A METHOD OF TESTING AN X-RAY TUBE FOR DEFINITION.

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A radiograph of a body may be regarded as a representation of the shadows produced by those parts which are, to any degree, opaque to the X-rays. The depth of shadow formed by any particular portion is determined by the extent of its absorption of the rays. With an X-ray tube the source of the rays is in the neighbourhood of the "focal spot," from which the rays emanate in straight lines; each small area of the spot being the source of a particular stream of rays.

The sharpness of the shadows produced on the radiograph depends on the nature of the focal spot; for instance, if it were a point source, perfectly sharp shadows would be produced for all positions of the tube, body under examination, and photographic plate. Here, of course, the effects of secondary radiation have been left out of account. In practice the spot always occupies a certain area of the target and consequently the "lack of definition," that is, the departure from perfect sharpness of shadow, depends on the size of the spot and also on the distribution of intensities over its area.

Some work might require an X-ray tube with good definition, as, for example, in eye localisation; for other work, only a fair definition would be quite satisfactory. The life of the target is generally longer with larger spots, hence in this latter case a tube with good definition would be wasteful and unnecessary. For instance, in metal examination it would be little use selecting a tube with very fine focus, for the effects of secondary radiation would mask any extreme sharpness of shadow produced on the radiograph. Therefore, in choosing an X-ray tube it would be wise to take into consideration the definition of the tube, and for this purpose the following methods might be used.

Simple Methods of Determining Size of Focal Spot.

The size of the focal spot is a very good guide to the definition which a tube will give. Visual observation of the spot while the tube is running affords one means of determining its size. With gas tubes, however, this method, though possible, is rather troublesome on account of the indefinite boundary of some spots, and also the fluorescence on the walls of the tubes. With hot cathode tubes the method is almost impossible, as the white light from the cathode masks the illumination of the spot. A new Coolidge tube often has a pitted target and the size of the pitted area roughly indicates the size of the spot. However, some other method of determining the definition is necessary in the case of hot cathode tubes, and with gas tubes a simple method would be useful.

Dr. Coolidge used the pin-hole method of obtaining a radiograph of the spot, on which the size of the spot could be measured. The objections to this method are that if the spot is diffuse, it might be difficult to decide its measurements. Then again, in the spot, there might be one or more centres of radiation, the effect of which, on the definition of the tube, should be taken into account.

Rough Method by the use of a Wire Gauze.

An idea of the definition of a tube can be obtained by taking a radiograph of a wire gauze of fine mesh (about 45 per inch). As the definition obtained depends on the distance of the photographic plate from the tube, a fixed distance may be considered, say 50 cms. Suppose the gauze is placed at a distance of 15 cms. from the plate, and parallel to it, and that radiographs of the gauze are obtained with different tubes, each tube being centred in the usual way. The radiograph produced with one tube might fail to show the gauze, whereas it might be quite distinct with another tube. As a result we could say that the definition of the latter is much better than that of the former, although nothing could be decided as to whether the former would satisfy requirements. The disadvantages of using a gauze are twofold. Firstly, on account of the irregular spacing of the wires, at one part of the negative the gauze might be distinct whilst at another part there might be only a suggestion of it. Secondly, with an elliptical focal spot the wires in one direction might be distinct and those at right angles not. In some experiments carried out on these lines a reversal effect was occasionally produced on the negative. Instead of obtaining lines of little exposure representing the wires with heavily exposed interspaces, as one would expect, the opposite result was noticed.

Suggested Method by the use of Two Wires.

In view of these difficulties it was found more satisfactory to employ two uniform parallel wires, of a given thickness and placed a definite distance apart. Maintaining the distance between the tube and photographic plate at 50 cms., a series of radiographs of the wires was taken, gradually increasing the distance of the wires from the plate. The orientation of the wires was always in the direction at right angles to the line joining the centres of the cathode and target, and parallel to the photographic plate, both being vertically below the target of the tube. As the distance from the plate increased, the wires became less and less distinct on the radiograph until finally, at a critical position, they could not be distinguished. This critical position it will be seen from the following may be taken as a measure of the "definition of the tube."

Examination of the "Shadows" Produced.

(1) *Line Source with a single wire.*

In the case of a uniform source it can easily be shown how this critical position is realised.

Consider, first of all, a uniform line source of length "S," at right angles to a single wire (Fig. 1). The intensity curve along ABCD may be deduced as follows. Taking into account the rays to the left of the wire only, the intensity at A is a maximum, and from A to C falls steadily until at C its value is zero. Similarly, considering the rays to the right of the wire, we get a straight line curve representing the intensity, with the maximum value at D and the zero value at B. By superposing the two intensity curves, we arrive at the actual curve along ABCD.

Thus we see that the intensity falls steadily from A to B (Fig. 1b), from B to C the intensity is constant, and from C the intensity steadily increases to its maximum value at D. In the diagrams the component parts of the curve are shown in dotted lines and the resultant curve in thick lines. The intensity curve along $A^1B^1C^1$ is shown in Fig. 1a. In this position the intensity falls from the maximum at A^1 to zero at C^1, at which point we just touch the extremity of the umbra, and then rises to the maximum value at D^1. This latter position is a definite one, and, other conditions being fixed, such as the diameter of the wire and its distance from the source, depends on the length of the source. This method might be used to determine the size of the spot, but it would be difficult to realise on the negative when this position had been reached, for positions just above or just below this would present almost the same appearance.

With a slit instead of a single wire, the difficulties of determining a definite position would be even greater.

(2) *Line Source with two wires.*

Now consider the case of two equal and uniform parallel wires at right angles to the uniform line source. It will be seen from Fig. 2 that the intensity curve at any position is obtained by superposing the effects produced by the two single wires; Figs. 2a and 2b, 2c and 2d represent the intensity curves at positions marked a, b, c and d respectively in Fig. 2, and show the changes introduced by increasing the distance between the wires and the photographic plate. At the position " a," represented by Fig. 2a, a deep shadow of each wire is obtained, these being separated by a strip of maximum intensity. In position " b," Fig. 2b, there is a broader shadow of each wire, the separating strip now being less intense than in Fig. 2a. In this position the two wires would still be easily distinguished although less distinct than in Fig. 2a. Fig. 2c shows that in position " c," which is the critical position for a uniform line source the two wires can no longer be distinguished. From this position, knowing the other dimensions, the length of the source may be calculated from the formula $s = \frac{(w + d)\,T}{L}$

where S = length of source;

w = space between the two parallel wires;

d = diameter of each wire;

T = distance of source from plate at the critical position.

L = distance of wires from plate at the critical position.

Passing through the critical position " c," the intensity curve at position " d " shows that the shadow of each wire would here be separated by a strip of less intensity than the shadows, that is, on the negative the separating strip would be less exposed than the shadows. It will be noticed that as the distance between the wires and the plate increases, the depth of the shadows of the wires decreases. The change may easily be demonstrated by the use of two pins and a Nernst filament lamp, and if photographs were taken at the various stages, it would be quite easy to interpret the results on the negative. A graphical attempt to show the shadows is reproduced in Fig. 1 and Fig. 2, which again will help to indicate the intensities at the chosen positions.

RADIOGRAPHIC SHADOWS OF A SINGLE WIRE PRODUCED BY A LINE SOURCE OF X-RAYS.

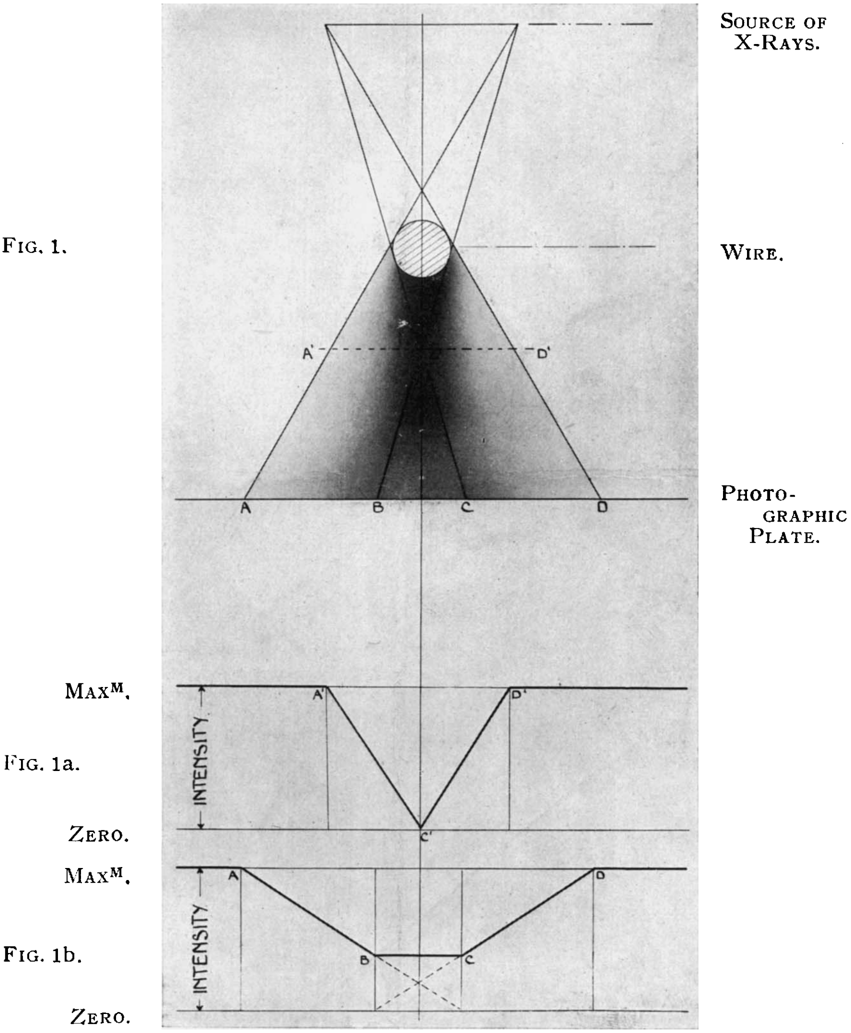


FIG. 1 SHOWS THE UMBRA AND PENUMBRA.
FIGS. 1a AND 1b SHOW THE INTENSITY OF ILLUMINATION ON A PHOTOGRAPHIC PLATE PLACED AT A^1D^1 AND AD IN FIG. 1.

Radiographic Shadows of Two Parallel Wires, Produced by a Line Source of X-Rays.

Source of X-Rays.

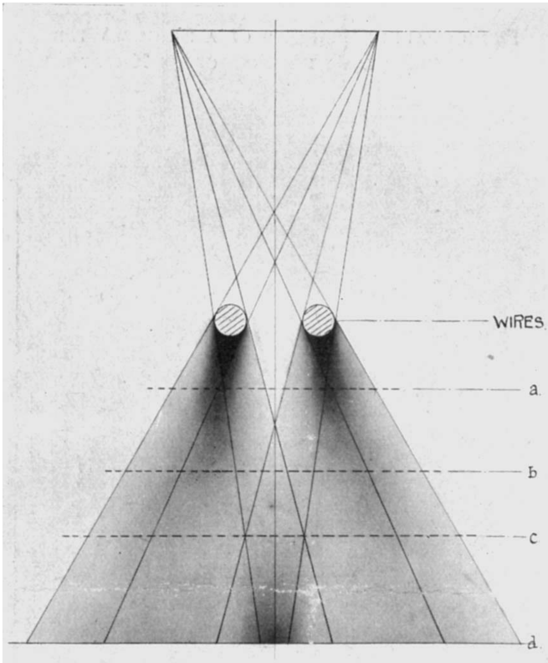


Photo-graphic Plate.

Fig. 2.

Intensity of Radiation of the Shadow with Circular Source of X Rays & Straight Edge interposed.

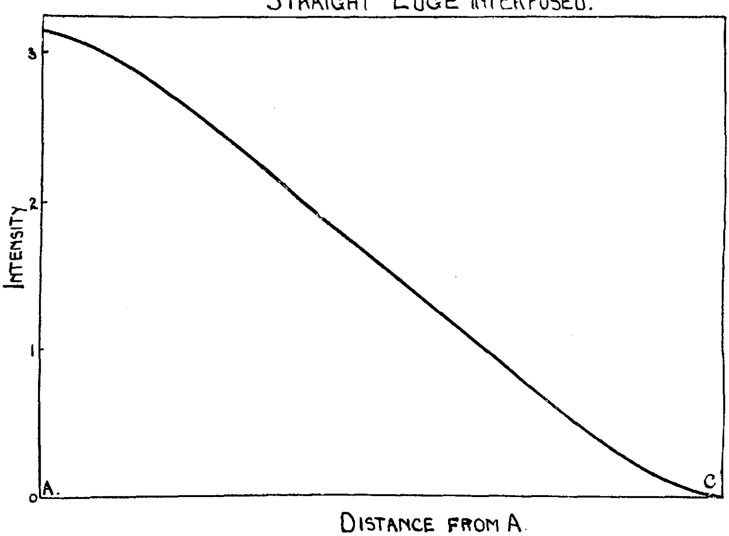
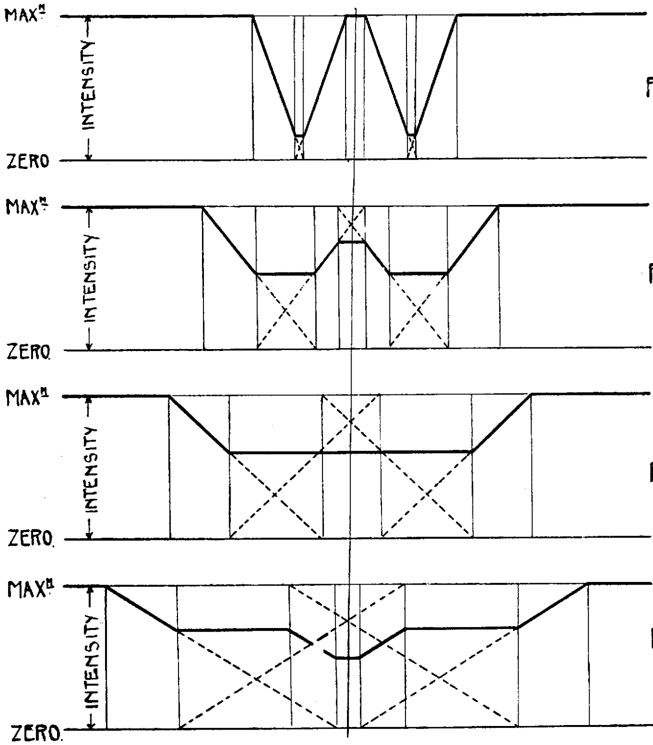


Fig. 3.

Radiographic Shadows of Two Parallel Wires produced by a Line Source of X Rays.



Figs. 2a, 2b, 2c, 2d show the Intensity of Illumination on a Photographic Plate placed at positions a, b, c, d in Fig. 2.

Radiographic Shadows of Wires.

Produced by a Circular Source of X Rays.

Single Wire

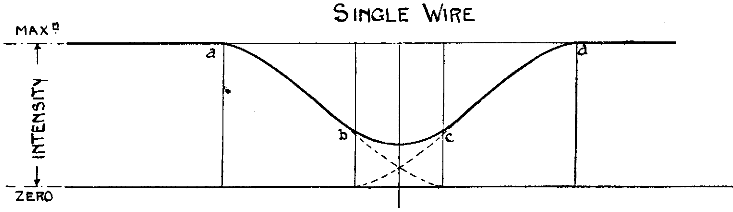


Fig. 4.

Two Parallel Wires.

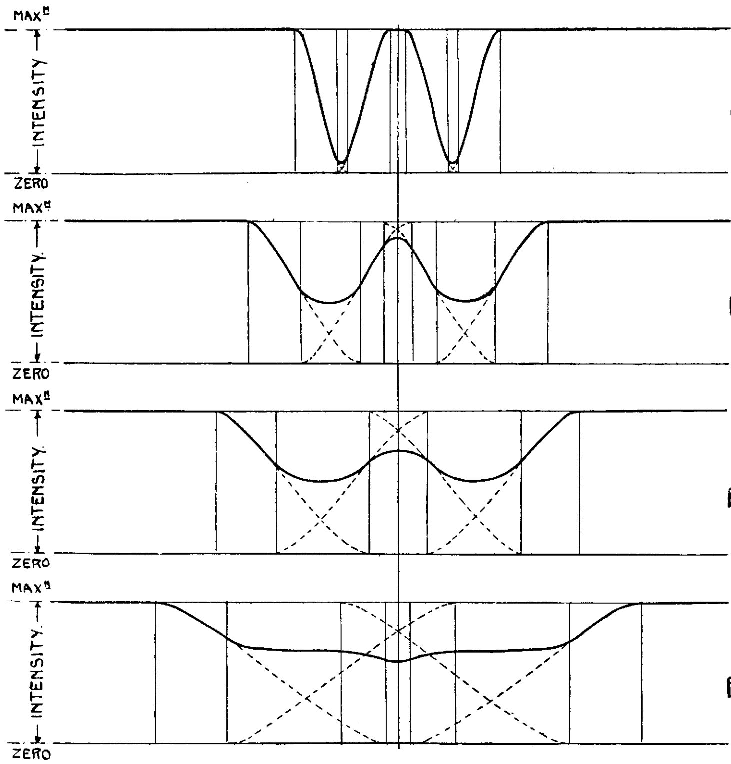


Fig. 5a.

Fig. 5b

Fig. 5c

Fig. 5d.

Figs. 5a, 5b, 5c, 5d correspond with positions a, b, c, d, in Fig. 2.

Although for simplicity a line source has been assumed, the same results would be obtained if the source were rectangular, *i.e.*, extended laterally parallel to the wires.

(3) *Circular Source with single wire.*

As a nearer approximation to the condition of the focal spot of an X-ray tube, let us now consider a circular source, over which the intensity of radiation is uniform. The shadow intensities obtained in the previous case may be modified to suit a circular source. Take the case of a single wire. Instead of the intensity from A to C (Fig. 1) falling steadily, the intensity curve now takes the form shown in Fig. 3. The intensities are calculated for a circle of unit radius. As a result the intensity curve along ABCD (Fig. 1) now has the form shown approximately in Fig. 4. It will be noticed that the points A, B, C, and D are not as sharply defined as in the case of a line source.

(4) *Circular Source with two wires.*

In the case of the two parallel wires, the same positions as in Fig. 2 have been chosen, and are represented in Fig. 5 (a, b, c, d). Similar results are obtained, but with slight modifications. For instance, in Fig. 5c, which corresponds to the critical position with a line source, the two wires would now be distinguishable, the shadows being separated by a strip of greater intensity than that of the shadows. In Fig. 5d, the two shadows would appear to be separated by a strip of less intensity than the shadows themselves. Here we have an explanation of the peculiar reversal effect that was obtained in some of the radiographs of the wire gauze mentioned previously, for in this case the wires must have been much further away from the plate than at the critical position.

It will be noticed that with a circular source the various stages are not as clearly defined as in the case of a line source, and that the critical position would be more difficult to decide upon. The position where the two wires fail to be distinguished would lie between the places represented by Fig. 5c and Fig. 5d. In practice it was found that this position can be obtained to within two or three centimetres in twenty, the distance of the tube from the plate being 50 cms. If the size of the spot were calculated from the formula given previously, the value obtained would be smaller than the actual or effective length of the spot in a direction at right angles to the wires. This method takes into account the effective length of the spot, and evades the difficulties met with in the other methods. Thus we can say that the position of the wires with respect to the tube and photographic plate at which they cannot be distinguished on the radiograph is a measure of the "definition" that the particular tube will give.

With X-rays diffraction difficulties are absent and the fact that the edges of the wires are more transparent to the rays than the thicker parts does not seem to be detrimental to the method.

Practical Application of the Method.

In using this method in the testing of tubes, the following procedure will be found useful. First, select a tube which gives the definition demanded by the particular type of work for which the tube is to be used. For the test the distance between the tube and the photographic plate might be fixed at 50 cms., the wires being .5 mm. thick and 1 mm. apart. The tubes should be run with a fixed energy input, say, at 5 milliamperes and 12 cms. hardness. Under these conditions find by trial the critical position for the wires with the selected tube. Put the wires at a slightly greater distance from the plate than that represented by the critical position, and take radiographs with the tubes under test, each tube being centred in the usual way. If the wires can be distinguished and the two shadows are separated by a strip of greater intensity than the shadows, the tube satisfies the requirements; if otherwise, the definition is not sufficiently good. Radiographs of the wires at one or two positions nearer the plate than the critical position would help in the decision. The radiographs require only a few seconds exposure, and each exposure need not occupy more than a few square centimetres of the negative. Moreover, the definition can be decided at a glance, although some tubes show the stages in a more marked degree than others, depending on the distribution of the intensity of radiation over the spot. It is generally sufficient to test the tube with the wires at right angles to the line joining the target and cathode, which position shows the definition at its worst, although the examination would be more complete if the tests were also carried out with the wires at right angles to this position. The definition in this latter position is much better than in the former.

Various methods of fixing the wires will suggest themselves. It is, of course, essential that the two wires are of uniform thickness and parallel, and that, after adjustment, there is no possibility of their relative position changing.

The method has already been put to practical use by Major C. E. S. Phillips, Officer-in-Charge, War Office X-Ray Laboratory, for the testing of tubes, and it is hoped will be found useful to purchasers of X-ray tubes, especially to those who handle them in large quantities.