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A Brief Discussion of Roentgen-Ray Equipment

BY O. W. BARD, '25

IDID not think, I investigated." Let this well-known quotation suffice to introduce the subject of this brief discussion. These words of Roentgen are more familiar to most people than the development of that great discovery which revolutionized the medical world and gave new powers to the physicist, the mineralogist, the botanist, and even to custom officials. If your first introduction to an X-ray machine was to painfully stretch a broken arm or leg across a film holder while a large vacuum tube glowed brightly for a few seconds, you probably did more thinking than investigating. The value of X-rays for diagnostic work was so quickly recognized by the medical profession that you will now find Roentgen equipment of some type in the offices of many physicians of general practice, as well as in the laboratory of the Roentgenologist and in every hospital.

Although the researches which eventually led to the discovery of X-rays began early in the nineteenth century, it was not until 1892 that Hertz inserted a piece of uranium glass, covered on one side with gold leaf and mica, into a Crookes tube and noted the phosphorescence which foreshadowed the discovery by Roentgen. Roentgen found that when cathode rays fell upon any solid substance that they gave rise to some phenomenon which caused certain chemicals, such as platinum-barium cyanide, to fluoresce even though the source of the rays were hidden from the chemical by a screen of heavy paper or wood. He showed that these vibrations or waves were in some respects similar to light, that they moved in straight lines, with the speed of light and tremendous penetrating power. Although not visible to the eye they affected photographic plates and ionized gases. They were not cathode rays but seemed to originate at the spot where the cathode rays struck. He called them X-rays, although they are now properly known as Roentgen rays.

The tubes used in early experiments were pear-shaped bulbs into which two platinum electrodes were fused by means of platinum connections. A small aluminum plate was mounted on the cathode so that the cathode stream was emitted at right angles to its surface and was focused upon a metallic plate at the other end of the bulb. This second plate was attached to the second elec-

trode so that it formed the positive pole of the tube. It was soon found that this plate or target must have a very high melting point because of the concentration of the cathode stream and the tremendous heat thus generated. It should also have a high thermal conductivity and a low vapor pressure. Experiments also showed that the ratio of X-rays produced to the cathode rays varied as the atomic weight of the target. This led to the use of tungsten targets, since this metal combined high atomic weight with a fairly high melting point.

Gas tubes in which a high though not complete vacuum exists are still used to some extent and are preferred by some physicians for radiographic work. The reliability and constancy of the gas tube may be compared with the modern Coolidge tube in about the same way as gas is compared to electricity for lighting purposes. Since these tubes may work beautifully one day and not at all the next, they have been replaced to a great extent by the Coolidge or electron tube. In this tube the vacuum is practically complete or more than 1,000 times greater than in a gas tube. The tube thus offers an infinite resistance to the passage of current; however, it is rendered conductive by the vaporization of electrons from a small spiral of tungsten wire which can be heated by an independent source of current at low potential. This filament is surrounded by a small molybdenum cylinder which focuses the cathode stream on the target. The size of this focal spot determines the quality of the tube and to a large extent the penetration of the rays. The anode is of wrought tungsten which is supported from the extreme end of the tube by a molybdenum rod and glass reinforcement. Several sizes of Coolidge tubes are made, the smaller tubes which are used only for radiographic work are approximately 18 inches long and 3 3/4 inches diameter at the bulb. The tubes which operate continuously at 200,000 volts must be much larger and are approximately 32 inches long and 10 inches in diameter at the bulb.

The tube is the heart of the X-ray equipment, yet it gives less trouble than the actual machine for generating the high tension current and there are many records of tubes that have been run continuously for a thousand hours and upwards.

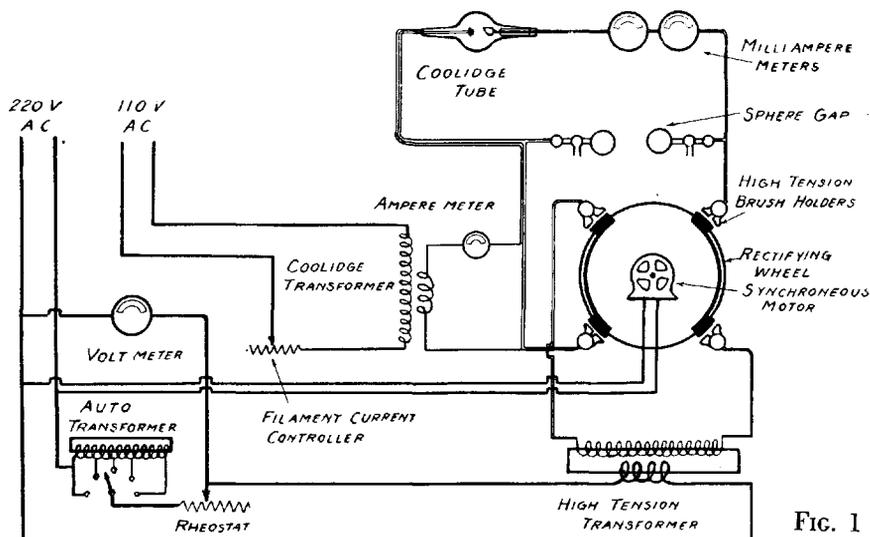


FIG. 1

The means of exciting X-ray bulbs have gone through three distinct stages of development. They are as follows:

1. Influence machines.
2. Induction coils.
3. Step up transformers.

Influence machines of the Winshurst type were used for some time before electric wiring brought current to the door of practically every physician's office. The unidirectional current from these machines gave a very beautiful discharge and it was possible to attain 15 to 20 milliamperes at almost any desired potential. Under certain atmospheric conditions these machines were very unreliable and insulation difficulties could not be met. They were also very noisy and great collectors of dust and small particles in the air which rendered them inefficient and caused excessive wear on the glass plates.

Induction coils gradually replaced the above mentioned machines and storage batteries were used to supply current. Since X-ray tubes must be energized by voltages ranging from 25,000 to 200,000 volts and with currents of 1 to 200 milliamperes, the ratio of transformation of these coils was very high. This incurred many electro-magnetic difficulties. The importance of breaking the primary current regularly, sharply, rapidly, and completely developed several types of interrupters. The mechanical or hammer type with which every one is familiar was very common but not as efficient as the mercury type. Several forms of mercury interrupters were used but all acted upon the principle of plunging an electrode through a non-conductor, such as oil or coal gas, into a pot of mercury. This insured a positive contact and because of the high dielectric properties of the oil made a very sharp and complete break.

Induction coils were extensively used for a long time; however, the modern X-ray unit utilizes whatever current is available by means of the high tension transformer and rectifying device and if the source is D. C. a rotary converter is added. The essential parts of a modern X-ray machine (Fig. 1) operating on alternating current are as follows:

- A. High tension transformer, oil immersed type.
- B. Primary current controls:
 1. Switchboard.
 2. Auto transformer or booster.
 3. Rheostat.
 4. Meters.
- C. Rectifying service:
 1. Synchronous motor.
 2. Bakelite disc or rectifying arms.
 3. High tension brush holders and contacts.
- D. Coolidge equipment:
 1. Coolidge transformer or storage batteries.
 2. Filament current controller.
 3. Meters.
- E. Sphere gap.

Great strides are being made in high tension transformer construction for X-ray work at the present time, as well as in methods of rectification of the high tension alternating current and improvements in high voltage tubes. The electrical efficiency of the transformers is much higher than in induction coils; however, since the cost of power is such a small item in comparison to the other costs in an X-ray laboratory less attention is given to the efficiency and more to reliability and fool proof factors. Early transformers of the closed core type were mounted in well-made cabinets and packed with an insulating wax. These were not satisfactory due to breakdowns of insulation when the wax cracked or to leaking and running out of the wax when the core became hot. Today all high tension transformers for this

use are oil immersed and vary in ratio of transformation from 500 to 1 up to 1,000 to 1. Great care must be used in having all parts of the transformer free from moisture before it is put in the heavy metal tank, since .01 of one per cent of water seriously impairs the dielectric properties of the oil.

The actual output in watts of an X-ray transformer is small, so that extensive cooling systems are unnecessary. The dimensions of transformers that will deliver 10 milliamperes at 200,000 volts vary considerably with the makes of different companies. One of the smallest and most efficient types is made by an American company and requires a tank approximately 26 inches square and sixteen inches deep. This of course does not allow clearance for the high tension secondary posts which extend for some distance above the top of the transformer.

Radiator type tubes which carry the heat from the anode very rapidly may be used with unrectified current; however, with tubes for continuous use and large outputs a unidirectional current is necessary. This is accomplished by various devices, the principle of which is illustrated by the rectifying wheel in Fig. 2. A synchronous motor is attached direct to a bakelite or phenol plastic disc to which are fastened four aluminum contact strips. These are joined together in pairs by a very light aluminum band around the periphery of the disc. When the motor has attained full speed it automatically goes into synchronism and by closing the X-ray switch current flows from the transformer toward "D" through the contact brushes and aluminum contacts "d-a" and out at "A", through the external circuit returning to the transformer through "C-c-b-B." As the wave reverses and current flows from the transformer toward brush holder "B" the disc has turned one-fourth revolution clockwise so that contact "a" coincides with "B" and current flows through "B-a-d-A," the external circuit, and back through "C-b-c-D" to the transformer. With 60 cycle current the disc must therefore make 1,800 r. p. m., since one electrical cycle is completed during each one-half revolution. The actual contact between the brushes and contact strips on the wheel covers but a small part of 180 electrical degrees as the base of the wave is not desirable for generating X-rays. Contact is therefore made only at the peak of the wave so that the current which flows through the tube is unidirectional and pulsating. Great care must be used in balancing the rectifying wheels as the diameter of the disc necessary on a machine delivering 200,000

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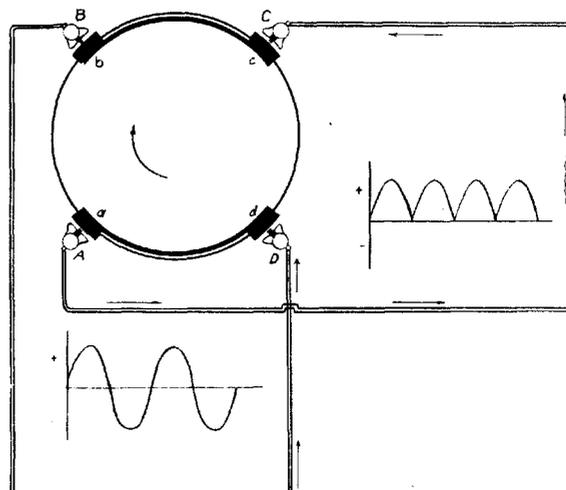


FIG. 2

A BRIEF DISCUSSION OF ROENTGEN-RAY EQUIPMENT

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the machine is running. Many other schemes of rectifying devices using metallic arms and banana-shaped brush holders have been devised to take care of the higher voltages and to provide better wave form, but the principle of rectification is the same as described above.

Since the amount of current that may be sent through the tube and the penetrating power of the rays is dependent upon the number of electrons that are liberated from the filament and the voltage of the energizing current as well as the type of tube, it is essential that these factors be controlled very accurately. Regulation of the high tension voltage is accomplished by varying the primary voltage by means of a single winding transformer from which a number of taps are taken or by a wire rheostat, or both. The taps are usually arranged so that adjustments of five kilowatts in the secondary can be made over the desired range. The voltmeter which is placed in the primary circuit may be calibrated for secondary volts, although a more accurate method of measuring the high tension potential is also provided by the sphere gap.

The current for heating the Coolidge tube filament may be either direct or alternating and capable of delivering approximately 6 amperes at 12 volts. If alternating current is available, a small step-down transformer is very satisfactory. This entire circuit is brought to the full potential of the tube so it is necessary that it be thoroughly insulated. Various methods of controlling this current are used, the most common of which are wire rheostats. Controls of the magnetic type have been recently introduced and it is claimed that much closer adjustment can be made without the effects of heating which introduce several variables in wire rheostats. An ampere meter is also used in this circuit for convenience of technique although the milliamperemeters in the high tension circuit are of greater importance, as they indicate the actual current that passes through the tube. The milliamperemeters should have a double scale of 0-10 and 0-100, as most treatment work is done below 5 milliamperes, while it is sometimes necessary to use 100 milliamperes to secure a good radiograph.

In our discussion thus far we have said nothing about the accessories which accompany the modern installation of X-ray equipment for medical purposes. However, the actual machine for producing the high tension pulsating current and the tubes in which the X-rays originate are a very small part of the Roentgenologist's laboratory.

In the larger installations the machine is placed in a room by itself and even the tube and high tension conduit may be concealed, thus removing much of the noise and unpleasant odors about the machine as well as the natural fear of high voltages from the room in which the usually none-too-well patient has to spend several hours in more or less discomfort.

As we stated before, X-rays have come into a very wide range of usefulness. They reveal hidden structures and defects to the mineralogist and botanist. They are used by custom officials in locating precious stones which are smuggled through their hands by all manner of means. They reveal internal flaws in aeroplane propellers and in sheets of insulation material that could not be found otherwise.

The physicist has found the X-ray of great value in his investigation of the electron and in his search for new elements. It is to physicists such as Hertz, Lenard, Roentgen, and J. J. Thompson that much of the credit for our present knowledge of X-rays must be given. Dr. W. D. Coolidge has probably given the greatest

American contribution in the form of the Coolidge tube, while such men as W. G. Hettich and C. B. Turner of the Standard X-ray Co., J. J. Grobe of the Acme International X-ray Co., and Dr. Roy Kegerrais (Ohio State '11) of the Mayo Clinic, are responsible for many recent improvements in mechanical and electrical design.

It was, however, only through the untold sacrifice and suffering of many pioneer Roentgenologists who gave their lives by exposure to the rays, which are almost as injurious to living, healthy cells as they are deadly to microscopic germs, that methods of controlling and directing Roentgen rays for diagnostic purposes and therapy have been learned. Thus while the physicist and engineer have carried out an important part of the work of development, too much credit cannot be given the medical profession, for after all the greatest value of these unseen rays is in their power to rebuild and heal man.