THE RADIATOR TYPE OF TUBE

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THE radiator type of tube has already been described.[1] Up to the present time, its use has been confined exclusively to the army and in this service it has been used as a self-rectifying tube in the Portable and Bedside outfits. Owing to the fact that the tube has recently become generally available for use on existing standard generating outfits, the following amplification of what has been published will perhaps be useful.

The leading motive in the development of this type was originally to get, in the form of a small simple and rugged structure, a tube which would operate satisfactorily when alternating current was supplied to its terminals. As will be seen from the following, however, the use of the tube should not be limited to such service,[2] for it will do better diagnostic work on any generating outfit than will the earlier form of hot-cathode tube with the solid tungsten target.

FIELD OF USEFULNESS OF THE RADIATOR TUBE

This type of tube makes possible the use of a simple transformer[3] as a current generating outfit (for direct current circuits a converter must be added). It has been found that a little transformer of suitable design and weighing but slightly over 50 pounds is adequate for supplying a current of 50 milliamperes at a useful gap of 5″ to a self-rectifying tube. This, of course, means that a very small and relatively inexpensive outfit of this type can be made to do even very rapid diagnostic work. The freedom from mechanical and electrical complications and from noise and the diminution in the odors attendant upon high tension discharges in air seem very much in favor of this system.

The tube operates satisfactorily on the transformer, the interrupterless outfit, and the induction coil, and is hence generally applicable to diagnostic work. With the induction coil it renders a valve tube unnecessary. With the interrupterless machine, it offers the advantage that it is not injured by a faulty setting of the mechanical rectifier. With every current source it permits of the intermittent use of more energy than could in practice safely be carried by a tube with a solid tungsten target and the same size of focal spot.

It is not, in its present form, adapted to therapeutic work, for, with continuous operation, it will carry less than one-fourth as much energy as the 7-inch hot-cathode tube with solid tungsten target.

CURRENT-CARRYING CAPACITY OF THE RADIATOR TUBE

For a given voltage, the current-carrying capacity of the radiator type of tube is a very definite quantity. This is due to the fact that the target of the radiator tube cools so rapidly, between exposures, that every exposure is started with a relatively cold target. What can be done with the tube then, in radiographic work, depends but little on its past history.

This will perhaps be made clearer by the following consideration: The target, with its heat-storage capacity, is like a reservoir used for the storage of water. It is capable of absorbing and storing up an amount

[1] *Gen. Elec. Rev.*, 21, pp. 55–60 (1918).

[2] It is, perhaps, necessary to place additional emphasis on this point for the reason that one is instructed in the U. S. Army *X*-ray Manual not to use this tube on large installations or interrupterless machines. This was doubtless, under the circumstances existing at the time, a wise regulation. To apply this regulation to civil practice, however, would be equivalent to saying that no 10 ma. *x*-ray tube should be operated from a large machine.

[3] This word, transformer, is so generally incorrectly used by the roentgenologist that a definition will not be out of place. A transformer is a device for transforming an alternating current of one voltage to that of another. In its simplest form, it consists of two coils of wire placed around a common iron core. It is *not* an "Interrupterless Machine"—the latter consists essentially of a transformer, a synchronous motor, and a mechanical rectifying switch.

of heat energy, which is determined by the size of the target and by the amount of heat already in it, just as the reservoir is capable of taking up an amount of water determined by its size and by the amount of water already in it. The capacity of the target to take up heat is always the same provided it is always at the same temperature at the beginning of the exposure.

It is then a simple matter for the manufacturer to specify the capacity of tubes of the radiator type.[4]

In the particular service for which the radiator tube was first developed, the amount of electrical energy available at the tube terminals was strictly limited and corresponded to 10 ma. at a 5-inch useful gap. The focal spot in the first model was then made as small as could be conservatively used with this amount of energy (1/8-inch in diameter). In this connection, the writer wishes to lay emphasis on the word *conservatively*. He has seen one of these tubes which had been in almost constant radiographic service in a base hospital for a period of several months. It had been operated on an interrupterless machine with a load of 10 ma. at a 5-inch gap. Inspection showed that the focal-spot had never even been frosted and could not be identified without operating the tube. Under such circumstances and with such consistent use, there is, of course, a temptation on the part of the operator to increase the load and to exceed the current specified by the manufacturer. The writer, however, cannot see a justification for doing this. If, without serious damage, a current of say 30 milliamperes could occasionally be used with a tube marked 10 ma., it might seem worth while; but it can't be done. It will ruin the tube. With the tube, in the base hospital in question, the current could undoubtedly have been raised 50 per cent and this would have reduced the time of exposure to two-thirds of what it had been. The point which the writer wishes to make, however, is that the gain derived from attempting to operate a radiator tube, or any other roentgen ray tube of any kind, or a jack-knife, or any other device, at the breakdown point is out of all proportion to the cost.

Later in the war it was felt by some that there was need, in the army service, of a limited number of mobile outfits having a higher current capacity than the standard U. S. Army Portable outfit. For this reason, experimental work was undertaken on a larger size, 3 K.W., Delco-light set. It developed that, with certain minor changes, this set, when connected to the small *x*-ray transformer used in the standard Portable outfit, was capable of delivering 30 ma. at a 5-inch useful gap to a self-rectifying tube.

It was found that a radiator type of tube with a 3/16-inch focal spot behaved nicely with the 30 milliampere load. Except for the larger focal spot, this tube was identical with the 10 milliampere radiator tube.

There is every reason to think that, with a still larger focal spot, this same design of radiator tube will be found equally satisfactory for 100 milliamperes or more, and that it will still operate just as well on alternating as on rectified current.

The current-carrying capacity is the same for alternating as it is for rectified current, as the tube will safely rectify any current which does not damage the focal spot.

OPERATION ON TRANSFORMER (WITHOUT MECHANICAL OR OTHER RECTIFIER)

When used where it has to rectify its own current, the radiator type of tube shows its greatest superiority over the hot cathode tube with the solid tungsten target,[5] used under the same conditions.

[4] In the case of the earlier type of tube with the solid tungsten target, the specification of current-carrying capacity was always rather unsatisfactory for the reason that the cooling of the target in this tube, between exposures, was relatively very slow. Because of this latter fact, the target temperature, at the beginning of an exposure might be anything between room temperature and intense white heat. The amount of heat which the solid tungsten target was capable of storing up and, hence, the current-carrying capacity, was then a very variable quantity, depending on the temperature of the target at the beginning of the exposure.

[5] The latter should never be used to rectify its own current. The reasons will be obvious from the following data.

This is illustrated by the following experimental data:

30 Milliampere Radiator Tube, Operated from Transformer (without Rectifier)

With the target at room temperature, a current of 30 milliamperes at a 5-inch useful gap was applied continuously for 35 seconds. At the end of this time, there was a slight flash of green fluorescence in the tube and evidence of a slight high voltage surge on the line. The target was bright red. No harm had been done to the tube, but it would have been unsafe to continue without interruption.

With intermittent operation, it was found that a 6-second exposure with 30 milliamperes at a 5-inch useful gap could be repeated indefinitely with 40 second intervals between exposures.

With suitable intervals between, exposures with 30 ma. ranging in time from 0 to 35 seconds could then be made.

Medium Focus 7-Inch Tube with Solid Tungsten Target, Operated from Transformer (without Rectifier).

Starting with the target at room temperature, this tube was operated with 30 milliamperes at a 5-inch useful gap for 10 seconds. At the end of this time it showed green fluorescence at the cathode end, indicating that it was beginning to pass inverse current. The target was red hot. Experience has shown that had the operation of this tube been continued further without interruption, it would have been put permanently out of commission, either from cracking the bulb back of the cathode or from deterioration of vacuum.

After waiting 15 minutes for the target to cool, it was found that the tube would carry the 30 ma. load for 5½ seconds, at the end of which time, inverse again appeared. After a further wait of 21 minutes, it was possible to operate it for 7 seconds.

This tube then would have stood, from a cold start, a single 30 ma. exposure of 10 seconds, and repeated exposures of 6 seconds duration with intervals of about 20 minutes between.

Broad-Focus 7-Inch Tube with Solid Tungsten Target, Operated from Transformer (Without Rectifier).

Experiment showed that this tube could be run with 30 milliamperes at a 5-inch gap for 6-second exposures at intervals of 15 minutes.

Further Considerations

With the present design, the 7-inch tubes with solid tungsten target show considerable differences in the evenness of distribution of energy over the focal spot. The two 7-inch tubes tested were taken at random and for this reason they do not represent the worst conditions. Other tubes will be found which will behave even worse than these when operating on alternating current.

It is also a fact that commercial experience with this type of tube operators directly from a transformer (without a rectifying device) has resulted in the rapid destruction of tubes and has been thoroughly unsatisfactory.

The 30 milliampere radiator tube was designed to rectify its own current. It was, in the above mentioned experiments, always much further from the actual breakdown point than were the other tubes. A load much higher than that used would have been necessary to produce inverse with the radiator tube (the fluorescence referred to in the test was due to gas given off from the hot copper and was not a manifestation of inverse current), and, had inverse been produced, it would have been intercepted by the hemispherical cathode and so kept from hitting the glass.

The above tests can then be summarized as follows: Running directly from a transformer (without a mechanical rectifying switch), the 30 milliampere radiator tube was operated for single periods of 35 seconds duration. while the limiting time of operation with the medium focus solid tungsten target tube was 10 seconds.

Six-second periods of operation could be repeated indefinitely with 40-second intervals with the radiator tube, while intervals of 15 and 20 minutes were needed with the other two tubes. Furthermore, the radiator tube was not endangered by the above tests, while the others were being operated very close to the breakdown point.

Attention should be called to the fact that the above tests were forced tests. They are given merely to show the radically different behavior of the two types of tube when operating on alternating current. At the present time, there is certainly no occasion in diagnostic work to use 30 ma. at a 5-inch useful gap for a period of anything like 35 seconds or to make any considerable number of consecutive 6-second exposures with a time interval of only 40 seconds between them.

OPERATION ON INTERRUPTERLESS MACHINE

For satisfactory diagnostic work, it is imperative that a voltage control of the auto-transformer type rather than the resistance type be employed. The use of auto-transformer control will ensure constant voltage and will hence greatly facilitate the duplication of results.

The results obtained should be better than with the tube having a solid tungsten target; for in general, for a given amount of energy, a smaller focal spot can be used in the radiator tube.

The tube also offers this additional advantage, for use on the above outfit, that a faulty setting of the rectifying device, resulting perhaps in sufficient inverse to ruin the tube with the solid tungsten target, will not injure the radiator tube.

OPERATION ON INDUCTION COIL

The radiator tube is well adapted to induction coil use and renders a valve tube unnecessary. The cathode filament may be supplied with current from an insulated storage battery or from a small converter and special step-down transformer. For diagnostic work, however, the induction coil outfit, because of its complications, does not seem competitive with the simple transformer.

USE OF LOW MILLIAMPERAGE

Some enthusiastic users of a 10 ma. tube seem to feel that there is some mysterious advantage derived from the use of low milliamperage per se. In some cases they have gone so far as to take tubes adapted to operation with say 40 ma. and run them at 10 ma.

There is no harm in doing this; but it is easy to show by actual experiment that, provided the same voltage and the same exposure time, reckoned in milliampere seconds, are used, radiographs made with a 40 ma. tube at 10 ma. cannot be distinguished from those made at 40 ma.

It is true that, unless the operator is equipped with a time switch adapted to the measurement of short time intervals, he will time his exposures more accurately when using low milliamperage and longer intervals.

The main advantage, however, to be derived from the use of low milliamperage comes from the fact that it makes possible the use of a tube with a small focal spot. It is easy to demonstrate that, with satisfactory immobilization of the subject, and the same focal-spot-plate distance, the same voltage and the same exposure in milliampere-seconds, the definition is always better the smaller the focal spot.

SHIELD FOR THE RADIATOR TUBE

The main advantage of the split glass shield which has been developed for the radiator tube, consists in the fact that it completely surrounds the tube and is made of thick glass having a high lead content.

In case the focal spot happens to be exactly in the plane of separation of the two halves of this shield, there is seen to be a very thin beam of roentgen rays escaping through the joint. This leakage is so slight, however, that it would seem to be unimportant. It can, moreover, be completely stopped by seeing that the focal spot is not in the plane of separation. One of the advantages of the present design lies in the fact that it makes possible the condition that each half shield shall fit together with every other half shield to make a pair.

The method of supporting the tube in the shield has come in for deserved criticism. An experimental model has been made in which the outer ends of the glass are threaded to take hard-rubber screw caps. These caps force tapered split bushings of some resilient material, such as cork, in between the arms of the *x*-ray tube and the shield. This holds the tube securely in position in the shield and prevents rotation.

EFFECT OF THE RADIATOR TUBE ON THE DESIGN OF GENERATING APPARATUS

While it is early to make many predictions concerning the new generating apparatus which will be developed for operating this tube, the following statements seem to the writer to be conservative.

Much fluoroscopic work and much radiographic work will be done with a simple transformer outfit operated from a lamp socket. Such small outfits will be very simple and can be made almost fool-proof.

There is a splendid field of usefulness for a small light-weight hand-portable outfit operating on this system, to use in the home of the patient who cannot be moved to a roentgen ray laboratory. Preliminary experiments seem to indicate that a suitable small transformer weighing not more than 40 or 50 pounds can be made for this service.

In the field of dental radiography, it seems certain that the outfits of this type which have already been developed by different manufacturers will find a wide field of usefulness.

CONSTRUCTION OF THE TUBE

The forced large-scale production of the tube, incident to its war use and certain war-time conditions, brought about several radical changes in tube construction.

The fact that an insufficient number of skilled glass-blowers was available made it necessary to develop special machines with which most of the glass-working could be done by girl operators. Help was also obtained by getting from the glass works mold-blown parts, such as the cathode side-arm, and the anode- and cathode-support tubes, instead of making these by hand from glass tubing.

About twelve dollars worth of platinum was needed in every anode and at one time the radiator tube enjoyed the unenviable reputation of being the biggest war-time consumer of platinum that there was. Research work which had been carried on for several years finally resulted in the production of an entirely satisfactory substitute for platinum in this field, consisting of an alloy of iron and nickel covered with copper.

The early exhaust work called for one skilled operator for each tube on the pumps, to control the current supplied to the tube. Experimental work in this field, however, finally resulted in the development of a very simple exhaust system which automatically accomplishes what the best operator had done. The system consists of a small high-tension transformer connected to the tube terminals. In series with the primary of this transformer is a large ballast resistance, the function of which is to lower the amount of energy supplied to the tube as gas is liberated from the glass and the electrodes. The filament-current transformer is operated in parallel with the primary of the high-tension transformer and, as a result of this connection, and the presence of the ballast resistance, the filament temperature is automatically lowered whenever gas is liberated during the exhaust. The entire operation is carried out without adjustment of either the ballast resistance or the filament current control.