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MEASUREMENT OF FOCAL SPOT SIZE OF DIAGNOSTIC X-RAY TUBES

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Dimensions of an x-ray tube focal spot were measured using pinhole camera, star test pattern and multiple bar pattern. The width of the examined focal spot was found to lie within the tolerance limits, but its length was twice larger than the stated one. Comparison of the applied methods has given no evidence for the tentative factor of 0.7 proposed by *ICRU* for correction of the focal spot length when measured with a pinhole camera. Dependence of the focal spot size on tube current and tube voltage was examined.

The focal spot of an x-ray tube is the area of the target (anode) which is bombarded by electrons from the cathode. The surface of the target forms and angle of several (~15) degrees with the direction in which x-rays emerge from the x-ray tube. As the focal spot is viewed from this direction it is foreshortened. The size of this effective, or apparent, focal spot is called *the focal spot size.*

The size and intensity distribution of x-ray tube focal spots are major influences on image resolution in diagnostic radiology. In many practical cases, such as acceptance tests of new tubes, a simple measurement of the image dimensions is sufficient to determine the focal spot size. There are two common methods for measurement of focal spot dimensions: (*a*) pinhole image and (*b*) line-pair resolution test pattern. The International Commission on Radiological Units and Measurements (*ICRU*) recommends the determination of the dimensions of focal spots by means of *x*-ray pinhole cameras[1]. The recommendation includes specification of the pinhole diameter, the geometry and the film to be used. The *ICRU* recommends the use of a pinhole with the diameter of 30 μm for imaging of focal spots with size below 1 mm. Such pinholes allow very little radiation to pass, and the investigator must often resort to multiple exposures and allow the tube to cool off between exposures. In the United States, the National Electrical Manufacturers Association (*NEMA*) has established a standard method for measuring the focal spot size[2] and has specified the amount that a focal spot can vary from its stated size (Table 1). The *NEMA* specifications call for focal spots of size 0.3 mm or smaller to be measured with a line-pair resolution test pattern (such as star pattern or multiple bar pattern), and those greater than 0.3 mm to be measured with a pinhole camera.

TABLE 1

Focal spot size (mm)	Tolerance Minus	Tolerance Plus
Less than 0.8	0%	50%
0.8 through 1.5	0%	40%
Greater than 1.5	0%	30%

Tolerance limits for focal spot size variation.

There are significant differences in interpreting the focal spot size as determined by these two methods. In this paper, both methods are compared by application to an *x*-ray tube which has capability of changing the focal spot size in two steps, named small and large focal spot. It has been stated that both apparent focal spots are square in shape. The small stated focal spot size is 0.6 mm, while the large one is 1.2 mm. It will be shown that the apparent focal spot is rectangular rather than square, and that the dimension in the anode-cathode direction is about twice larger than the stated one. This dimension is called *the focal spot length*, while the focal pot dimension perpendicular to the anode-cathode direction is named *the focal spot width*.

The *ICRU* has proposed a factor of 0.7 for correction of the focal spot length when measured with a pinhole camera[1]. The need for this fractional multiplier for correction of the measured image length arises from the fact that the lengthwise distribution of energy in the focal spots tends to be peaked in the center and diminishes gradually to zero at the ends. The *ICRU* has pointed out that this factor is a tentative one pending more detailed investigation. Such investigation is performed in this paper. Additionaly, the effect of the tube current and tube voltage on the focal spot size is considered quantitatively by using both the pinhole camera and the star test pattern.

A pinhole camera[3] manufactured in accordance with *ICRU* specifications[1] was used. The pinhole had a diameter of 30 μm. Both, the pinhole and the film were aligned along the central ray of the x-ray tube, perpendicularly to the beam (Fig. 1). The focus-pinhole distance, a, was approximately 30 cm, and the pinhole-film distance, b, was 90 cm.

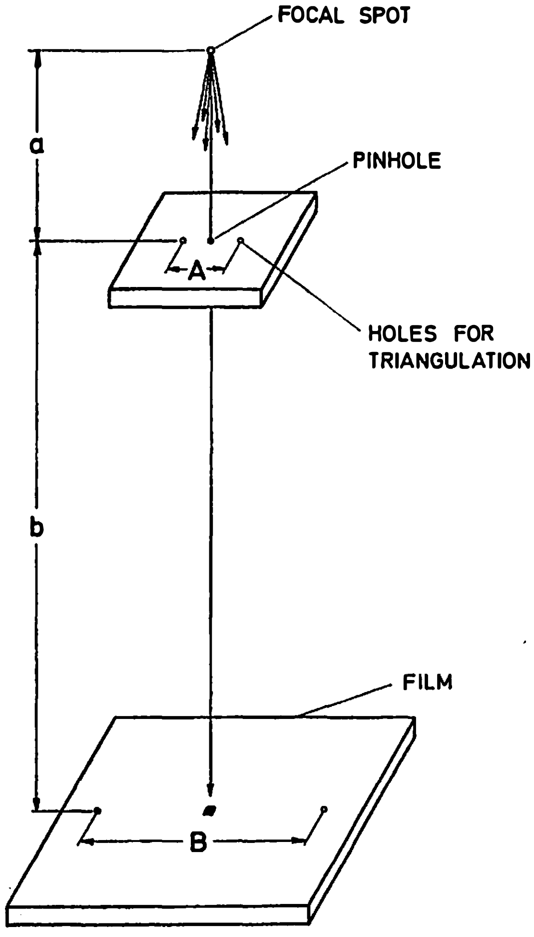

Figure 1. Pinhole camera setup.

The enlargement factor, E, of the focal spot is equal to the ratio b/a. It is an advantage to use high enlargement, because it is difficult to measure dimensions of small images. On the other hand, large focal spot images require relatively large x-ray exposures in order to produce acceptable photographic density. This means that the focal spot image must be small to avoid overloading the tube. In order to alleviate these difficulties, Arnold, Bjärngard and Klopping[4)] suggested the use of fast screen-film combinations and a high degree of magnification.

Since the distance a is not easily determined, two holes in the plate containing the pinhole were used to determine the magnification. By measuring the distance,

A, between the holes and the distance, B, between their images on the film, the enlargement factor can be calculated as

$$E = \frac{b}{a} = \frac{B}{A} - 1. \tag{1}$$

In this investigation the enlargement factor was found to be 3.2.

Films were developed by the standard developing technique. Image density was regulated by means of exposure time only. The image of the focal spot was examined using magnifying glass with build-in scale, 0.1 mm divisions, as recommended by *ICRU*[1]. Both the image length, in anode-cathode direction, and its width, perpendicular to anode-cathode direction, were measured, including all perceptable portions of the image. If f' is the length or width of the focal spot image including penumbra and d the diameter of the pinhole, the corresponding focal spot size, f, can be determined using

$$f = \frac{a}{b}(f' - d) - d. \tag{2}$$

The pinhole technique demonstrates also the intensity distribution of radiation from the focal spot, which is much greater along the edges of the focal spot than in the central area.

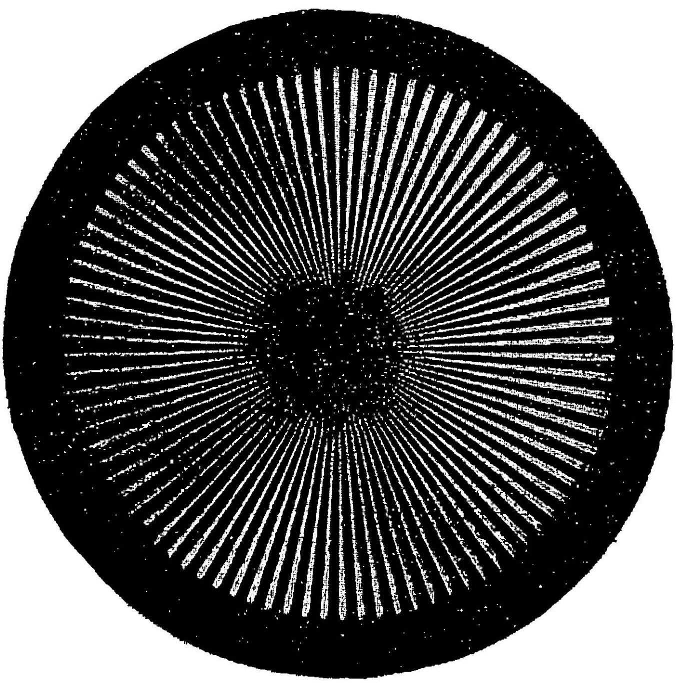

Figure 2. Photograph of a star resolution test pattern.

Because of the problems associated with the use of a small pinhole, *line-pair resolution test patterns* are now recommended for imaging focal spots of 0.3 mm or less. They are commonly manufactured in the form of a star pattern[5] or a multiple bar pattern[6]. *The star test pattern,* illustrated in Fig. 2, can be considered as a device which offers a continuous change in the line-spacing of radiographically opaque strips separated by transparent strips. This pattern consists of a circular sheet of lead 50 μm thick, with a diameter of 45 mm, divided into 180 spokes of which 90 are lead and 90 are blank. Each spoke subtends an angle of 2°. To measure the focal spot size, the star test pattern was positioned about midway between the focal spot and film, exactly parallel to the film, and in the central axis of the x-ray beam. A non-screen film was used.

For a given line-spacing, the geometric configuration for determining an x-ray tube focal spot size is shown in Fig. 3. Here the focal spot size is designated by f, and the line-spacing by h. The x-ray intensity pattern occuring in the image plane depends upon the ratio of the focal spot size to the line-spacing of the test object, the focal spot intensity distribution, and the magnification

$$M = \frac{a + b}{a}. \tag{3}$$

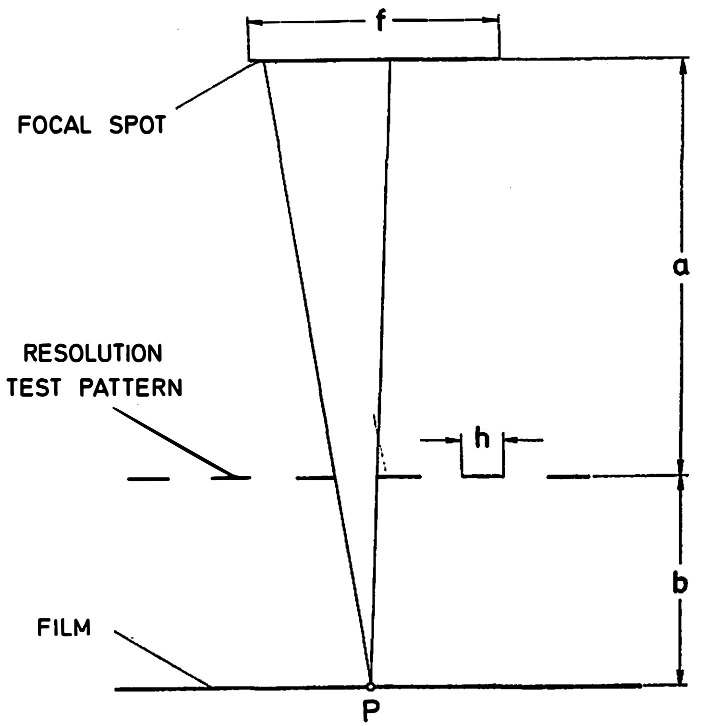

Figure 3. Schematic representation of the geometry employed in the measurement of the focal spot size using a line pair resolution test pattern.

The magnification was determined by comparison of the diameter of the test pattern with its image on the film.

If one assumes uniform intensity distribution of the focal spot, the blur zones (zero contrast) are predicted in the image when

$$\frac{2nh}{f} = \frac{b}{a+b} \tag{4}$$

where n is an integer. When (4) is satisfied, each point, P, in the film will »see« precisely one half of the focal spot. As one moves toward the center of the image, an area is encountered where the image of the prongs of the star gradually disappears. This is termed the area of failure of resolution, and the diameter, D, of the blurred image is measured both parallel and perpendicular to the anode-cathode axis of the tube. It must be noted that D is measured perpendicular to the desired dimension of the focal spot. One then calculates the focal spot size by the formula

$$f = nD\Theta \frac{a}{b} \tag{5}$$

where Θ is the angle in radians, of one of the lead spokes.

Measurement of the focal spot size with *a multiple bar pattern* is based on the same principle as the measurement with the star pattern. The difference is the bar pattern having parallel radiographically opaque and transparent strips. Since the line-spacing changes in discrete steps, only quantitized values for focal spot size can be obtained.

The stated length and width of *the small focal spot* are 0.6 mm each. These dimensions were measured at the tube current of 50 mA and the tube voltage of 70 kV. When measured with the pinhole camera the focal spot length was found to be 1.09 mm and its width 0.62 mm. The corresponding values, obtained using the star test pattern, are 1.12 mm for the focal spot length and 0.69 mm for the width.

The large focal spot, of stated square shape and size 1.2 mm, was measured at various values of tube current and tube voltage in order to study their effect on the focal spot size. Values of the current and voltage are specified in Fig. 4, which shows also the corresponding focal spot dimensions. As small changes in the focal spot size cannot be detected by the multiple bar pattern, this modality is not suitable for studying effects of tube current and tube voltage on focal spot dimensions. Both, the pinhole camera and the star pattern measurements demonstrate an increase of the focal spot length and width with increasing tube current. This effect, called »blooming«, is more marked parallel to tube axis [7-10]. Focal spot dimensions decrease slightly with increasing tube voltage[11]. There is no industry standard regarding focal spot blooming. Since blooming will vary significantly between supposedly identical tubes, one may need to specify the acceptable amount of focal spot blooming when purchasing a tube.

Comparison of stated and measured focal spot dimensions indicates, for both 0.6 and 1.2 mm focal spots, that their widths lie within the tolerance limits (Table 1), but the lengths are about twice larger than the stated ones. In order to bring the length of the focal spot closer to the to erance l'mit, *ICRU* proposed the focal spot length, as measured with the pinhole camera, to be multiplied with a tentative correction factor of 0.7. If such a factor were applied, the focal spot size would fall about 30% lower than the focal spot size measured with the star or bar pattern. As the focal spot d'mensions obtained using all three methods agree better than 20%, there is no evidence for introducing such fractional multiplier.

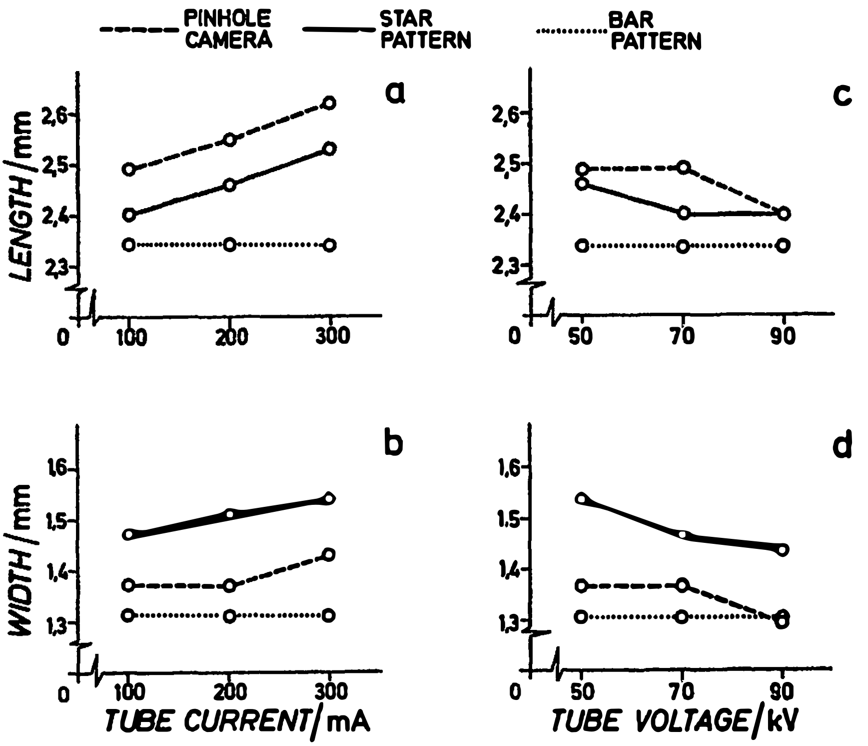

Figure 4. Dependence of focal spot dimensions on tube current and tube voltage. The stated length and width of the focal spot are 1.2 mm each.

(a and b) Tube voltage was kept constant at 70 kV.

(c and d) Tube current was kept constant at 100 mA.

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MJERENJE VELIČINE ŽARIŠTA DIJAGNOSTIČKIH RENDGENSKIH CIJEVI

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Dimenzije žarišta rendgenske cijevi su mjerene pomoću kamere s rupicom, te pomoću radijalnog i prugastog uzorka. Nađeno je da širina žarišta leži unutar granica tolerancije, ali njegova duljina je dvostruko veća od nominalne. Usporedba korištenih metoda ne opravdava uvođenje faktora 0.7 za korekciju duljine žarišta mjerene pomoću kamere s rupicom, koji je predložila Međunarodna komisija za radiološke jedinice i mjerenja. Ispitana je ovisnost veličine žarišta o struji i naponu rendgenske cijevi.