RTI Slit Camera

User's Manual – English – Version 1.0D

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1. Introduction

1.1. About this Manual

This manual is divided into a few main parts.

1. A general description of the Slit Camera.
2. Descriptions and hints on performing measurements.
3. Troubleshooting tip, and FAQ.

Typographical Rules

Terms in **bold** face are references to texts on screenshots, like buttons and texts, and menu items. Other terms are *italicized*.

1.2. Introduction to the Slit Camera

Congratulations to your purchase of the Slit Camera from RTI. You have now in your hand a quality tool for focal spot size evaluation. It has been carefully designed to meet the needs of modern X-ray systems.

If you have questions, comments, or feel that some functionality is missing, you are welcome to contact us at RTI Electronics at sales@rtigroup.com. You can of course also call (see notice section for details).

Note!

The Slit Camera does not come with any evaluation tool.
RTI recommends digitalizing the slit image and using an image evaluation tool to measure in the image. An example of such software is ImageJ, http://imagej.nih.gov/ij/

2. Description of the RTI Slit Camera

The RTI Slit Camera for x-ray focal spot measurement comes with a stand with an adjustable rod. Optionally also a tilting device is available.

Figure 2-1 *Slit Camera with (left) and without (right) the optional tilting device.*

The Slit Camera can be rotated 90 degrees in the Slit Camera holder. See figure 2-2 below. The 90 degree rotation simplifies the measurement of length and width measurements of the focal spot since the slit only have to be aligned once.

Figure 2-2 *The Slit Camera can be rotated by means of 90 degrees.*

The optional tilting device enables measurements where the reference position is not orthogonal to the image plane, which is normal in mammography. See figure 2-3 below.

Figure 2-3 *The optional Tilting Device is ideal for use in mammography where the reference position normally is not orthogonal to the breast support.*

2.1. Setting Up the Slit Camera for the First Time

Before you use your Slit Camera for the first time, mount the Slit Camera and the stand to make sure that all mechanical parts fits together, and that no parts have been damaged during transportation.

2.2. Hardware and Specifications

All specifications can be changed without prior notice. RTI assumes no responsibility for any errors or consequential damages that may result from the misuse or misinterpretation of any information contained in these specifications.

2.2.1. Slit Camera

Supporting standards	IEC 60336
Tube focal spot types	Radiographic, CT, Mammographic, Dental
kV range	18 - 150 kV
Enlargement factor E E = n/m, where: n = slit to detector distance m = slit to focal spot distance	0.8 - 5
Measurement range	0.1 - 5 mm

2.2.2. Dimensions

Slit holder size	118.5 x 42 x 6 mm
Slit dimensions	10 µm (as defined by IEC 60336)
Slit material	Tungsten (W, 99.9 %)

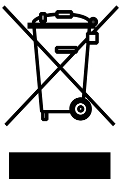
2.3. Standards and Compliances

Hereafter you can find declarations of conformity, as well as documents describing the intended use of the Slit Camera.

2.3.1. Waste Electrical and Electronic Equipment (WEEE)

The European Union Directive 2002/96/EC on Waste from Electrical and Electronic Equipment (WEEE) places an obligation on manufacturers, distributors, and retailers to take back electronics products at the end of their useful life.
The WEEE directive covers all RTI products being sold into the European Union (EU) as of August 13, 2005. Manufacturers, distributors, and retailers are obliged to finance the cost of recovery from municipal collection points, reuse, and recycling of specified percentages per the WEEE requirements.

Instructions for disposal of WEEE by Users in the European Union



The symbol, shown left, is marked on the product, which indicates that this product must not be disposed of with other waste. Instead, it is the user's responsibility to dispose of the user's waste equipment by handing it over to a designated collection point for the recycling of waste electrical and electronic equipment. The separate collection and recycling of waste equipment at the time of disposal will help to conserve natural resources and ensure that it is recycled in a manner that protects human health and the environment. For more information about where you can drop off your waste equipment for recycling, please contact your local distributor from whom you purchased the product.

3. Theory of Focal Spot Reproduction

3.1. Theory

The focal spot is being reproduced (depicted) according to the IEC 60336 [Reference 1], standard through a 10 µm wide slit, and then registered with an image receptor (not included in the RTI Slit Camera). This is described in figure 1 below. The reproduction is a one-dimensional “picture” of the focal spot in one direction and a perpendicular measurement has to be done to get the characteristics of the focal spot in both length and width directions.

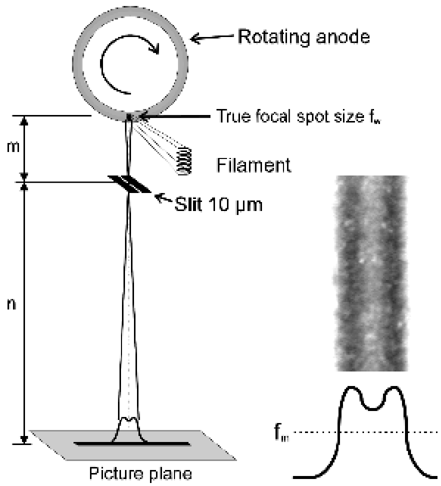


Figure 3–1 *Focal spot reproduction. The grey part to the right shows an image taken with a film in the picture plane. Note the lighter part in the middle indicating the dip between the two peaks.*

As shown in Figure 3–1, you get a measured width of the focal spot, f_m. This measured focal spot is an enlargement of the true focal spot on the anode, f_w, magnified by the factor E, which is n divided by m.

The distance from the true focal spot to the slit is m, and n is the distance from the slit to the image receptor. The slit width is denoted by *s*. The true focal spot width can thus be calculated as:

$$f_w = \frac{m}{n} f_m - \chi \qquad \text{(Eq. 3.1)}$$

where

χ represents the penumbra from the slit.

$\chi = \frac{m+n}{m} s$ if the width is calculated at 0 % of the LSF, and

$\chi = 0$ if the width is calculated at 50 % of the LSF.

Unfortunately the standards specify calculation depending on film blackening, which represents roughly 10 – 20 % of the LSF. However, normally χ is so small that you can forget about it since s is much smaller than f. It (χ) will though not be small for small mammographic focal spots. The standards specify that you shall use large enlargement factors for small focal spots, which reduces the χ a bit but not as much as the reduction of the focal spot size. The relative error will thus be larger for small focal spots.
This calculation of χ is done for a square shaped focal spot, it will however do as an approximation for a focal spot of any shape.

3.2. Why measure the focal spot?

The main aspect of X-ray imaging is to get images of objects. A typical X-ray focal spot is shown in Figure 3–2. As seen, there are two peaks in the width direction, which depends on the tube filament (cathode). The filament is in this case a metallic thread in a spiral form. The tube current gives rise to an electron cloud (or space charge) around the filament. The distribution of the electrons is roughly constant around the filament. Since the surface of the filament is rounded in one direction there are more electrons along the sides when viewed from the anode. See Figure 3– below. This distribution becomes reproduced on the anode when the electrons in the cloud around the filament accelerate towards the anode by the tube voltage. On many newer X-ray tubes, especially with small foci, this cannot as easily be seen as new methods to focus the electron beam and different cathode structures have been developed.

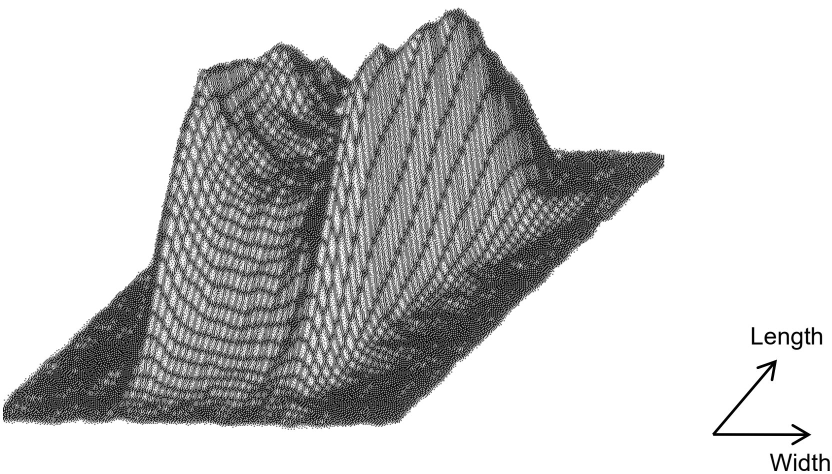


Figure 3–2 *Image of the focal spot of a radiographic X-ray tube.*

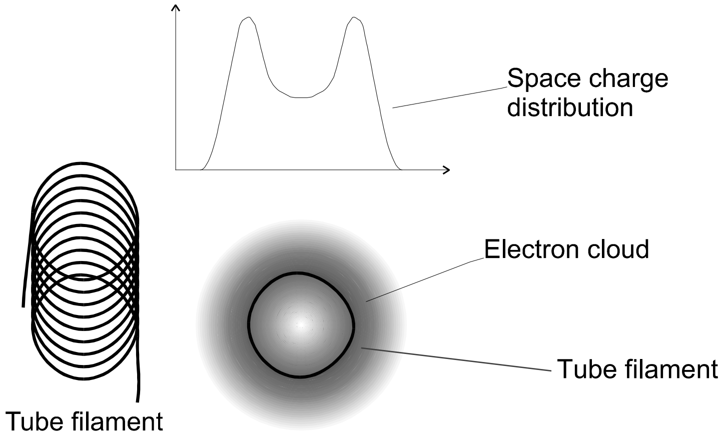


Figure 3–3 *The tube filament.*

To make it possible to view small details of an image, it shall be as clear as possible with high resolution. There are several things that cause blurring of the X-ray radiograms.

1. Geometrical blurring
    a. Focal spot size
    b. Object to picture distance
2. Movement blurring
3. Material blurring

Of these things the focal spot size is the only one directly connected to the X-ray equipment. The other depends on how you perform the imaging.
The Figure 3–4 and Figure 3–5 gives a description of what the size and shape of the focal spot mean for the reproduction of objects.

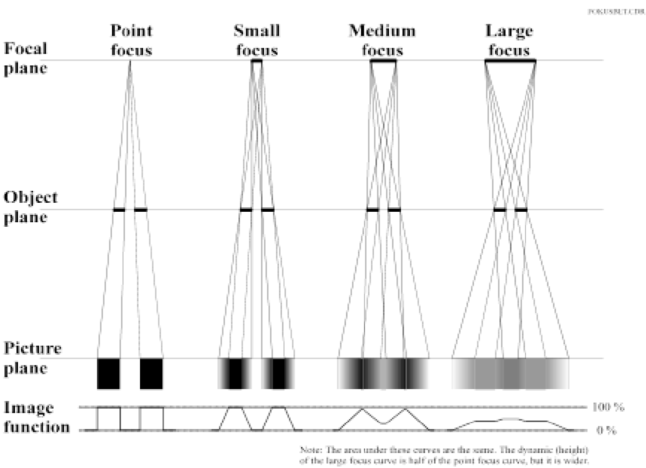


Figure 3–4 *X-ray images for different sizes of the foci.*

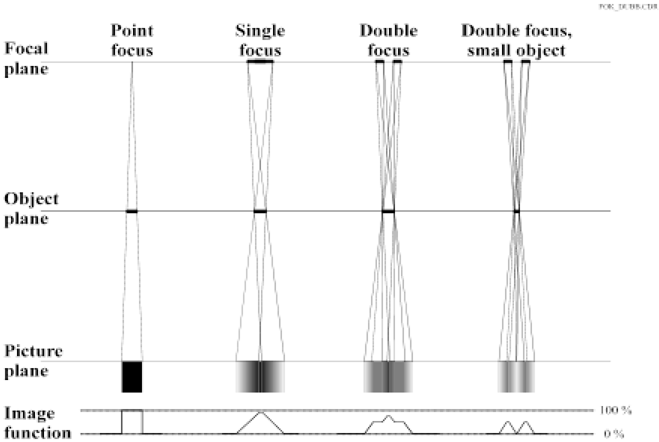


Figure 3–5 *Reproduction of an object with different foci.*

If the tube filament is worn-out and about to break you can often see this on the focal spot and therefore be prepared to replace the tube when it breaks.

4. X-Ray Tube Focal Spot Measurements

4.1. Purpose

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

4.1.1. Equipment Recommended for Focal Spot Measurements

1. Slit assembly
2. A Focal Spot Test Stand (See Figure 4-1)
3. Alignment Tools
4. Metric ruler
5. Reading tools
   - Image analyzing software for digital images
   - Magnifier (>6X) with 0.1 mm scale for film analysis

***Figure 4-1**. Focal Spot Test Stand*

4.2. 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, with the slit direction perpendicular to the direction you intend to measure the focal spot dimension.
3. Adjust to maximize the slit to image receptor distance and adjust the focal spot-to-film distance to obtain the correct magnification factors (Table 4-1).
4. Use the light field (if available) to position the slit and slit holder where you intend to perform the measurement.
5. Make an exposure and verify that the image of the slit holder is centered over the position you intended to evaluate the focal spot at.

***Table 4-1** Minimum Magnification for Slit Measurement Technique*

Nominal focal spot value, f	Enlargement factor E = n / m
$f \leq 0.4$	$E \geq 3$
$0,5 \leq f \leq 1.0$	$E \geq 2$
$1.1 \leq f$	$E \geq 1$

4.3. Slit Measurement Using Film and Magnifier Lens

1. When the alignment described above is acceptable, the evaluation of the focal spot shall be done. 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.
2. On the radiograph of the slit holder, measure the distance, in mm, between the front edge and the open part of the slit holder, using a ruler (X_2 in the figure below).
3. Calculate the magnification using the following formula:

$$E = \frac{n}{m} = \frac{X_2 - 42}{42} \qquad \text{(Eq. 4.1)}$$

where:

n = slit to detector distance
m = slit to focal spot distance
X_2 = image edge distance measured in the x-ray image in mm
(34 mm is the true physical distance from the front edge to the edge of the open part of the slit holder.)

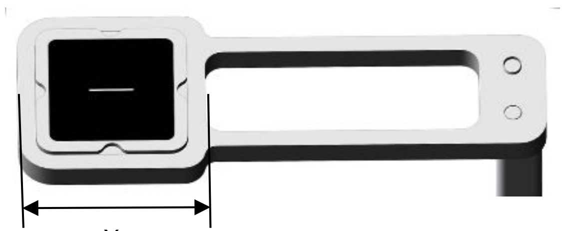


Figure 4-2. *Slit Holder showing the distance X_2 between the front edge and the open part of the slit holder. The true physical distance is 42 mm.*

For example, assume the image edge separation was measured as 105 mm. The magnification (E) is then

$$E = \frac{n}{m} = \frac{105 - 42}{42} = 1.5 \qquad \text{(Eq. 4.2)}$$

4. Measure across the middle of the slit image using the magnifier lens (with a built-in graticule).

5. To determine focal spot size, divide the measured value by the enlargement factor. For example, if the measured length (f_m) of the slit image is 1.76 mm and the enlargement factor is 1.5, then:

$$f = \frac{1.76}{1.5} = 1.17 \qquad \text{(Eq. 4.3)}$$

4.4. Slit Measurement Using Digital Image

4.4.1. Evaluation using ImageJ

Independently of which software tool is used to make the evaluation there are a few “musts”.

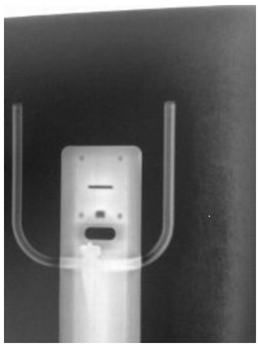
1. The image has to be calibrated in terms of size. I.e. one has to be able to measure the size of an object in the image plane in units of mm.
2. One has to be able to get the intensity profile across the image of the focus slit.

In example below the image size has been calibrated by knowing the true size of the digital detector and measure the number of pixels from edge to edge in the evaluation software. An alternative way is to place an object of known size directly on top of the image detector, and use that for the calibration.

Note:
In the example below the image of the RTI Slit Camera shows a former version of the Slit Camera and holder. Even if the images are not recognized, the principles for the evaluation are the same.

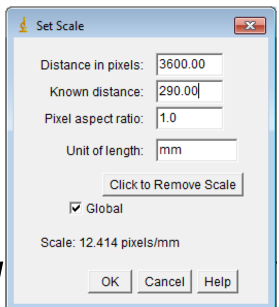
4.4.1.1. Preparing the image

The figure to the left shows the original image of the focal slit as it was exported from the workstation. In this case a jpg file. To be able to measure the intensity profile with ImageJ one must calibrate the pixel values, rotate, and invert the image. The procedure is shown below.



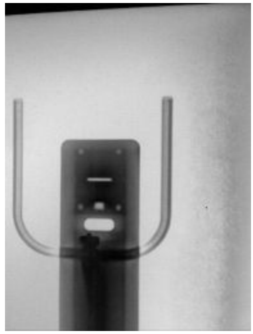
4.4.1.2. Calibrate the pixel values

In ImageJ the calibration is performed by “setting scale”. This is done from the menu *Analyze/Set Scale…*.
In this case the number of pixels was 3600 for a known distance of 290 mm.



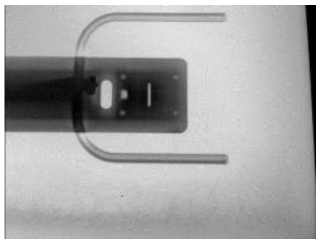
4.4.1.3. Invert the image

The original image is inverted. This is done from the menu *Edit/Invert*, (or Ctrl+Shift+I).



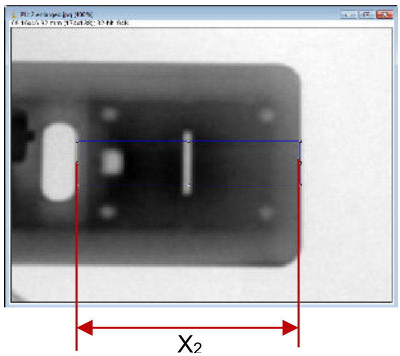
4.4.1.4. Rotate the image

If the image of the slit is horizontal the image must be rotated 90 deg before measure with ImageJ. This is done from the menu *Image/Transform/Rotate 90 Degrees Right.*



4.4.1.5. Measure the distances, X_1 and X_2

In the image the distance, X_2, between the front edge and the edge of the open part of the slit holder is measured.
In ImageJ this distance can be measured by using either the rectangular or the line tool. In the image to the right the rectangular tool is used and the width is read to be 82.17 mm. One can also read the x-values by moving the pointer over the image. In this case the x-value for the left edge was 117.61, and the right edge was 199.78. That gives the width.



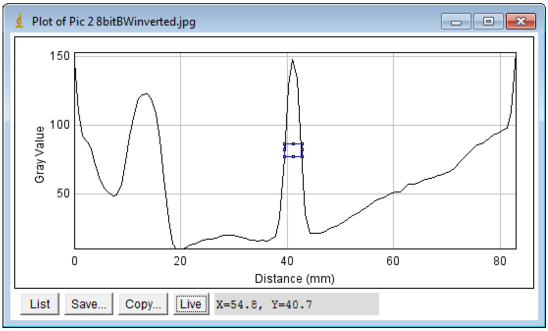
$$X_2 = 199.78 - 117.61 = 82.17 \text{ mm}$$

The true distance, X_1, between the front edge and the edge of the open part of the slit holder is 42 mm.

X_1 = 42 mm

4.4.1.6. Measure the focus size, f_m

To measure the focus size one need the line spread function (LSF) of the image of the focal spot through the slit. This is done from the menu *Analyze/Plot Profile,* (or Ctrl+K). ImageJ will plot the profile of the area marked in the image with the rectangular tool.



In the image of the line spread function the width can now be measured. Either using the rectangular tool and read the width, or reading the cursor x-values on the left and right edge. The cursor x-value is show in the lower part of the window. In this example the width is measured as FWHM (Full Width Half Maximum), and is 2.24 mm.

f_m = 3.32 mm

4.4.1.7. Calculate true focal spot size, f

Using Eq. 4.1, and the values above gives following:

$$f \quad = \frac{X_1}{X_2 - X_1} f_m = \frac{42.0}{82.17 - 42.0} 2.24 = 2.34\text{mm}$$

This is the final result for a measurement of the length of the focal spot.

4.4.1.8. Measure the width of the focal spot

Rotating the Focus Slit 90 degrees in the holder (The stand should not be moved), and then repeating the above procedure, will give the width of the focal spot.
In this case the result was 1.86 mm.

f = 1.86

4.4.1.9. Nominal focal spot value

The IEC 60336 standard specifies the Nominal focal spot value in a look-up table, see Appendix A. Using the results above (width = 1.86, length = 2.34) and the look-up table, gives a nominal focal spot value of 1.6.

5. Word List

Word	Explanation
Actual focal spot	*"Area on the surface of the TARGET that that intercepts the beam of accelerated particles."* (From the IEC 60788 standard) The TARGET for an X-ray tube is the same as the anode.
Depiction	An image or reproduction of an object, e.g., as seen trough a slit as in this case.
Effective focal spot	*"Perpendicular projection of the ACTUAL FOCAL SPOT on the REFERENCE PLANE."* (From the IEC 60788 standard)
Enlargement factor	The factor that enlarges the true focal spot to the reproduction in the REFERENCE PLANE through the SLIT. Denoted by "E". $E=\frac{n}{m}$
Focal spot	The same as "effective focal spot".
FWFM	Full Width Fifth Maximum. *For a bell shaped curve, distance parallel to the abscissa axis between the points where the ordinate has one fifth of its maximum value.* (Analogous to FWHM and FWTM from the IEC 788 standard)
Length	*For measurements over the length of the FOCAL SPOT, the direction of evaluation shall be parallel to the longitudinal axis of the X-RAY TUBE ASSEMBLY. If the X-RAY TUBE ASSEMBLY does not have an identifiable longitudinal axis, a longitudinal axis shall be specified together with the FOCAL SPOT characteristics.* (Adapted from the IEC 60336 standard) The length is normally parallel to the perpendicular projection of the anode cathode axis on the REFERENCE PLANE.
LSF	"*Line Spread Function. In an imaging system, distribution of the intensity from a line source along a straight line in a specified image plane where the straight line is normal to the image of the line source.*" (From the IEC 60788 standard) The intensity function below the slit perpendicular to the slit. The slit represents the line source.

Magnification factor

The MAGNIFICATION FACTOR is the ratio of the focal spot to image distance and the focal spot to object distance. It is denoted by ”M”.
The spatial frequency is of the MTF is calculated for a specific magnification factor, as follows.

$$f = f_i \frac{M}{M - 1}$$

where:

f is the corrected spatial frequency.

f_i is the spatial frequency obtained by a Fourier transform of the LSF.

M is the magnification factor.

The different standards specifies that you should use standard magnification factors depending on the nominal focal spot size as shown in Table 5–1 below. If you use the choice ”Full MTF” you can set M as you like (1-10).

Table 5–1 *The standard magnification factors.*

Nominal focal spot, **f**	Standard magnification, $\mathbf{M_S}$
$f < 0,6$	2
$0.6 \leq f$	1.3

Penumbra

In RADIOLOGY, spatial region around the RADIATION BEAM where the value of radiation flux is between two specified or specific fractions of the value that is measured in the RADIATION BEAM AXIS.

Note.- The existence of such spatial region can be due to one or more of the following phenomena:
- *EXTRA-FOCAL RADIATION,*
- *SCATTERED RADIATION,*
- *absence of lateral electronic equilibrium,*
- *pair production,*
- *geometry of the RADIATION SOURCE and of the BEAM LIMITING SYSTEM.*

(From the IEC 788 standard)

Reference axis

”*For a RADIATION SOURCE, line in the REFERENCE DIRECTION through the centre of the RADIATION SOURCE.”*
(From the IEC 788 standard)

Reference direction

”*For a RADIATION SOURCE, specified direction to which characteristics such as TARGET ANGLE, RADIATION*

FIELD, and specifications with respect to the imaging quality of the RADIATION SOURCE, are referenced.” (From the IEC 788 standard)

Reference plane	”*In diagnostic X-ray equipment for an EFFECTIVE FOCAL SPOT, plane perpendicular to the REFERENCE DIRECTION containing the point at which the REFERENCE AXIS intersects with the ACTUAL FOCAL SPOT.* *By convention, the point of intersection forms the center of the EFFECTIVE FOCAL SPOT.”* (From the IEC 788 standard)
RMS	Root Mean Square, a proposed new method of focal spot, (From the IEC 788 standard)
Slit	Narrow but long opening between two solid materials. In this case the slit is 10 µm wide and 5 mm long. The material is Tantalum. These specifications comply with the IEC 60336 standard.
Width	*For measurements over the width of the FOCAL SPOT, the direction of evaluation shall be, in general, normal to the direction for LENGTH.* (Free from the IEC 60336 standard) The width is normally perpendicular to the perpendicular projection of the anode cathode axis on the REFERENCE PLANE.

6. Appendix A

This appendix shows the tables for the nominal focal spot values for the different standards.

6.1. A.1. Nominal Focal Spot Size - IEC 60336

The publication IEC 60336 describes the different methods to measure the characteristics of the focal spot. In IEC 60336 the slit method is recommended to get accurate determinations of the focal spot dimensions. The other methods, pinhole and star pattern, are also described in IEC 60336 because they are often used by manufacturers and for clinical testing of X-ray tubes.

The nominal focal spot value (f) is a dimensionless quantity defined by IEC and the permissible values of focal spot dimensions measured with the slit method is shown in table A-1. For instance, if the dimensions of the focal spot size measured with a slit is 0.31×0.60 mm then, according to table A-1, the nominal focal spot size is 0.3.

When the dimensions of the focal spot are measured with the slit method the length shall be multiplied with a factor of 0.7 if the nominal focal spot size is larger than 0.3. In IEC 60336 the motivation for this is that the distribution in radiant intensity over the length has relatively shallow shoulders, and the linear dimensions for length of the focal spot become larger compared to the width even though the MTFs for both width and length may be approximately equal. The reason for not using the multiplier 0.7 on tubes with nominal focal spot sizes below 0.3 is said to be that in that range the dimensions of the distribution of radiant intensity are more rectangular over both length and width. The reasons given above for multiplying the length of the focal spot with 0.7 for focal spot sizes larger than 0.3 implies special tube constructions which are out of date when today's X-ray tubes are concerned, especially modern mammography X-ray tubes.

To get accurate results of the focal spot size measurements with slit and film they shall be performed with an enlargement factor described in table A-2. This will not be a problem when the manufacturers do the measurements because they have the opportunity to dismantle parts of the X-ray unit (for instance the breast support). However, when the slit method is used in a clinical environment to measure the focal spot size on mammography X-ray tubes it may be impossible to get the magnification of the focal spot required. The nominal focal spot value is often less than 0.4 and the distance between the collimator and the breast support is not large enough to get an enlargement factor as large as three.

When the slit method is used to estimate the focal spot size only (not MTF calculations) it is accepted, according to IEC 60336, to examine the slit images by eye trough a magnifying lens. The magnifying lens shall have a built-in graticule with divisions of 0.1 mm and a magnification of 10.

Table A-1 *Nominal focal spot values according to IEC 60336. The dimensions shall be measured with the slit method. Because of the multiplier 0.7 for focal spot sizes larger than 0.3 there is a "jump" in permissible values of length in the table.*

Nominal focal spot value	**Focal spot dimensions Permissible value (mm)**	
f	**Width**	**Length**
0.1	0.10 - 0.15	0.10 - 0.15
0.15	0.15 - 0.23	0.15 - 0.23
0.2	0.20 - 0.30	0.20 - 0.30
0.25	0.25 - 0.38	0.25 - 0.38
0.3	0.30 - 0.45	0.45 - 0.65
0.4	0.40 - 0.60	0.60 - 0.85
0.5	0.50 - 0.75	0.70 - 1.10
0.6	0.60 - 0.90	0.90 - 1.30
0.7	0.70 - 1.10	1.00 - 1.50
0.8	0.80 - 1.20	1.10 - 1.60
0.9	0.90 - 1.30	1.30 - 1.80
1.0	1.00 - 1.40	1.40 - 2.00
1.1	1.10 - 1.50	1.60 - 2.20
1.2	1.20 - 1.70	1.70 - 2.40
1.3	1.30 - 1.80	1.90 - 2.60
1.4	1.40 - 1.90	2.00 - 2.80
1.5	1.50 - 2.00	2.10 - 3.00
1.6	1.60 - 2.10	2.30 - 3.10
1.7	1.70 - 2.20	2.40 - 3.20
1.8	1.80 - 2.30	2.60 - 3.30
1.9	1.90 - 2.40	2.70 - 3.50
2.0	2.00 - 2.60	2.90 - 3.70
2.2	2.20 - 2.90	3.10 - 4.00
2.4	2.40 - 3.10	3.40 - 4.40
2.6	2.60 - 3.40	3.70 - 4.80
2.8	2.80 - 3.60	4.00 - 5.20
3.0	3.00 - 3.90	4.30 - 5.60

Table A-2 *Required magnification for focal spot slit radiograms in accordance with IEC 60336.*

Nominal focal spot value, f	**Enlargement factor E = n / m**
$f \leq 0.4$	$E \geq 3$
$0,5 \leq f \leq 1.0$	$E \geq 2$
$1.1 \leq f$	$E \geq 1$

7. Index

Note!
Page references in this index points to the first page of the section it mentioned, not the exact page.

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