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Improving the control and self-rectification of gas X-ray tubes

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IMPROVING THE CONTROL AND SELF-RECTIFICATION OF GAS X-RAY TUBES. By WILLIAM BAND, M.Sc. (Liverpool),

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ABSTRACT. This paper describes a new X-ray tube anti-cathode designed to improve the stability and rectifying efficiency of gas tubes of the clamped electrode variety. Methods of increasing the control of such tubes are discussed. Tests on a tube actually made to this design show that steady currents up to 15 milliamperes can be used; and the rectifying efficiency is fairly constant under working conditions, between 60 per cent. and 70 per cent. for the ratio D.C./A.C.

Theory of Self-Rectification

The self-rectification of gas X-ray tubes is of course the same phenomenon as occurs in any rectifying cell, depending on the asymmetrical conductivity of the system. It is known that in a rarefied gas there is a greater potential drop in the neighbourhood of the cathode than near the anode, and that ions by collision are formed chiefly in this region of great potential drop. If therefore one electrode of a system is pointed so that it accentuates any potential gradient near it, and if it is surrounded by a large free space, there will be a large number of conducting ions formed in that space when the point is cathode. If at the same time the other electrode is flat in shape and enclosed in a relatively small space, there will be relatively very few conducting ions formed by collision when this electrode is the cathode.

A similar system was followed by the original Shearer tubes. It was departed from to some extent in the later developments where clamped electrodes have been used. The contingencies of mechanical construction apparently necessitated imperfect self-rectification. In the writer's experience the steadiness of the tube was less satisfactory on account of this; and the rectification disappeared if the pressure was reduced too far in order to allow a high voltage input.

This was particularly marked in the tube described by the writer in collaboration with Alan J. Maddock, M.Sc. (1), due presumably to the fact that the target projected within the main gas space for about $\frac{3}{4}$ in. The target formed a point electrode comparable in conducting efficiency with the aluminium rod intended for cathode; the sputtering of the latter was rather large with this tube. There is a similar defect in the design of Owen and Preston (2), the target projecting at an incline into the gas space and forming quite a sharp point electrode which must be a fairly efficient cathode during the inverse phase of the input A.C.

To run gas tubes on high voltages, or for that matter on lower voltages with accurate control, requires a steady and efficient rectification. An attempt was therefore made to design an anti-cathode end that would retain the high rectification efficiency of the Shearer type, and at the same time allow the electrodes, etc. to be clamped in position as for the later tubes.

We describe the design in the following section; a tube was actually constructed to this design in these workshops and tests carried out upon it with results as given in a subsequent part of this paper.

The New Anti-cathode Design

The essential feature of this design is that the target is inserted in a recess drilled out of the main piece of metal that forms the anti-cathode end; there is not the least portion of the target projecting into the gas space. The surface presented to the cathode is thus a hollow cone with a small cup cut out at the apex, within which is the target. The target is inserted through one slant face of the end-piece so that its focal spot comes very close to the small window-hole in the other slant face. The metal end-piece is of course cut from a solid rod and is thick enough for the target to be completely surrounded in its walls. Dimensional details can be found from the scale diagrams (Figs. 1 and 2).

While the angle of the internal cone is made 90° as usual, the angle between the two slant faces of the end-piece is about 80°. The reason for this is that there is then more space on the slant face for the system of clamping screws, etc., and also that it brings the target nearer to the window than would otherwise have been possible. If the angle between the slant

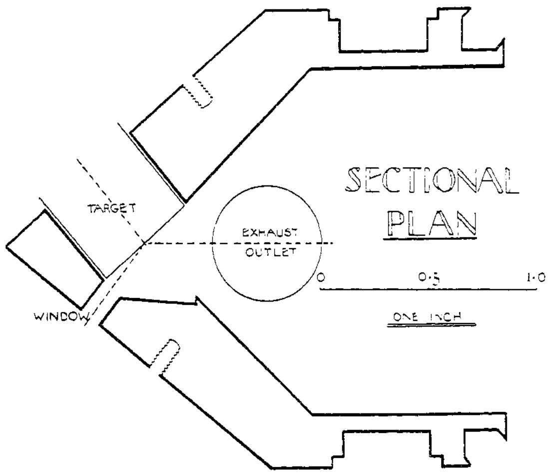

Fig. 1

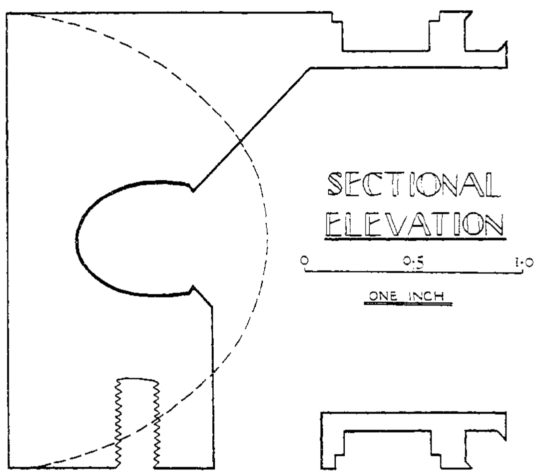

Fig. 2

faces had been 90°, the necessity for clamping space would have made the minimum distance between the edge of the target and the window-foil about 0·25 in.; at present it is only half this value. There is the further advantage that the targets can have their faces cut normal to their axes, and when placed in position in the tube, still present an angle of 10° to the emerging beam of X-rays. This is generally recognized as about the best angle from the point of view of compromise between the inconsistent conditions of maximum steadiness and maximum intensity. The cathode stream strikes the target with a glancing angle of 40°

instead of the 35° that would have been necessary with perpendicular slant faces and a slanted target face.

A ½ in. hole is drilled with axis parallel to the slant faces, and the exhaust tube soldered with ¼ in. projecting into the metal of the end-piece through this hole. A ¼ in. tapping is made 0·6 in. in front of the centre of this exhaust hole, for supporting purposes. The internal diameter of the end-piece is only 1½ in. and the outer diameter 2 in.; there is thus room for a circular water-cooling canal of about 0·15 in. depth round the end-piece just behind the exhaust tube and in front of the wax seal.

The porcelain tubes previously used were not available in Peking, so that the present tube was designed for use with Pyrex glass tubing and de Khotinsky cement. Obviously the design could easily be adapted for use with the more convenient porcelain insulators. It is worth remarking in passing, however, that the de Khotinsky cement gives a perfectly reliable joint much easier to make than the usual sealing-wax joint; if the pumping system available is not of high speed, the use of this cement may be preferable to rubber washers in spite of the latter's convenience.

In actually constructing the end-piece it was found unnecessary to mill the flat slant faces; they were filed by hand with considerable accuracy by a skilled mechanic. Then the holes were drilled for the target, window, and clamping screws, and the faces polished up on a cloth wheel. Finally, to produce a perfectly smooth surface for the rubber washers under the target flange and the window, the end-piece was nickel plated and again polished.

Perhaps the greatest constructional difficulty was in the drilling of the hole for the target in the slant face. The end-piece had to be clamped firmly on the stand of a vertical drill, and the levelling of the slant face adjusted as accurately as possible. It was found sufficiently accurate to do this by means of a small metal square to set the face perpendicular to the axis of the drill. The axis of the target hole is 0·5 in. from the apex of the slant faces, as also is that of the window. The diameter of the target is a snug fit into the ½ in. hole; its length depends upon the thickness of the rubber washers used, but in any case must just reach the edge of the 0·1 in. window hole—0·4 in. from the entrance of the target hole. The axis of the window hole then passes through the centre of the end of the target.

Performance of the New Tube

On first setting up the tube a rough estimate was obtained of the current giving maximum X-ray intensity for various voltages; this was done merely by observing a fluorescent screen placed in front of the window, so that for high voltages the estimate is very rough indeed. It serves, however, to show what currents the tube can be run on: and we give below the smoothed averages.

Kilovoltage	10	15	20	25	30	35
D.C. for maximum intensity	5	7	9	11	13	15 m.a.

This test was repeated after the tube had run for about 170 milliampere-hours, and no perceptible difference was observed.

Breakdown of rectification occurs only because of brush discharge between the cathode end and the anti-cathode end; the currents given above could be maintained quite steadily for any length of time, but for higher voltages the insulation was not sufficient and the brush discharge destroyed the steadiness. This, however, is not a defect of the anti-cathode design.

Measurements of actual rectification efficiency of this tube were made. A thermocouple A.C. meter and a D.C. meter in series with the tube gave the rectification efficiency as the ratio of D.C./A.C. The diagram (Fig. 3) gives three curves showing efficiency of rectification (in percentages) against the corresponding D.C. through the tube; the three curves correspond respectively with 7, 13 and 16 kilovolts applied to the tube.

The sudden drop in efficiency at low pressures, *i.e.* at small currents, is very marked; but for currents above about 3 milliamperes the efficiency is fairly constant. As the voltage is increased the efficiency becomes more independent of the pressure in the tube for the useful currents between 5 and 15 milliamperes, and it does not change very much as the potential changes.

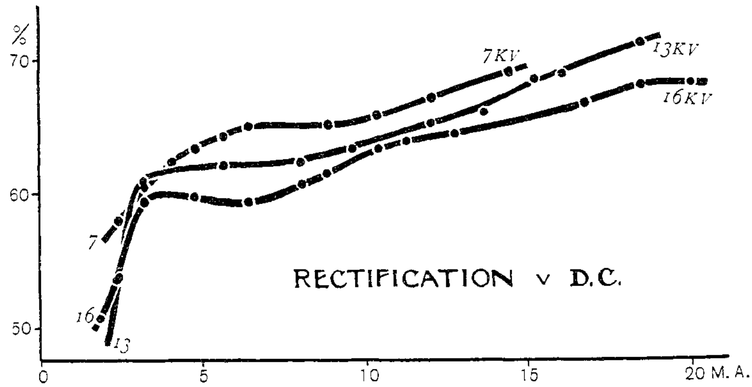

Fig. 3

Output Control

The output of a gas tube depends upon three factors: alternating voltage input, resistance of tube, and rectification efficiency of the tube. Complete control over the output theoretically requires separate and independent control of each of these three factors.

With an external resistance control of the input voltage—a variable resistance in series with the A.C. generator put directly across the tube—it is impossible to separate the input voltage from the resistance of the tube. A variation of the pressure of the gas in the tube will change all three factors simultaneously—a change of resistance of course producing a change in the voltage across the tube. With this type of control it is almost impossible to change the current through the tube without also changing the voltage; it is necessary to change both the external resistance and the pressure.

With a transformer control of input voltage, using a variable secondary winding to give the voltage to the tube, the input voltage is found to be almost constant for a given position of the transformer tapping; an increase in pressure gives an increased current without any change in the voltage. This method of control thus separates the voltage from the other two factors; but it is impossible to separate the resistance from the rectification efficiency.

However, the experimental measures of the rectification efficiency given above show that this does not change greatly as the pressure of the gas, and its conductivity, change, provided that the pressure is above a certain value. Thus, using a constant voltage and a direct current through the tube above about 3 milliamperes, any change in pressure of the gas changes only the resistance of the tube. The rectification efficiency does not enter into the question in practice, and is, in fact, very nearly constant.

I wish to express my indebtedness to Mr Ch'u Sheng Lin, B.S., for the reliable way in which he has carried out the actual tests of performance of this tube.

References

(1) Maddock. *Journ. Sci. Instr.* 6, 160 (1929).
(2) Owen and Preston. *Ibid.* 4, 273 (1927).