIGURE 2, the preferred construction utilizing the benefits of this invention is disclosed. Here the wattmeter 18' is provided only for the purpose of giving a visual indication of the operating condition of the X-ray tube. A thyatron tube 30 replaces the wattmeter contacts serving essentially the same function and purpose. A current transformer 32 is also provided.

The thyatron tube 30 has a grid 31 which is connected to the secondary winding 33 of the current transformer 32. The primary winding 34 of the current transformer 32 is in series with the field winding 11 just as is the current winding 19 of the wattmeter 18. The thyatron tube 30 is connected in parallel with the field winding 10 in a manner similar to the voltage winding 17 of the wattmeter 18. Thus, a conductor 35 connects the cathode 36 of the thyatron to one side of the field winding 10. Another conductor 37 connects the plate 38 of the thyatron 30 to the other side of the winding 10.

The exposure control solenoid, here designated by the number 40, and corresponding in purpose and function to the control solenoid 24, is, in this instance, connected to the conductor 37. When the thyatron 30 is energized above a predetermined minimum level by the current supplied by the current transformer winding 33 and the voltage supplied by the parallel connection with the field winding 10, the tube will fire and the solenoid 40 will be energized. Energizing the solenoid 40 closes a double pole switch 41. One pole of the switch 41 energizes an X-ray exposure circuit designated generally by the numeral 42.

There are instances where a physician may wish to intentionally overload an X-ray tube and cause an exposure to be made even though he knows that the tube is not operating properly. To permit this intentional overloading to be obtained, a manual override pushbutton switch 45 is connected in parallel with the solenoid control pole of the switch 41. The physician conducting an X-ray examination may intentionally close the switch 45 to override the control mechanism and energize the X-ray exposure circuit.

One of the advantages of this invention is that with the preferred construction of FIGURE 2, and with other equivalent constructions which will be apparent, a greater flow of electric energy is required to initiate the firing of the thyatron tube 30 than is required to maintain the firing. To a certain degree, a slowing of the rotation of the anode during an exposure can be tolerated without any fear of causing injury to the target. Since a lower energy level is required to cause the thyatron tube

5

to continue to operate than is required to initiate the operation, a decrease in energy to the thyatron will maintain the solenoid 40 in an energized condition. This is true even though the speed of rotation may be below a safe initial level and even though the anode becomes hot. Thus, a properly designed system will accommodate both the expected heating up of the anode and possible slowing down of it during an exposure. With the properly designed system, the thyatron will nonetheless cease to fire, de-energizing the solenoid as the temperature or speed of the anode reaches an unsafe condition. When one wishes to use this feature of automatic reopening of the exposure circuit, the switch 41 is a single pole switch with the second and as yet undescribed pole eliminated.

While this described construction with the safety of automatically interrupting the exposure circuit as the conditions of the rotating anode type X-ray tube reach an unsafe condition is usually desirable, it is recognized that a construction which may cause an X-ray tube beam to stop in the middle of a study is a construction which will not be tolerated by some radiologists. For this reason, conductors 46, 47 and the connecting pole 48 of the switch 41 provide a condition maintenance circuit which shunts around the thyatron. Once the thyatron 30 has fired and the solenoid 40 has closed the switch 41, the solenoid will be maintained in an energized condition. This maintenance is through a circuit from the conductor 13 through the conductors 35 and 46; thence through the pole 48 of the switch 41, the conductor 46 and then the conductors 37 and 12. This circuit, then, maintains the solenoid energized so long as the field windings 10, 11 are energized from the source L₁.

While the invention has been described with a great deal of particularity and detail, it is believed that it essentially comprises a mechanism for protecting the anode of a rotating type anode X-ray tube which mechanism includes a control means responsive to the voltage in one of the X-ray tube field windings and the amperage in the other of the field windings.

Although the invention has been described in its preferred form with a great deal of particularity it is understood that the present disclosure of the preferred form has been made only by way of example 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. A mechanism for protecting the anode of a rotating anode type X-ray tube by detecting rotational speed of the anode comprising, first and second parallel connected field windings connected to an A.C. source for inducing the rotation of the anode, a capacitor in series with the first winding to maintain the two windings in an out-of-phase relationship, wattage responsive means connected to the windings and responsive to wattage induced by the voltage of one winding and the amperage of the other winding, an X-ray exposure circuit, and switch means connected to the X-ray exposure circuit and controlled by the wattage responsive means for closing the X-ray exposure circuit when the wattage is above a predetermined minimum level indicating a predetermined anode rotational speed.

2. In an X-ray apparatus including a rotating anode type X-ray tube having first and second field windings for inducing the rotation of the anode, the combination of, conductors connecting the first and second windings in parallel with one another and to a source of alternating current, a phase shifting capacitor in series with one of the windings to maintain the two windings 90° out of phase when the anode is at rest, phase angle comparison means responsive to the voltage in the first winding and the amperage in the second winding for indicating a predetermined rotational speed of the anode, a solenoid connected to said phase angle comparison

6

means for selective energization when said anode rotation is at said predetermined speed, an X-ray exposure circuit, a normally open double pole switch, said normally open switch being selectively closable by said solenoid, one pole of said switch being connected to the X-ray exposure circuit for selectively energizing the X-ray exposure circuit, and a condition maintenance circuit paralleling the phase angle comparison means and in series with the solenoid, said condition maintenance circuit including the other pole of said switch for maintaining the solenoid in an energized condition.

3. In an X-ray apparatus including a rotating anode type X-ray tube having first and second field windings for inducing the rotation of the anode, the combination of, conductors connecting the first and second field windings in parallel with one another and to a source of alternating current, a phase shifting capacitor in series with one of the field windings to maintain the two field windings 90° out of phase when the anode is at rest, a wattmeter having an amperage winding series connected with the first field winding, said wattmeter having a voltage winding parallel connected to the second field winding, contact means controlled by the wattmeter, a solenoid connected to the contact means for selective energization when said anode is rotating properly as determined by the current-voltage-phase relationship detected by the wattmeter, an X-ray exposure circuit including a normally open switch being selectively closable by said solenoid.

4. In an X-ray apparatus including a rotating anode type X-ray tube having first and second field windings for inducing the rotation of the anode, the combination of, conductors connecting the first and second windings in parallel with one another and to a source of alternating current, a phase shifting capacitor in series with one of the windings to maintain the two windings 90° out of phase when the anode is at rest, a current transformer having a primary winding series connected with the first winding, a thyatron tube having a grid connected to the secondary of the current transformer, said thyatron having a cathode connected to one side of the second winding and a plate connected to the other side of the second winding to place the thyatron plate and cathode in a circuit parallel with the second winding, a solenoid in series in said plate, cathode parallel circuit, an X-ray exposure circuit including a normally open switch, and said normally open switch being selectively closable by said solenoid when said anode is at a predetermined rotational speed.

5. A mechanism for protecting the anode of a rotating anode type X-ray tube by detection of the rotational speed of the anode comprising, first and second parallel connected field windings for inducing the rotation of the anode, means connected to the windings to maintain the two windings in an out-of-phase relationship, phase angle comparison means connected to the windings and responsive to the differential between the phase angle of a circuit quantity in the first winding and the phase angle of a circuit quantity in the second winding, an X-ray exposure circuit, and means controlled by the phase angle comparison means for permitting the actuation of the X-ray exposure circuit when the differential between the phase angle of the first circuit quantity and the phase angle of the second circuit quantity has changed a predetermined extent to indicate a predetermined anode rotational speed.

6. A mechanism for protecting the anode of a rotating anode type X-ray tube by detecting the rotational speed of the anode comprising, first and second parallel connected field windings for inducing the rotation of the anode, the field windings being connected to a voltage source, means connected to the windings to maintain the two windings in an out-of-phase relationship, phase angle comparison means including a voltage responsive portion connected to one of the windings and an amperage responsive portion connected to the other of the windings, said

phase angle comparison means being responsive to the differential between phase angles of the voltage in said one winding and of the current in said other winding, an X-ray exposure circuit, and means controlled by the phase angle comparison means and connected to the X-ray exposure circuit for closing the X-ray exposure circuit when the phase angle differential has changed to a predetermined point thereby indicating a predetermined anode rotational speed.

7. The device of claim 6 wherein the phase angle comparison means includes a wattmeter.

8. The device of claim 6 wherein the phase angle comparison means includes a thyatron.

9. In combination a rotating anode type X-ray tube, an X-ray exposure circuit connected to the tube and selectively energizing the tube, said tube including first and second parallel connected field windings for selectively causing said anode to rotate, said field windings being connected to a source of alternating current, phase shifting means connected to the field windings to maintain the two in an out-of-phase relationship, switch means connected to the X-ray exposure circuit for selectively closing the circuit, phase angle comparison means connected to the switch means and to the field windings to cause said switch means to close said circuit when said anode is rotating at a predetermined level, said phase angle comparison means including one portion connected in parallel

with the first field winding and another portion connected in series with the second field winding, said phase angle comparison means being responsive to a change in the differential between the phase angle of the voltage in said first winding and the phase angle of the current in said second winding, and said phase angle comparison means operating said switch means to close said X-ray exposure circuit when said differential is at a predetermined value indicating said anode is rotating at a predetermined speed.

10. The device of claim 9 wherein said phase angle comparison means includes a wattmeter having voltage and amperage windings and wherein said one portion is the voltage winding and said other portion is the amperage winding.

11. The device of claim 9 wherein the phase angle comparison means includes a thyatron tube and wherein the said one portion includes the plate and the cathode of the thyatron and wherein said other portion includes the thyatron grid.

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