FLUKE®

Biomedical

Nuclear Associates

Radiographic and Mammographic Focal Spot Measurements Products

Users Manual

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Section 1
Introduction

1.1 Introduction

This manual is to be used for the following models:

07-624, 07-624-1000, 07-624-2222 - Slit Cameras

07-622 - Multipurpose Focal Spot/HVL Test Stand

07-623 - Mammography Focal Spot Measurement Test Stand

07-503, 07-509, 07-510, 07-542, 07-543, 07-550 - Star X-Ray Test Patterns for Measuring Focal Spot Size

07-611, 07-613, 07-617 and 07-633 - X-Ray Pinhole Assemblies

Focal spot size and intensity distribution play a significant role in mammographic image quality. It is particularly important to verify the size of the focal spot during acceptance testing of new mammographic equipment or when a new x-ray tube is installed.

The National Electrical Manufacturers Association (NEMA) has developed a standard of describing a technique for measuring the focal spot size. Some of the aspects of the standard are difficult, if not impossible, to meet in the clinical setting. This manual follows as closely as possible, the present NEMA standard.

Additional information regarding focal spot measurement techniques is available in the references cited on page 2-12. Data is available that indicates that detail screen-film systems can be used in place of direct x-ray exposure film, with a considerable reduction in x-ray tube loading[1]. Studies also indicate that the slit measurement technique, the recommended NEMA technique, is a repeatable method for acceptance testing, but that the star measurement technique can also be used as a repeatable method for obtaining quality control measurements[1].

The American College of Radiology has published a document regarding quality control in mammography. This document, which has separate sections for the radiologist, medical physicist, and technologist, describes tests that will help assure quality mammographic imaging. The Mammography Focal Spot Test Stand (Figure 1-1) can be used as one of the tools in the ACR Mammographic Quality Control Program.

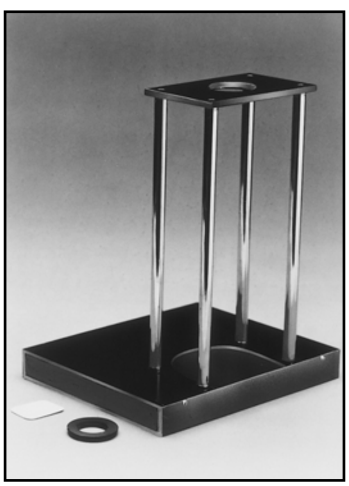

Figure 1-1. Mammography Focal Spot Test Stand (Model 07-623)

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Section 2
Operation

2.1 X-Ray Tube Focal Spot Measurements

2.1.1 Purpose

To assure that the tube and x-ray tube focal spot size is within acceptable limits.

2.1.2 Equipment Needed/Recommended for X-Ray Tube Focal Spot Measurements

1. Slit assembly, Pinhole, or Star Pattern.
2. A Focal Spot Test Stand (See Figure 2-1), with small and large adapter rings, and fluorescent screen.
3. Focal Spot Test Stand Alignment Device (Figure 2-2).
4. 8" X 10" (20 x 25 cm) screen-film extremity or mammography cassette and film, or direct-exposure x-ray film.
5. Clear plastic metric ruler.
6. Spirit level.
7. 6X magnifier with graticule scale in 0.1 mm divisions.

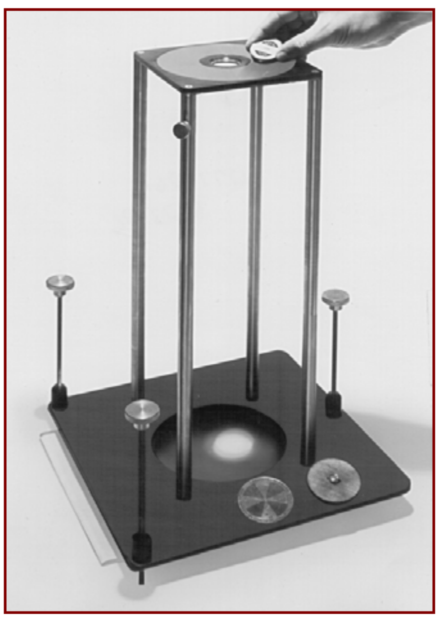
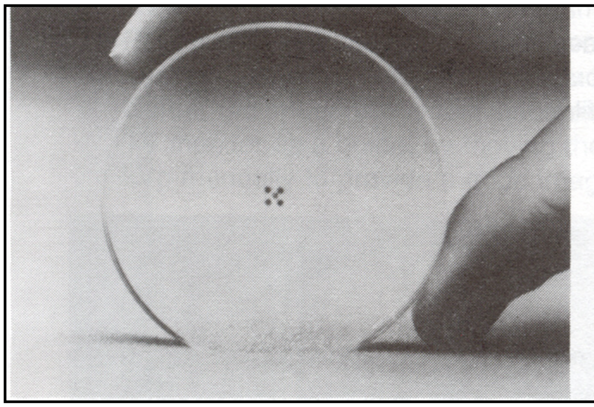


Figure 2-1. Multipurpose Focal Spot Test Stand (Model 07-622)



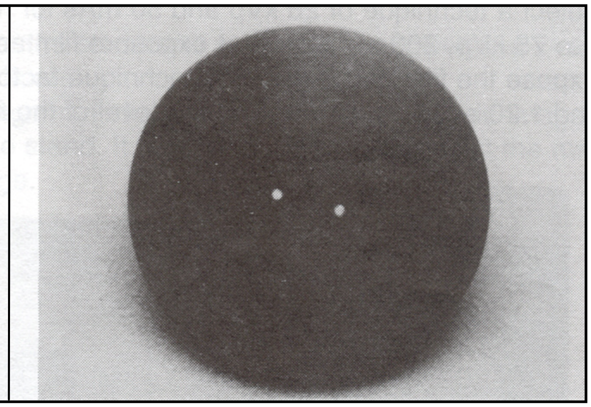


Figure 2-2. Focal Spot Test Stand Alignment Device   *Figure 2-3. Magnification Insert*

2.1.3 Equipment Needed/Recommended for Mammographic X-Ray Tube Focal Spot Measurements

1. Slit assembly, Pinhole, or Star Pattern.
2. A Focal Spot Test Stand (See Figure 1-1), with adapter ring, fluorescent screen and Magnification insert (Figure 2-3).
3. Focal Spot Test Stand Alignment Device (Figure 2-2).
4. 18 x 24 cm mammography cassette and film and 8" x 10" direct exposure x-ray film.
5. Clear plastic metric ruler.
6. Spirit level.
7. 6X magnifier with graticule scale in 0.1 mm divisions.

2.1.4 Procedure for Over-Table X-Ray Tube Focal Spot Test Stand Alignment

1. Remove all objects between the focal spot and table, e.g., compression device, diaphragms, cones, etc., which can be removed easily.
2. Place the focal spot test stand on the imaging table* (Figure 2-4).
3. Place the test stand alignment device in the top of the focal spot test stand (Figure 2-5).
4. Align the array of four beads so they are parallel with the anode-cathode axis of the x-ray tube.
5. Adjust the alignment device-to-film distance and focal spot-to-film distance (if variable) to obtain the correct magnification factors (Table 2-1).
6. Level the base of the test stand with the spirit level, using the unit adjustments. Verify that the top of the test stand is also level.
7. Place the fluorescent alignment screen on the test stand base plate.
8. Set a radiographic technique of about 28 kVp, 50 mA, and 2 sec for mammographic units. For R/F units set the radiographic technique at 75 kVp, 50 mA and 2 sec.
9. Rough alignment* can be carried out using the collimator light with the room lights off.
10. Turn off all room lights and view, on the fluorescent screen, the x-ray image of the five beads*. (This usually requires two people.)
11. Shift the test stand to assure that the stand is aligned with the central ray*, i.e., the one bead is centered between the four beads (Figure 2-6).
12. Replace the test stand alignment device with the magnification insert.
13. Place the direct exposure x-ray film in the test stand tunnel.

* *Unlike conventional x-ray equipment, the central or perpendicular ray is usually located near the edge of the x-ray field, i.e., near the chestwall side.*

14. Select a technique of 28 kVp and 50 mAs for mammographic units. For R/F units use 75 kVp, 300 mA for direct exposure film and 30 mAs for cassette exposure.
15. Expose the film at the selected technique factor. Film density should be between 0.80 and 1.20 above the base-plus-fog level of the film.

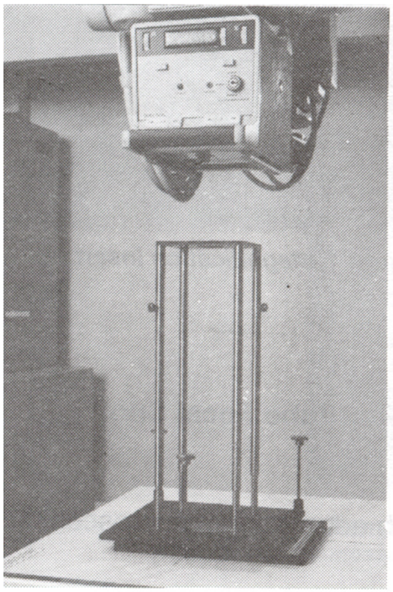


Figure 2-4. Focal Spot Test Stand on Table Alignment Device (Over-Table X-Ray Tube)

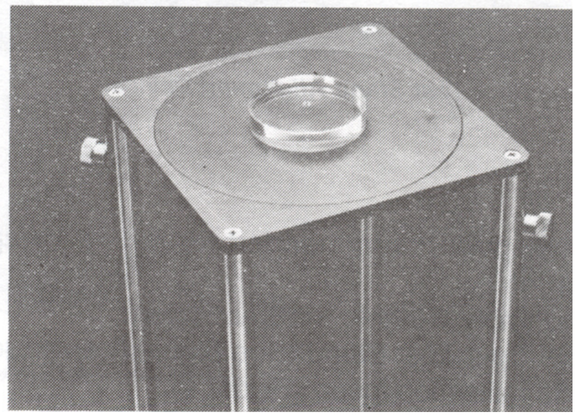


Figure 2-5. Focal Spot Test Stand on Top of Test Stand

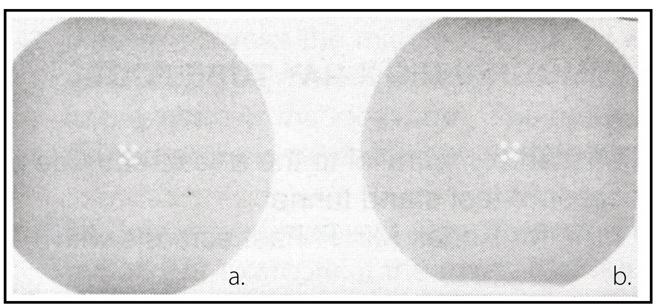


Figure 2-6. Radiograph of the Five Beads in the Focal Spot Test Stand Alignment Device:
a. Correctly aligned
b. Improperly aligned

Table 2-1.

Minimum Magnification for Slit, Pinhole, or Star Measurement Technique	
Nominal Focal Spot Size (F, mm)	**Magnification**
F < 0.4	> 3
0.4 ≤ F ≤ 2.5	> 2
F > 2.5	> 1

2.1.5 Procedure for Under-Table X-Ray Tube Focal Spot Test Stand Alignment

1. Level the tabletop using a spirit level and place the test stand on x-ray tabletop (Figure 2-7). Assure that the leveling screws are flush with the bottom of the stand.
2. Level the bottom of the stand using a spirit level, by adjusting the leveling screws.
3. Place the large adaptor ring and test stand alignment device on the base of the stand.
4. Rotate the test stand alignment device array of four beads so they are parallel to the anode-cathode axis.
5. Repeat steps 4 and 7 from the Procedure for Over-Table X-Ray Tube Focal Spot Alignment, Section 2.1.4.
6. Place the image intensifier tower over the stand and verify that the tower and x-ray tube are aligned, i.e., the interlocks allow fluoro.
7. Center the image of the test stand alignment device, using the fluoroscopic image on the TV monitor as a guide, by moving the stand. It may be necessary to adjust the mA and kVp manually to provide a good image.

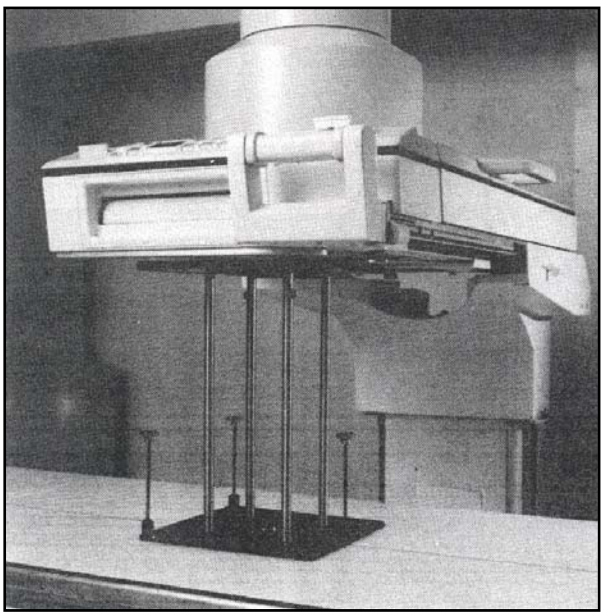


Figure 2-7. Focal Spot Test Stand on Table (Under-Table X-Ray Tube)

2.1.6 Procedure for Slit Measurement For Mammographic X-Ray Tube Focal Spot Measurements

1. Replace the magnification insert with the slit assembly, parallel to the anode-cathode axis.
2. Place the mammographic cassette in the focal spot test stand tunnel.
3. Select a technique of about 28 kVp and 30 mAs for Kodak Min R Fast screens with TMM II film.
4. Align the slit assembly parallel to the anode-cathode axis to make the focal width measurement.
5. Expose the cassette at the selected technique factors. Film density should be between 0.8 and 1.2 above the base-plus-fog of the film.
6. Rotate the slit assembly 90° to measure the focal length.
7. Expose the cassette or film at the selected technique factor.
8. Process and view the slit images (Figure 2-8).

9. On the radiograph of the magnification insert, measure the distance (in centimeters) between the images of the holes of the magnification insert using the ruler.
10. Divide image hole separation by 1 cm, the separation of the holes in the magnification insert. Calculate the magnification using the following formula:

$$\left[\frac{\text{image hole separation}}{1\text{ cm}}\right] - 1 = \text{Magnification}$$

For example, assume the image hole separation was measured as 3.20 cm

$$\left[\frac{3.20\text{ cm}}{1\text{ cm}}\right] - 1 = 2.20$$

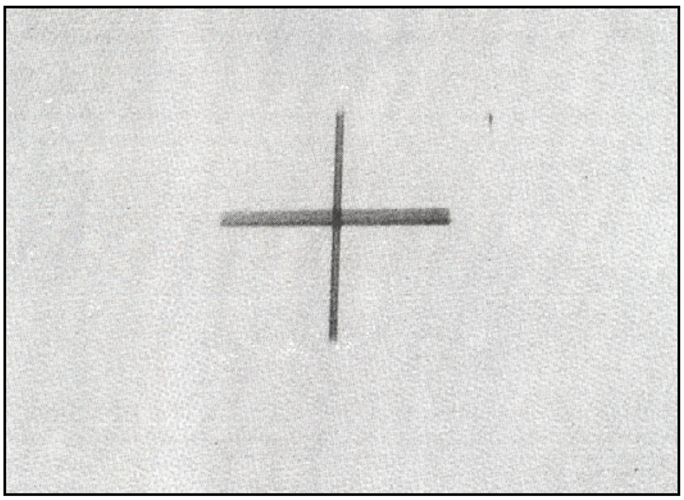


Figure 2-8.Slit Image Parallel and Perpendicular to the Anode-Cathode Axis

11. Measure across the middle of each slit image using the magnifier lens (with a built-in graticule). The measurement across the band parallel to the anode-cathode axis is related to the width of the focal spot. The measurement of the band perpendicular to the anode-cathode axis is related to the "length of the focal spot.
12. To determine focal spot size, divide the measured width and length by the magnification factor. For example, if the measured length of the slit image is 1.76 mm then:

$$\left[\frac{1.76}{2.20}\right] = 0.80\text{ mm (length of focal spot)}$$

13. Since many mammographic x-ray tubes are mounted at an angle (the anode-cathode axis is not parallel to the image receptor), it is necessary to correct the focal spot length measurement for the tube assembly tilt angle. The following formula is used:

$$L = F\left[\frac{\text{Sin (A)}}{\text{Sin (T + A)}}\right]$$

where

L = the actual focal spot length

F = the users measured length

A = x-ray tube anode (target) angle (Provided by the x-ray tube manufacturer.)

T = tube assembly tilt angle (Provided by the x-ray system manufacturer.)

For example, for a 0.80 mm measured focal spot length (F), an anode angle (A) of 20°, and a tube assembly tilt angle of 8°, one obtains

$$L = 0.80\text{ mm}\left[\frac{\sin(20°)}{\sin(8° + 20°)}\right]$$

$$L = 0.80\text{ mm}\left[\frac{0.34}{0.47}\right] = 0.58\text{ mm}$$

14. Compare the dimensions to the focal spot size tolerance limits in Table 2-2. The manufacturer may not accept screen-film slit image measurements for acceptance testing purposes. In this case, it may be necessary to repeat the procedure using direct exposure x-ray film.

Table 2-2.

Focal Spot Size Tolerance Limits (For Slit Camera Method)		
Nominal Focal Spot Designation (F)	**Maximum Focal Spot Dimensions in mm (F_{eff})**	
	Width	Length
0.05	0.075	0.075
0.1	0.15	0.15
0.15	0.23	0.23
0.2	0.30	0.30
0.25	0.40	0.40
0.3	0.45	0.65
0.4	0.60	0.85
0.5	0.75	1.1
0.6	0.90	1.3
0.7	1.1	1.5
0.8	1.2	1.6
0.9	1.3	1.8
1.0	1.4	2.0
1.1	1.5	2.2
1.2	1.7	2.4
1.3	1.8	2.6
1.4	1.9	2.8
1.5	2.0	3.0
1.6	2.1	3.1
1.7	2.2	3.2
1.8	2.3	3.3
1.9	2.4	3.5
2.0	2.6	3.7

2.1.7 Procedure - Slit Measurement of Focal Spots

1. Replace the test stand alignment device with the slit assembly, parallel to the anode-cathode axis.
2. Place a direct exposure x-ray film or cassette under the base for over-table x-ray tubes or on top of the stand for under-table tubes.
3. Using the x-ray tube rating chart, select a technique of about 75 kVp and one-half the maximum rated mA at 0.1 sec exposure for the appropriate focal spot size.
4. Select the exposure time to obtain about 300 mAs for the direct exposure film or 30 mAs for the cassette at a 36-inch (90 cm) source-to-image distance (film density should be between 0.8 and 1.2 above the base-plus-fog of the film).
5. Align the slit assembly parallel to the anode-cathode axis to make the focal width measurement.
6. Expose the cassette or film at the selected technique factors (steps, 3 and 4, above).
7. Move the cassette a few inches (to prevent double exposure).
8. Rotate the slit assembly 90° to measure the focal length.
9. Expose the cassette or film at the selected technique factor.
10. Process and view the slit images (Figure 2-9).
11. Measure the center-to-center distance between the localization holes on the radiograph using the ruler.
12. Divide image localization hole separation by the small adapter ring localization hole distance (40 mm). Calculate the magnification using the formula below:

$$\left[\frac{\text{image hole separation}}{40\text{ mm}}\right] - 1 = \text{Magnification}$$

For example, assume the image hole separation was measured as 90 mm

$$\left[\frac{90\text{ mm}}{40\text{ mm}}\right] - 1 = 1.25$$

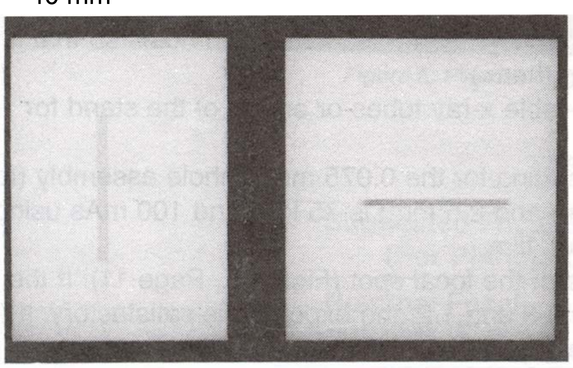


Figure 2-9. Slit Image Parallel and Perpendicular to the Anode-Cathode Axis

13. Measure across the middle of each slit image using the magnifier lens (with a built-in graticule). The measurement across the band parallel to the anode-cathode axis is related to the width of the focal spot. The measurement of the band perpendicular to the anode-cathode axis is related to the length of the focal spot.
14. To determine focal spot size, divide the measured width and length by the magnification factor. For example, if the measured width of the slit image measured 1.8 mm then

$$\left[\frac{1.8\text{ mm}}{1.25}\right] = 1.44\text{ mm (width of focal spot)}$$

15. Compare the measured dimensions to the Focal Spot Size Tolerance Limits in Table 2-2. The manufacturer may not accept the screen-film slit image measurements for acceptance testing purposes. In this case it may be necessary to repeat the procedure using direct exposure x-ray film.

2.1.8 Procedure - Pinhole Measurement Technique

1. Replace the test stand alignment device with the appropriate pinhole assembly. (The size of the pinhole diameter is engraved on the pinhole assembly.)

   The following pinhole assemblies should be used:

Nominal Focal Spot Size (F, in mm)	Model	Pinhole Diameter
$0.3 < F \leq 1.2$	07-613	0.030 mm
$1.2 < F \leq 2.5$	07-617	0.075 mm
$F > 2.5$	07-611	0.100 mm

2. Cover the localization holes only, not the pinhole insert, with 0.25 mm lead-equivalent rubber. (This reduces the exposure and film density of the localization holes so that it will be easy to measure the distance between them.)
3. Place a cassette under the base for over-table x-ray tubes or on top of the stand for under- table tubes.
4. Expose the cassette. A suggested x-ray setting for the 0.075 mm pinhole assembly (for use with a focal spot size between 1.0 mm and 2.5 mm) is 75 kVp and 100 mAs using Kodak Lanex Fine screens and Kodak TML film.
5. Develop and examine the resulting image of the focal spot (Figure 2-10). If the density of the densest portion is between 0.8 and 1.2, the exposure is satisfactory. If the density range is unsatisfactory, adjust the exposure conditions and repeat.
6. Measure the center-to-center distance between localization holes on the radiograph using the ruler and determine the magnification using the formula:

$$\left[\frac{\text{image hole separation}}{\text{Sin (T + A)}}\right] - 1 = \text{Magnification}$$

   where 13 mm is the separation of the localization holes in the pinhole assembly.

7. Place the focal spot image on an illuminated surface and measure with a 6X magnifier with graticle scale. Most focal spots consist of two fairly dark lines having a relatively lighter area between them. The focal spot dimensions are determined by measuring all perceptible portions of the image width and length.
8. Follow step 14 of the Slit Measurement Procedure in Section 2.1.7.
9. For line-focus tubes, the measured focal spot <u>length</u> should be multiplied by a correction factor of 0.7.
10. Suggested focal spot size tolerances are given in Table 2-3. However, these measurements may not be accepted by the manufacturer for acceptance test purposes. In this case, the size should be verified using the slit measurement technique.

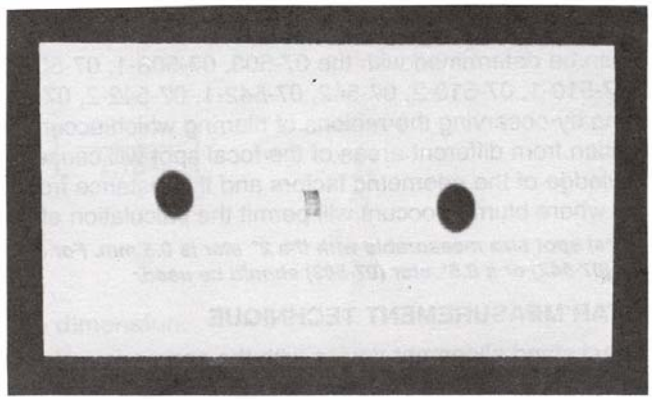


Figure 2-10. Pinhole Image with Localization Holes

Table 2-3.

Suggested Focal Spot Size Tolerances (For Pinhole Camera Method)		
Nominal Focal Spot Size (F, mm)	**Tolerance (%)**	
	Minus	**Plus**
F < 0.8	0	50
0.8 ≤ F ≤ 1.5	0	40
F > 1.5	0	30

2.2 Star Measurement Technique

2.2.1 Physical Description of Star Test Pattern

The Model 07-503, 07-503-1 and 07-503-2 consists of 60 spoke pairs divided into four 15° sectors. Each spoke diverges at an angle of 0.5°.

The Model 07-509, 07-509-1 and 07-509-2 consists of 44 spoke pairs divided into four 45° sectors and diverging at an angle of 2° for each spoke.

The Model 07-510, 07-510-1 and 07-510-2 is divided into 90 spoke pairs; each spoke diverges at an angle of 2°.

The Model 07-542, 07-542-1 and 07-542-2 consists of 56 spoke pairs divided into four 28° sectors and diverging at an angle of 1° per spoke.

The Model 07-543, 07-543-1 and 07-543-2 consists of 48 spoke pairs divided into four 35° sectors. Each spoke diverges at an angle of 1.5°.

2.2.2Instructions for Use

Focal spot size can be determined with the 07-503, 07-503-1, 07-503-2, 07-509, 07-509-1, 07 -509-2, 07-510, 07-510-1, 07-510-2, 07-542, 07-542-1, 07-542-2, 07-543, 07-543-1 and 07-543-2 test patterns by observing the regions of blurring which occur when the star pattern is radiographed. Radiation from different areas of the focal spot will cause a periodic blurring of the pattern image. Knowledge of the geometric factors and the distance from the center of the pattern to the region where blurring occurs will permit the calculation of the focal spot size.

NOTE

The minimum focal spot size measurable with the 2° star is 0.5 mm. For smaller focal spots, a 1.5° star (07-543), a 1° star (07-542) or a 0.5° star (07-503) should be used.

2.3 Procedure - Star Measurement Technique

1. Replace the test stand alignment device with the appropriate star test pattern.
2. Place a direct exposure x-ray film under the base for over-table x-ray tubes or on top of the stand for under-table tubes.
3. Select a technique of 75 kVp, one-half of the maximum mA and about 40 mAs.
4. Expose the x-ray film at the selected technique factors.
5. Process the film and examine the image (See Figure 2-10).
6. Determine the magnification (M) by dividing the diameter of the radiographic image of the star pattern by the true diameter (45 mm) of the spokes only, i.e., do not include the outer edge of the pattern (See Figure 2-10).
7. Scan image of the star pattern inward from the periphery to find the outer-most region at which the image of the sectors bends or disappears. This is the region of zero contrast. Measure the diameter of this region across its greatest extent. Repeat the measurement in the perpendicular direction. Let these diameters be called D_1 and D_2.
8. The focal spot size corresponding to the individual diameter dimensions can be determined by formula:

$$F = \left[\frac{N}{57.3}\right] \times \left[\frac{D}{(M-1)}\right]$$

Where: F is the focal spot size in mm.

N is the angle of the star pattern line (which is marked on the test pattern: 0.5°, 1°, 1.5°, or 2°).

D is the diameter of the zero contrast region in mm.

M is the magnification.

9. For the radiograph shown:

N = 2

$$\text{Magnification } M = \left[\frac{98\text{ mm}}{45\text{ mm}}\right] = 2.18$$

(M-1) = 1.18

For the anode-cathode dimension:

D_1 = 28 mm

$$F_1 = \left[\frac{2}{57.3}\right] \times \left[\frac{28\text{ mm}}{1.18}\right]$$

F_1 = 0.83 mm

For the transverse dimension:

D_2 = 34 mm

$$F_2 = \left[\frac{2}{57.3}\right] \times \left[\frac{34}{1.18}\right] = 1.01 \text{ mm}$$

The focal spot is 0.8 mm x 1.0 mm at the kVp and mA setting used.

10. Since these measurements yield the equivalent homogenous focal spot size they cannot be compared directly to specified tolerances in Table 2-2, or Table 2-3. However, any changes noted in the focal spot size with this technique should be indicative of changes in the actual size. In this case, the size should be verified using the slit measurement technique.

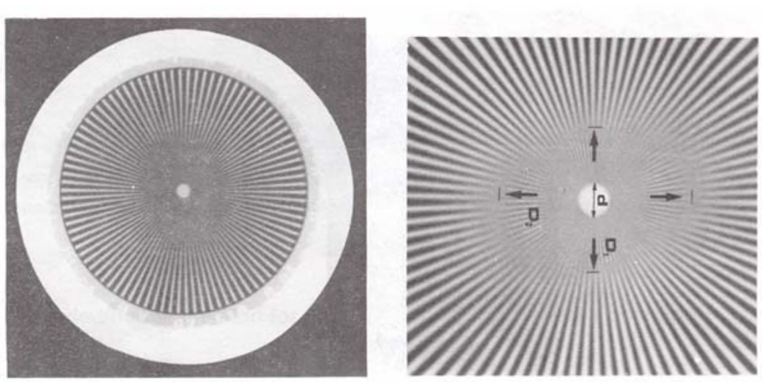


Figure 2-11. Star Pattern Image Showing the Measurement of the Diameter of the Image of the Pattern and the Diameter at Zero Contrast.

NOTE

1. Misalignment of the test stand with respect to the central beam of the x-ray tube can alter the measurements.
2. The focal spot size may change with mA and kVp. Refer to methods for evaluating x-ray tube blooming characteristics[1].
3. The manufacturer may require the use of direct x-ray exposed film instead of an extremity or mammography cassette system for acceptance testing.
4. With the Star Test Pattern, several regions of zero contrast may be found on a single film. It is extremely important that the largest one be used. If there is any doubt (i.e., the focal spot calculation yields low values), then a second exposure with a lower magnification should be made and evaluated.

5. For the Star Test Pattern, the formula and data presented yield the equivalent homogeneous focal spot size, not the actual size.

2.4 Procedure - Half-Value Layer Measurements

1. Place the focal spot test stand on the tabletop. Adjust the leveling screws so that the base is raised 1" (2.5 cm) above tabletop.
2. Place a sheet of lead under the base.
3. Adjust the stand so that the top is located at one-half of source-to-tabletop distance, e.g., for a 40" source-to-table-top distance adjust the stand to 20".
4. Place both the large and small adaptors in the top of the stand.
5. Collimate the x-ray beam to the top aperture of stand.
6. Place the ionization chamber on the base just above the aperture (Figure 2-11).
7. Select the technique factors that will produce about 300 mR at 80 kVp.
8. Make an exposure without added aluminum and record the result.
9. Add 2 mm of type 1100 aluminum.
9. Make an exposure and record the result.
10. Repeat steps 9 and 10, adding an additional 1 mm of aluminum each time until the exposure reading is approximately 100 mR.
12. For data analysis, potential problems, and acceptance limits, See Reference 2 on page 2-12.

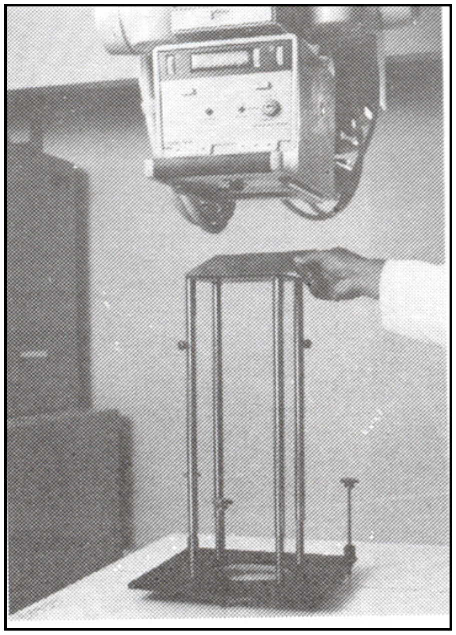


Figure 2-11.
Arrangement of the Focal Spot Test Stand for Measurement of the Half-Value Layer

References:

1. Everson J.D., Gray J.E., "Focal-Spot Measurement: Comparison of Slit, Pinhole and Star Resolution Pattern Techniques," Radiology, 1651 (1987), 261-264.
2. Measurement of Dimensions and Properties of Focal Spots of Diagnostic X-Ray Tubes, Standards Publication No. XR 5-1984 National Electrical Manufacturers Association (NEMA), 2101 L Street N.W., Washington, DC 20037.
3. J.E. Gray, N. T. Winkler, J.G. Stears, E.D. Frank, "Quality Control in Diagnostic Imaging," (Aspen Systems Corporation, Rockville, Maryland).
4. American College of Radiology, "Mammography Quality Control-Manual for Radiologists, Physicists, and Technologists," (1990), Reston, Virginia.

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