New method of measuring μ-focus spots of X-ray tubes

M Gnedin[1], E Usachev[2], V Valikov[3], V Gheveler[4] and A Shteyn[5]

[1] Leading specialist of ESPC «Instruments of NDT», MTU MIREA, Moscow, Russia
[2] Director of ESPC «Instruments of NDT», MTU MIREA, Moscow, Russia
[3] Engineer of ESPC «Instruments of NDT», MTU MIREA, Moscow, Russia
[4] Leading engineer of ESPC «Instruments of NDT», MTU MIREA, Moscow, Russia
[5] Engineer, Institute of Non-Destructive Testing, Tomsk Polytechnic University, Tomsk, Russia

E-mail: shteyn@tpu.ru

Abstract. The practice of non-destructive testing shows that despite the whole range of working standards that define the methods of measurement of μ-focus spot sizes, the consistency and spread of the obtained results are considered unsatisfactory. In the meantime, knowing the accurate size of μ-focus spot is the determinant factor in optimization of control parameters, which is often carried out with geometric magnification. A new design of test object is proposed, a new method of differentiated line profiles of test object digital image is developed and tested, the computing chain and allowances are described. The obtained results have formed the basis for elaboration of a Standard to measure μ-focus spot size of an X-ray tube.

1. Introduction

Focal spot size is of a great importance in formation of an X-ray image thus affecting technological capabilities of the equipment and geometric unsharpness, and hence the image quality and detection of imperfections with little opening and contrast.

According to [1], the nominal size of X-ray tube micron spots is up to 100 μm, with permissible deviation of +100 μm.

At present, there is an active standard [2] in the Russian Federation that also governs the measurement method of a μ-focus spot up to and including 0.1 mm.
This section of the Standard may be considered obsolete because it provides for using radiographic film as a detector, sample of a metal grid as a test object, and image optical densities are measured on a microphotometer in the manual mode.

There is an EU Standard that includes five individual standards that standardizes various methods of measuring focal spots, including those of μ-focus tubes [3]. Besides acquisition of an X-ray image of a test object (wire grid or ball) on a film and further photometric measurement on a microdensitometer, the standard allows for the use of an X-ray viewing system and building two-dimensional line profiles of the image intensity.

The issue of measuring effective focal spot of X-ray tubes, including μ-focus ones, is studied in report [4]. The bulk of research was related to measurements of focal spots of 150 μm and more.

Summary data of multiple foreign measurements of focal spots of similar X-ray tubes made by different standards being part of EN 125543 and listed in report [4] have shown that the validity and spread of the obtained values of measurements carried out in accordance with the above-mentioned standard are inadequate.

This can be justified without limitations by so-called "wings" of the obtained images of test objects, which challenges the accuracy of the initial measurements, and also by small line dimensions of the registering surface.

In report [4], it was suggested using a serial laminated holed image quality indicator (IQI) as a test object, which is used in the US radiography practice, and building an integrated line profile of the obtained image and computation algorithm of focal spot sizes, with some allowances. By author's opinion, it all contributed to a better validity of measurements and ability to envisage changes in the respective US and EU standards.

2. Experimental verification of conclusions of the author [4]

The conclusion on poor validity of measurements against EN 12543-5 was verified experimentally by X-ray pattern of figure 1, with the use of eight test objects in the form of steel balls.
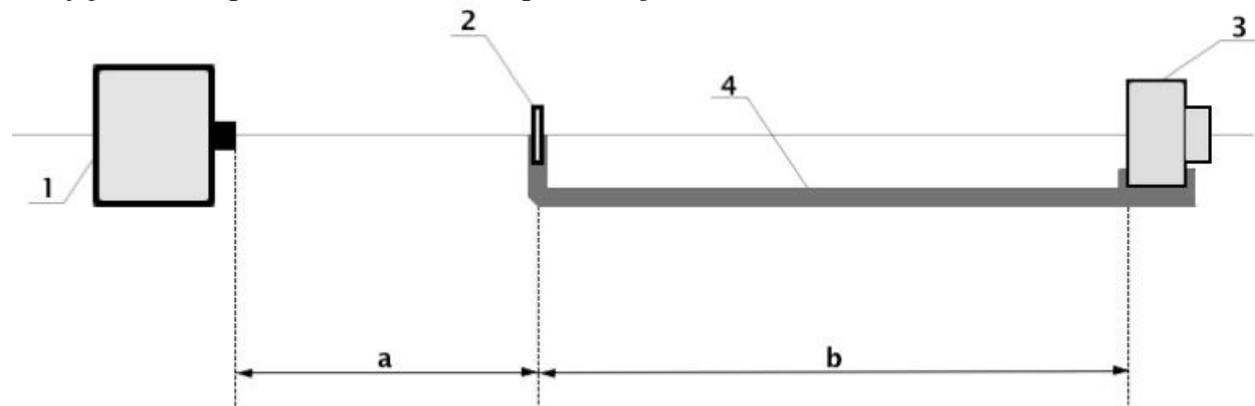
Figure 1. Installation layout. 1 – X-ray source; 2 – test object; 3 – digital X-ray converter; 4 – positioning frame; a – distance between test object and X-ray source; b – distance between test object and converter.

The results obtained are presented in table 1.

Table 1. Focal spot values for eight exposures of test objects.

№	Ball diameter, μm	Focal spot size, (X axis), μm	Focal spot size (Y axis), μm	Accepted focal spot size, μm
1	500	56.8	53.5	56.8
2	500	45.2	66.2	66.2
3	500	49.1	87.0	87.0
4	500	53.1	91.7	91.7
5	500	60.7	108.7	108.7
6	500	52.2	69.1	69.1
7	500	52.3	59.1	59.1
8	1100	34.3	45.0	45.0

The spread of µ-focus spot values for one and the same tube was from 45 µm to 108.7 µm, deviation being 140%.

3. Development of a new measurement method of µ-focus spot size

The following tasks have been solved when developing a new measurement method of µ-focus spot size:
- use of a new design of test object (figure 2);
- use of a better resolution detector;
- differentiation of the obtained image of a test object;
- improved the accuracy of pixel value due to increased registering surface;
- increased the number of simultaneous measurements over one exposure;
- use of extra options of "Diada" software.

Test object is made of five balls fixed on a common basement of thin carton and distanced at finite distances a_{12}, a_{23}, a_{42}, a_{52}. Test object is marked by lead character "T" in the top right corner (fig. 2). The balls are made of steel, d diameters are the same and make 1.15 mm, distances a_{12}, a_{23}, a_{42}, a_{52} (fig. 2) are about the size of the ball diameter d, and measured with an error of no more than 15 µm on the optical microscope MBS-9. Measurement results are recorded in the passport of the test object.

In PR-4 converter (of «Norka» device), an X-ray luminescent screen based on RENEX ERL-G 100 screen of 20 line pairs/mm resolution is used.

"Diada" software for processing digital images has a function of line profile differentiation (LPD) of an image and ability to build an image LPD chart along X and Y axes.
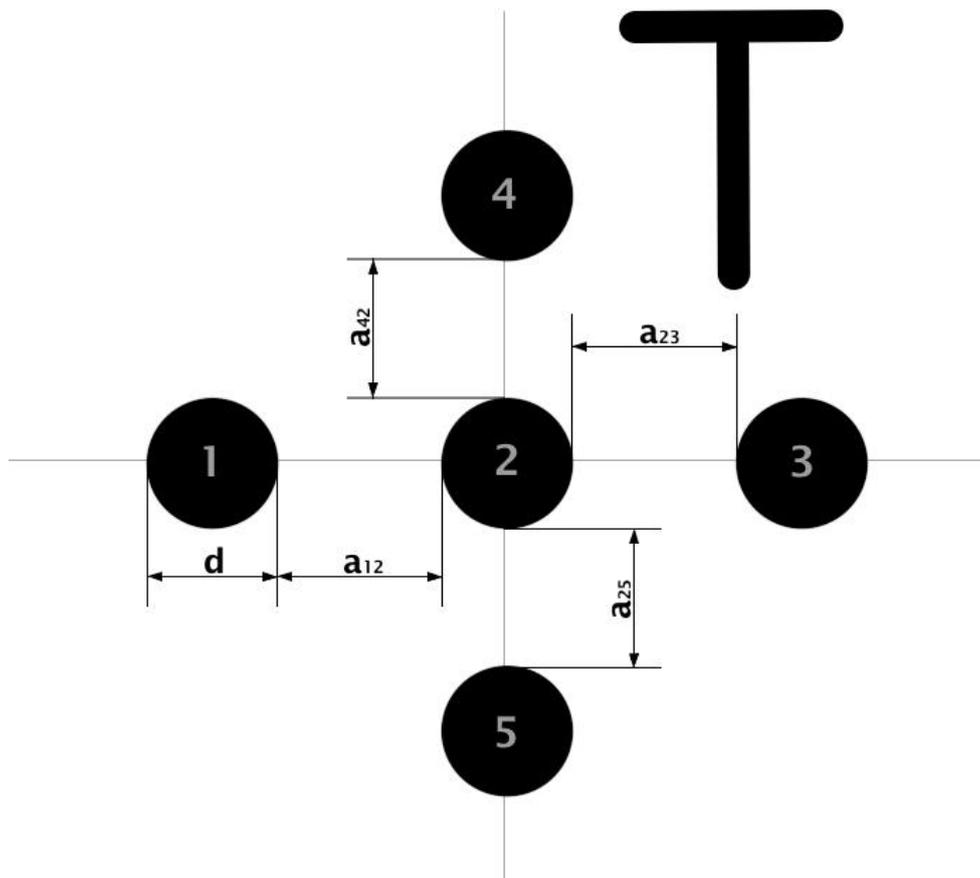

Figure 2. Schematic view of a multi-element test object.

4. Experimental measurements of a μ-focus spot

A test sample (made as per fig. 2) is placed into the device at 280 mm distance (fig. 1, *b* value) from the digital converter using a positioning frame. Distance *a* (fig. 1) is set as 14 mm using laminated caliber.

Geometric magnification value is calculated by formula 1 and makes 21 for the given parameters.

$$M = \frac{a+b}{a}.$$ (1)

As a result of exposure of test object 2 by radiation source 1, a digital X-ray image of a test object shown in figure 3 is derived with a help of a digital converter 3.


Figure 3. Digital X-ray image of a test object.

"Diada" software allows performing LPD along X and Y axes of the obtained digital X-ray image of a test object, the result of which is presented in figure 4.
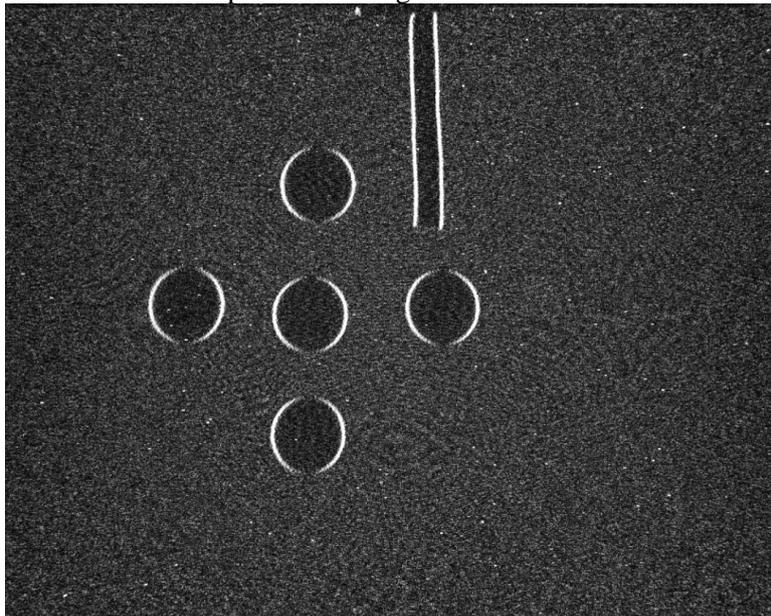
Figure 4. Line profile differentiation along X axis of the obtained digital X-ray image of a test object.

Afterwards, software allows building image LPD charts along X and Y axes, figure 5 showing the result.
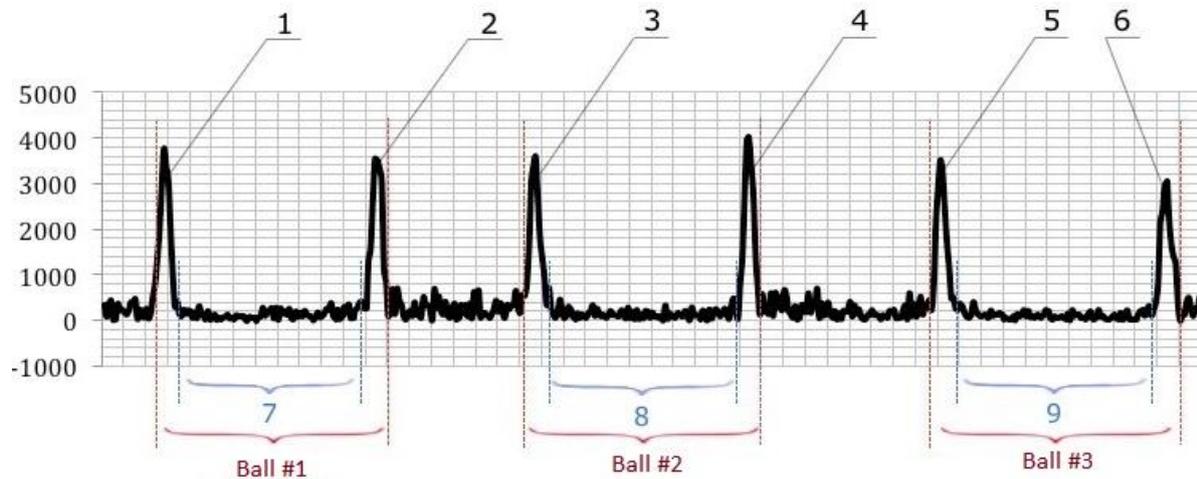
Figure 5. Chart as a result of processing a differentiated image of balls at horizontal/vertical scanning.

Inscriptions "ball #1", "Ball #2", "Ball #3" identify histograms of the respectively numbered balls at horizontal scanning, fig. 2. At vertical scanning, ball #1 will be ball #4, ball #3 – ball #5; 1; 2; 3; 4; 5; 6 are peaks that correspond to the maximums of differentiated image intensity.

5. Defining the X-ray tube µ-focus spot size

Computing is performed in Microsoft Excel, which is part of Microsoft Office package.

The charts obtained are used to do the following (along X and Y axes):

- determine coordinates of the ball centers;
- compute distance in pixels between ball centers;
- find maximum value of the intensity of each peak $I max$;
- determine the minimum value of the intensity of each peak by averaging numerically low values of intensity between adjacent peaks $I мин$.

In order to find the minimum value of intensity I_{min}, "Diada" helps determining the arithmetical average of all numerically low numbers of intensity between the peaks, for instance, between the back edge of peak #1 and front edge of peak #2 in the area of lowest values 7 (figure 5):

- coordinate $I_{0.5}$, is determined by formula (2)

$$I_{0.5}; = (I max + I мин) * 0.5 \tag{2}$$

- the width of every peak at 0.5 level of the intensity in pixels is determined.

The following formula is used to determine the focal spot: (3)

$$\Phi = a * X_{0.5}/C \tag{3}$$

where a is a distance between ball centers in µm (taking values $(a_{12} + d)$; $(a_{23} + d)$; $[(a_{12}+a_{23}) + d]$; $(a_{42} + d)$, $(a_{52} + d)$; $[(a_{42}+a_{52}) + d]$, see figure 2;

d is a diameter of the balls;

$X_{0.5}$ is an averaged width of two peaks of one ball in 0.5 cross-section; along X or Y axis in pixels

C – is determined (by chart) distance between the ball centers, in pixels.

Then we compute the average values of the focal spot size for each ball along X and Y axes. $\Phi_{(x)av}$ and $\Phi_{(y)av.}$

The largest mean value of $\Phi_{(x)av}$ and $\Phi_{(y)av}$ is taken for the focal spot size.

6. Experimental work

Three same-type test objects were used in measurements (1-T, 2-T, 3-T), each was used to determine three values of the μ-focus spot along X axis and three values along Y axis. The largest obtained value of $\Phi_{(x)av}$ and $\Phi_{(y)av}$ is taken for the focal spot size.

The obtained averaged values of the μ-focus spot along X and Y axes for each test object and final values (semi-bold) are presented in table 2.

Table 2.

Test object no.	1 - T	2 -T	3 -T
Φx_{av} μm	**74.7**	71.4	72.73
Φy_{av} μm	71.33	**78.8**	**73.3**

In this case, the spread in values was 5.5 μm or 7.5% ($\Phi_{(x)av}$ 75.6).

It is notable that according to table 1, the average value of a μ-focus spot is 72.7 μm (8 individual measurements) and well correlated with the measurement results on the new method. It again emphasizes poor validity of the results of single measurements.

7. Conclusions

1. The obtained results allow recommending the proposed measurement method of the effective focal spot of micro-focus X-ray tubes for actual application.

2. As a result of work, a company Standard is worked out, and patent application for the method and test object is filed.

References

[1]   GOST 8490-77 X-ray tubes. General technical specification
[2]   GOST22091.9-86 X-ray devices. Measurement of the effective focal spot size
[3]   EN 12543-5 Non-destructive testing - Characteristics of focal spots in industrial X-ray systems for use in non-destructive testing -Part 5: Measurement of the effective focal spot size of mini and micro focus X-ray tubes
[4]   Bavendiek K, Ewert U, Riedo A, Heike U and Zscherpel U 2012 New measurement methods of focal spot size and shape of x-ray tubes in digital radiological applications in comparison to current standards *18th World Conference on Nondestructive Testing, 16-20 April 2012, Durban, South Africa*