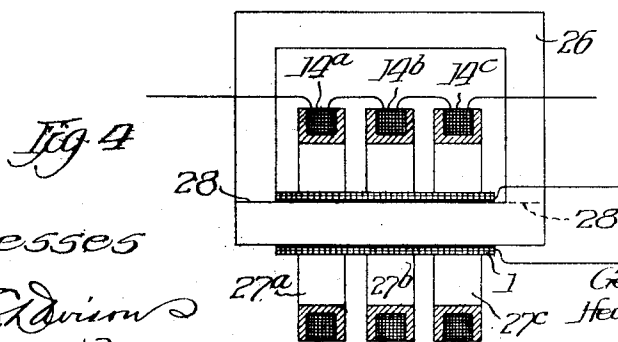
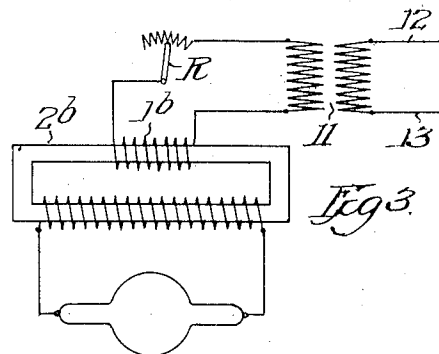
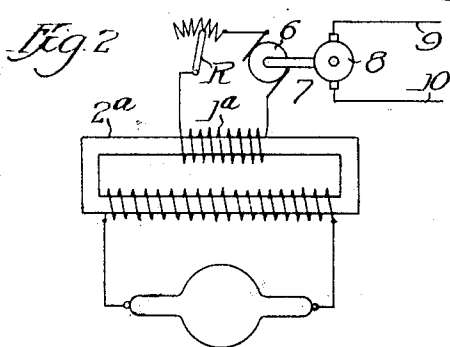
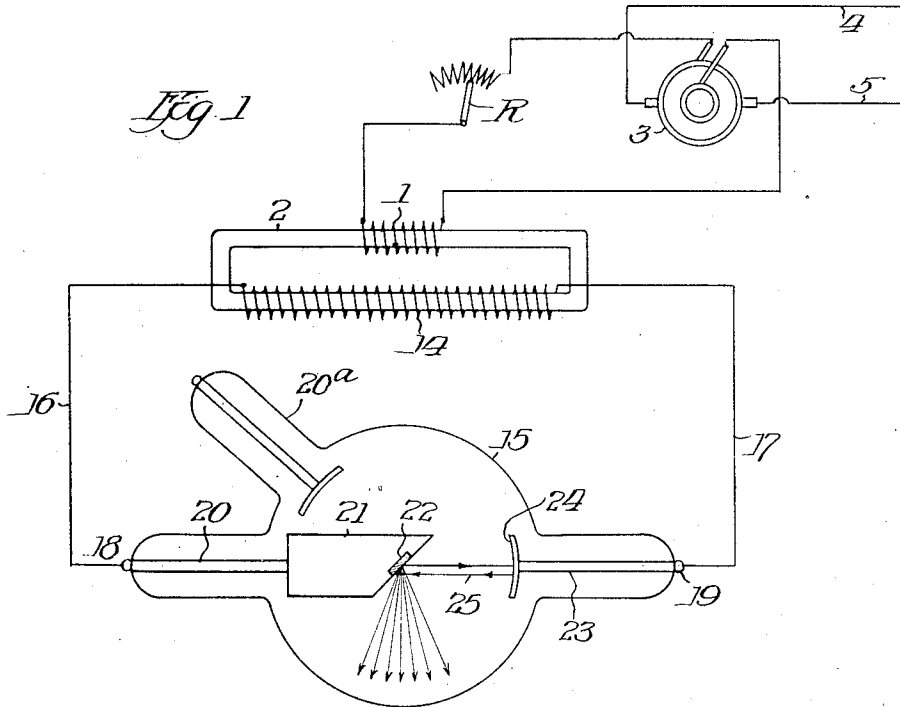


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SYSTEM OF X-RAY TUBE OPERATION.
APPLICATION FILED APR. 13, 1914.

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To all whom it may concern:

Be it known that we, GEORGE R. HOGAN and HECTOR P. MACLAGAN, citizens of the United States, residing at Chicago, in the county of Cook and State of Illinois, have invented certain new and useful Improvements in Systems of X-Ray-Tube Operation, of which the following is a full, clear, concise, and exact description, reference being had to the accompanying drawings, forming a part of this specification.

Our invention relates to an improved system of X-ray tube operation by which a more intense X-ray field is produced with simpler apparatus than has heretofore been possible in the art.

Our invention is characterized by the use of such a voltage of alternating current impressed directly upon the terminals of an X-ray tube that the current will flow in one direction through the tube, whereas it will not flow in the other direction. Or in other words, the properties of the tube are such that half of the waves of the high tension alternating current impressed upon the terminals of the tube are suppressed within the tube itself.

Heretofore in the art it has been customary to excite X-ray tubes in several ways.

One of the earliest systems employed involved the use of a static machine for generating the high tension current delivered to the X-ray tube. Subsequently high tension induction coils were employed for this

purpose with the result, however, that it was almost, if not quite, impossible to prevent the flow through the X-ray tube of current rays in the reverse of the desired direction with the accompanying production of the so-called "inverse" waves in the tube, which produced a character of illumination preventing the proper use of the tubes. It has always been found that the production of these inverse waves results

in an illumination due to a more or less pronounced disruptive arcing within the tube between its terminals, and the production of such arcs makes it impossible at the same time to produce in the tube the X-rays which are required for radiographic purposes. The ideal character of illumination in the tube for radiographic purposes is one resulting from a quiet discharge in but one direction through the tube, which produces

a yellow greenish illumination upon one side only of the target of the tube, as a re-

sult of which, for ideal conditions there is a pronounced hemisphere of illumination with practically an entire absence of illumination in the other half of the tube. It has been found to be practically impossible to secure this character of illumination with the induction coil system of operation.

The systems more recently used, and with much better results, are of two kinds; first the high frequency system, in which so-called Tesla coils are used; and the transformer system in which a rectifying switch of one kind or another, or equivalent rectifying devices are employed in the high tension circuit connecting with the tube. In the former of these systems, the tube is connected directly with the terminals of the secondary winding of the transformer but it is found necessary to invariably use in this system an X-ray tube provided with a so-called "valve" for suppressing the inverse waves which would otherwise be produced in the tube. The primary winding of the transformer in such a system may be operated either by direct current or by alternating current, but in any event an interrupter is used, the terminals of which have connected around them a condenser of large capacity, as a result of which a high frequency oscillatory discharge is produced through the primary winding of the transformer, and thus a high frequency high tension current is delivered from the terminals of the secondary winding of the transformer to the X-ray tube. The transformers used in this system are not equipped with magnetic core, for the reason that the high frequency of operation prevents an effective and efficient transformation of the current. The transformer system of operation consists in using a high tension step-up transformer, the primary winding of which is supplied directly with alternating current produced either by a rotary converter when the source of current supply is an alternating current or by the alternating current generator of a motor generator set when the source of motor supply is a direct current. In connection with this system of operation it is customary to provide a rectifying switch mounted upon the shaft of the rotary converter or motor generator, so that the switch will operate at all times in perfect synchronism with the alternating current generator, and this rectifying switch is connected with the

circuit extending from the secondary winding of the transformer so as to deliver these high tension impulses to the X-ray tubes always in the same direction. Various modifications of this co-called transformer system have been proposed, such for example as substituting for the rectifying switch rectifying devices of other descriptions in the secondary circuit.

In every case of X-ray tube operation as far as we are aware, with the exception of systems in which valve tubes are employed, it has been found necessary to deliver to the terminals of the X-ray tube, a uni-directional current, for otherwise it has been found that inverse waves are produced in the tube.

By our present invention we are able to connect the terminals of the high tension secondary winding of the transformer directly with the terminals of the X-ray tube without the use of rectifying devices of any kind or description. That is to say, we impress upon the terminals of the tube an alternating high tension electromotive force, and yet by the particular relation of that electromotive force to the constants of the tube we produce a uni-directional flow of current through the tube. We are not entirely informed as to why this result is produced, but our experiments thus far indicate that the resistance of the tube from the target to the mirror or cathode is less than the resistance from the mirror to the target, for we find that reversing the connections of the secondary winding to the terminals of the tube merely changes the direction of current flow in said winding without producing any change whatever in the character of operation of the tube and, furthermore, for either connection current flowing through the secondary circuit is uni-directional. It will be understood that in our improved system we employ ordinary high tension X-ray tubes without valves and that, therefore, the entire effect of suppressing the high tension alternating current waves of one sign is produced by the target and cathode in some manner.

From results secured by our system we conclude that every X-ray tube has a critical value of operating electromotive force which if impressed upon the terminals of the tube, even though the electromotive force be alternating in character, will produce a uni-current flow through the tube, whereas if the potential impressed upon the terminals be increased somewhat the flow of current through the tube becomes alternating in character and at once the inverse waves are produced and the tube no longer operates as it should to produce the X-ray field.

Our invention, therefore, contemplates impressing upon the particular X-ray tube employed a sufficiently high alternating cur-

rent motive force to produce a brush discharge from the target to the cathode and maintaining the said electromotive force at a value too low to produce a disruptive alternating discharge between the target and cathode, for we find there is a distinctly appreciable range of operation of various X-ray tubes, each having its characteristic range, through which a uni-directional brush discharge may be produced by a high tension alternating electromotive force of proper value without the production of an alternating disruptive discharge, and that for this range of operation a practically perfect hemispherical illumination resulting from the cathode rays reflected by the mirror upon the target is produced.

In carrying out our invention we find it advisable to use a transformer having a closed magnetic path, since the efficiency of transformation is relatively high by means of such a device.

The several drawings illustrating our invention are as follows:

Figure 1 is a diagrammatic view showing our system, in its complete embodiment, current being supplied to the tube by means of a rotary converter; Fig. 2 shows in a similar diagrammatic view our system operated by means of a motor generator set; Fig. 3 shows in a view similar to Fig. 1 our system operated by means of alternating current supplied to the transformer directly from the line; Fig. 4 is a detail view of the transformer used in connection with our system. Similar numerals refer to similar parts throughout the several views.

In carrying out our invention it is immaterial in what manner the primary winding of the transformer is excited as long as an alternating current of proper potential and current strength is delivered to the primary winding of said transformer. The operation of the system in any event is precisely the same so that it will be necessary to describe the operation in detail in connection with but one embodiment of our system, for example that shown in Fig. 1. The primary winding 1, of the transformer 2 is supplied with alternating current from the rotary converter 3, which rotary converter is driven by direct current supplied by the main feed wires 4 and 5. With this system the potential of the current delivered to the primary winding 1, is of course, substantially the same as the potential between the main feed wires 4 and 5. In the system shown in Fig. 2, on the other hand the primary winding 1^a of the transformer 2^a is supplied with alternating current from the alternating current generator 6, of the motor generator 7, the motor element 8 of which is driven by direct current supplied from the main feed wires 9 and 10. With this embodiment of our system it will, of course, be

understood that the electromotive force delivered by the alternating current generator 6 may have any desired relation to the electromotive force between the direct current feed wires 9 and 10.

In the embodiment of our system shown in Fig. 3, the alternating current is supplied to the primary winding 1^b of the transformer 2^b, either by means of a transformer 11 supplied with alternating current directly from the line wires 12 and 13 or if the alternating voltage between the line wires 12 and 13 is of the proper value, the line wires may be connected directly with the terminals of the primary winding 1^b.

The differences described are the only ones existing in the operation of the various embodiments of our system disclosed, and any one of these systems of operation will properly energize the transformer so as to deliver the desired alternating high tension current from the secondary winding of said transformer. To consider the further operation of our system, therefore, it will be necessary to describe but one embodiment of our system, as for example, that shown in Fig. 1.

As a result of the excitation of the core of the transformer 2, by the alternating current flowing through the primary winding 1, a high tension electromotive force is developed in the secondary winding 14 of the transformer 2, of a proper voltage to carry out our system in connection with the tube 15. The terminals of the secondary winding 14 are connected by conductors 16 and 17 with the terminals 18 and 19 respectively of the tube 15. The terminal 18 is connected by a rod 20, preferably with a copper cylinder 21 having its inner end beveled at substantially 45 degrees, and provided with a central circular target 22, preferably of tungsten. The other terminal 19 is connected by a rod 23 with a concave mirror 24 facing the beveled end of the cylinder 21. The mirror 24 is made preferably of aluminum, and in all respects the tube 15 is of standard construction, designed for use in connection with high tension operation, by means of a rectifying or transforming switch. The alternating electromotive force developed by the secondary winding 14 is sufficient when impressed upon the cylinder 21 and mirror 24 to cause a brush discharge or non-arcing current flow from the cylinder to the mirror as indicated. This high tension electromotive force is not sufficient, however, to cause a current flow of any description from the mirror to the cylinder, as a result of which, the current flowing through the tube is uni-directional and pulsating, the effect being to utilize the entire energy represented by all of the high tension electromotive force waves of one sign with the greatest efficiency and at the same time the effect upon

the alternating high tension waves of opposite sign is substantially the same as though at the particular instance of the occurrence of these waves of opposite sign the secondary circuit of the transformer 2 were open. Our experiments have shown, conclusively, that with the same high tension alternating electromotive force developed by the secondary winding 14, when this electromotive force is sufficient to produce a brush discharge from the cylinder 21 to the mirror 24, for the particular size and vacuum of the tube employed, that it is immaterial which terminals of the tube are connected to the conductors 16 and 17. In other words, as long as the high tension alternating electromotive force is of a sufficient value to produce the brush discharge referred to and insufficient to produce a disruptive arcing effect within the tube, all of the high tension electromotive force waves of the sign tending to send the current from the cylinder 21 to the mirror 24 are effective in producing the brush discharge referred to, while all of the high tension electromotive force waves of the opposite sign are suppressed, and this occurs irrespective of what the particular sign, that is whether positive or negative, of the effective and non-effective electromotive force waves may be. Furthermore, by using a polarized mill-ammeter in the secondary circuit, a reversal of the tube 15 in the secondary circuit was shown to reverse the direction of current flowing in the secondary circuit, and that for either connection of the tube the amount of current flow was substantially the same and always uni-directional.

Our experiments further show that there is a considerable range between what may be called the critical values for any particular X-ray tube. For example, an X-ray high tension tube designed for use with a rectifying switch on voltages from 125,000 upward, may have a critical break-down value for the brush discharge from the cylinder 21 to the mirror 24 of about 80,000 and at about 105,000, to 110,000 volts, a second critical value is reached beyond which the voltage will produce a disruptive arcing discharge which not only produces a comparatively white light in the tube which is totally unsuited for the production of X-rays, but in addition rapidly disintegrates the target 22 and terminates the usefulness of the tube. By operating the tubes with our system, however, the target and mirror show no appreciable wear, even after extensive use, since at no time is the current flowing through the tube of the disruptive or arcing variety.

Having established the uni-directional current flow through the tube as above described the cathode rays are reflected, of course, from the mirror or cathode 24

against the target 22 and X-rays are generated upon the surface of the target and projected from the tube, as indicated by the arrows producing practically a complete hemisphere of illumination in the tube.

In carrying out our invention we find it desirable to use a transformer having a closed magnetic path, as indicated in Fig. 4, although it will be understood that while other forms of transformers are not of as high an efficiency of operation as this type, still they may be employed providing they are designed to deliver the proper value of high tension electromotive force. The transformer shown in Fig. 4 consists in a plurality of hollow continuous rectangular punchings or stampings 26 assembled together, and having wound around one side thereof a primary winding 1, which of course, is properly insulated from the core. The secondary winding consists preferably of a plurality of sections 14^a, 14^b and 14^c, each wound upon its own insulating spool or bobbin 27^a, 27^b and 27^c, these bobbins being of sufficiently large diameter to place the high tension secondary windings sufficiently remote from all metal parts of the transformer, so that no short circuiting of the secondary windings results. The openings in the rectangular stampings are preferably of such a size that the circular spools or bobbins pass substantially through the center of the openings, with sufficient space around them so that there is no danger of arcing from the winding of one section of the secondary coil to another section, or to the core. The stampings are preferably cut at one point, as indicated at 28, so that they may be inserted through the primary and secondary windings to facilitate assembling the transformer. These cuts are, of course, alternated as indicated in the stampings, or staggered in any desired manner so as to make the magnetic path of as low reluctance as possible. The transformer thus constructed is preferably immersed in a bath of oil, having a high insulating value.

In carrying out our invention we find it desirable to employ a controlling rheostat R in the primary circuit of the transformer 2, so that the electromotive force developed in the secondary winding of the transformer may readily be adjusted to the proper value between the two critical values referred to above for the particular X-ray tube being operated so that the uni-directional current flow above described may be secured through the secondary circuit of the transformer without the production of a disruptive discharge in the tube. It will also be understood that our invention is equally applicable to X-ray tubes in which an auxiliary anode 20^a is employed, although in using such tubes we find it preferable to make no circuit connection to said auxiliary anode.

It will be understood that our system works equally well whether the tube 15 is provided with the auxiliary anode 20^a or not.

While we have shown our invention in the embodiment herein shown and described, it will be understood that we do not limit ourselves to the particular arrangement or mechanisms shown and described, as we may employ any devices that will produce a high tension alternating electromotive force of proper value to be impressed upon the terminals of an X-ray tube to produce a resulting uni-directional current flow there-through without the use of extraneous devices for rectifying or modifying the alternating current. Each tube employed, of course, has its own critical values of operation determined by the construction of the tube, that is by its size, the distance apart of the cylinder and mirror and the degree of vacuum in the tube, and any means employed to deliver to such a tube an alternating electromotive force of a voltage between the critical values of said tube will realize our invention.

What we claim is:

1. A system for operating X-ray tubes, comprising the combination of a transformer having primary and secondary windings, an X-ray tube having its terminals connected directly with the terminals of the secondary winding of said transformer, and means for controlling the operation of the transformer to produce an electromotive force in the secondary winding thereof of symmetrical wave form greater than that required to cause current to flow from the anode to the cathode of said tube, and less than that required to cause current to flow from the cathode to the anode of said tube.
2. In a system for operating X-ray tubes, the combination of a transformer having primary and secondary windings, a source of alternating current connected with the primary winding, an X-ray tube directly connected with the secondary winding, and means for producing in said secondary winding a potential of symmetrical wave form sufficient only to cause a uni-directional current flow through said tube.
3. In a system for operating X-ray tubes, the combination of an X-ray tube, a closed high tension circuit directly connected with the terminals of said tube, and means for producing in said circuit an alternating electromotive force of symmetrical wave form sufficient only in amount to produce a uni-directional current flow through said tube.
4. In a system for operating X-ray tubes, the combination of a high tension X-ray tube having no valve, a closed circuit directly connected with the terminals of said tube, and means for producing an alternating electromotive force of symmetrical wave

form in said circuit, intermediate in value between the critical break-down values for the gap between the electrodes of said tube.

5. In a system for operating X-ray tubes, the combination of a transformer having a closed magnetic circuit provided with primary and secondary windings, an X-ray tube having its terminals connected directly with the terminals of said secondary winding, and means for controlling the operation of said transformer to produce an alternating electromotive force of symmetrical wave form in said secondary winding sufficient only to produce current flow in said tube from the anode to the cathode of said tube.

6. In a system for operating X-ray tubes, the combination of a valveless tube, a circuit directly connecting a source of alternating current with the terminals of said tube, means for producing in said circuit an alternating electromotive force of symmetrical wave form sufficient only to produce a unidirectional current flow through said tube.

7. In a system for operating X-ray tubes, the combination of a transformer having primary and secondary windings, a source of alternating current connected in circuit with said primary winding, current controlling devices in said primary circuit, and an X-ray tube directly connected with the secondary winding of said transformer, the amount of current flow through said primary circuit being proportioned to produce an electromotive force of symmetrical wave form in said secondary circuit sufficient only to produce a uni-directional current flow through said tube.

8. The method of operating X-ray tubes which consists in subjecting the terminals of a valveless tube to an alternating electromotive force of symmetrical wave form sufficient to produce current flow through the tube and insufficient to produce a disruptive current flow through said tube.

9. The method of operating X-ray tubes which consists in subjecting the terminals of a valveless tube to an alternating electromotive force of symmetrical wave form of a value between the critical breakdown values for the gap between the electrodes of said tube.

10. In a system of X-ray tube operation, the combination of a source of alternating current of symmetrical wave form, a transformer having primary and secondary windings, an X-ray tube, connections between the source and said primary winding, and con-

nections between said secondary winding and the X-ray tube, whereby symmetrical current waves are delivered to said transformer and tube, the current waves of the secondary circuit being of a potential to produce current flow through said tube without disruptive discharge.

11. In a system of X-ray tube operation, the combination of a source of alternating current of symmetrical wave form, a transformer having primary and secondary windings, an X-ray tube, and connections delivering symmetrical current waves to said primary winding and connections delivering symmetrical current waves from said secondary winding to said tube at a potential sufficient only to produce unidirectional current flow through said tube.

12. In a system of X-ray tube operation, the combination of a source of alternating current of substantially sine wave form, a transformer having primary and secondary windings, an X-ray tube, and connections between said source and said transformer and between said transformer and said tube for delivering to said transformer and said tube current waves of substantially sine form of a voltage sufficient to produce current flow and insufficient to produce disruptive discharge through said tube.

13. In a system of X-ray tube operation, the combination of a source of alternating current of substantially sine wave form, a transformer having primary and secondary windings, a valveless X-ray tube, and connections between said source and said transformer and between said transformer and said tube for delivering to said transformer and said tube current waves of substantially sine form of a voltage sufficient to produce current flow and insufficient to produce disruptive discharge through said tube.

14. The method of operating X-ray tubes which consists in impressing upon the terminals of the tube a symmetrical alternating electromotive force sufficient to produce current flow between the anode and cathode of the tube and of too low a value to produce an alternating discharge between the electrodes of the tube.

In witness whereof, we hereunto subscribe our names this 11th day of April, A. D. 1914.

GEORGE R. HOGAN.
HECTOR P. MacLAGAN.

Witnesses:

ALBERT C. BELL,
IRENE FORREST.