euspen's 18th International Conference & Exhibition, Venice, IT, June 2018
www.euspen.eu

A new conversion approach between different characterization methods to measure the spot size of micro computed tomography systems

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Abstract

Up to date, several different approaches are proposed in standards and guidelines to determine the spatial resolution and the focal spot size of micro X-ray sources. From a metrological point of view, the precise measurement of the focal spot is essential, as this is one of the main factors determining the uncertainty of computed tomography dimensional measurements. Besides the fact that the available standards and guidelines are only specified for spot sizes down to 5 µm, there is no consistency among the results of the different approaches. In this work, two commonly adopted approaches, one using a knife edge and the other one using a resolution test chart with line and radial features, are used to evaluate the focal spot size of a micro X-ray computed tomography system. With the combination of these two methods, it is possible to characterize the focal spot of micro X-ray sources over a broad range of the input parameters consistently. The obtained results show the evolution of the focal spot for different source parameters and can be used to determine the optimal source parameters to be set for a desired resolution.

X-ray computed tomography, Spatial Resolution, Spot Size.

1. Introduction

When analysing micro-features and structures using X-ray computed tomography (CT), a sufficiently small focal spot size is necessary to obtain high-resolution images and high metrological structural resolution [1]. The existing standards for the characterization of the focal spot size of micro X-ray sources are collected in the series EN 12543 [2], which propose different methods for the evaluation of micro focus X-ray sources in a range of 5 µm to 300 µm. However, none of these methods is fully comparable to the others, leading to different results for the same source [3]. New proposed methods allow the measurement of spot sizes below 5 µm (e.g. in [4]), but no specific standard for their evaluation has been issued so far.

For fast visual inspection, standard JIMA resolution charts [5] can be used as spatial resolution benchmark to get an estimate of the resolution limit. However, these charts cover only a few distinct values and thus the true resolution limit is likely to lie between two distinct lines of the target. Moreover, it is not easy to quantitatively analyse the resolution with this method.

Another common method used to assess the spatial resolution of X-ray radiography is the slanted edge or knife edge method [6,7]. The main aim of this approach is to determine the Modulation Transfer Function (MTF) of the system under investigation. Drawbacks of this method are the alignment of the edge with respect to the optical axis and its finite thickness, which can influence the measurement. Besides the application for radiographic systems, the MTF is also commonly determined for optical systems [8]. To overcome the limitations of the above-mentioned methods, this work presents a new approach and a newly designed test-chart with both line and radial features to measure the focal spot size of micro X-ray CT systems. Results of this method are compared to results obtained with the knife edge method and with the JIMA resolution test-chart.

2. Experimental approach

2.1. Test-chart design

The proposed test-chart (see Figure 1) is designed to cover a broad resolution range starting from 66 µm down to 200 nm to fit also the requirements of new X-ray sources with sub micrometre spot sizes [9]. The chart includes linear pattern in a continuous way (in contrast to the JIMA resolution charts) as well as Siemens stars to evaluate the spot size in angular directions. This work focuses on the linear patterns, which are arranged in a row to allow a fast evaluation of the whole resolution range in vertical and horizontal directions. For this reason, a better sampled MTF can be obtained. The broad resolution overlap with methods specified in existing standards allows furthermore the comparison with methods specified in these standards. Thus, this target yields a basis to extend existing standards to smaller spot sizes.

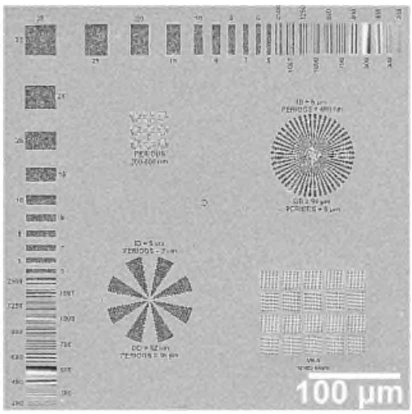

Figure 1. SEM image of the proposed test-chart

2.2. Evaluation method

The evaluation of the different features included in the test-chart (Figure 1) is based on the Michelson contrast defined as:

$$I_{m_i} = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}, \quad (1)$$

whereas I_{m_i} is the contrast for one particular feature pair and I_{max} and I_{min} are the maximum and minimum intensity of this pair. The obtained values are subsequently divided by the contrast of the largest feature which is assumed to be fully resolved. The full workflow to obtain the final MTF values consists of five main steps: (i) test-chart alignment at the highest possible magnification (the test-chart must be imaged parallel to the X-ray detector), (ii) source conditioning and radiograph capture using specific acquisition parameters, (iii) image cropping and region of interest selection, (iv) determination of max/min intensities, and (v) MTF calculation and fitting.

3. Results

Figure 2 shows the obtained contrast values and the fitted MTF for two different parameter settings taken as examples, with source voltages of 40 and 80 kV and fixed power of 6 W. The focal spot-size was determined at 10 % of the MTF (i.e. cut-off frequency of an imaging system) to be equal to 10.1 µm and 8.0 µm, respectively for the two used settings.

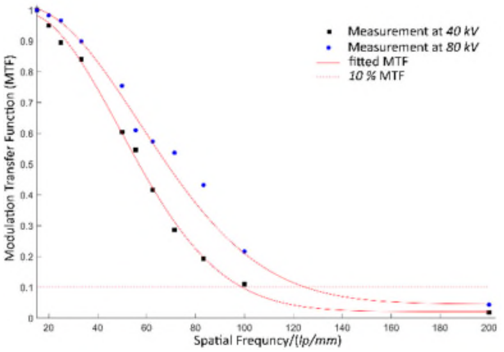

Figure 2. Modulation transfer function obtained for 40 and 80 kV and a fixed power of 6 W.

4. Comparison with other methods

In this section, the results obtained with the new approach are compared with the results of the slanted edge method and the JIMA resolution chart.

4.1. Comparison between test-chart and slanted edge method

The diagrams in Figure 3 show as an example the MTFs measured at 80 kV and 6 W obtained with the test-chart and a tungsten slanted edge with a thickness of 0.25 mm.

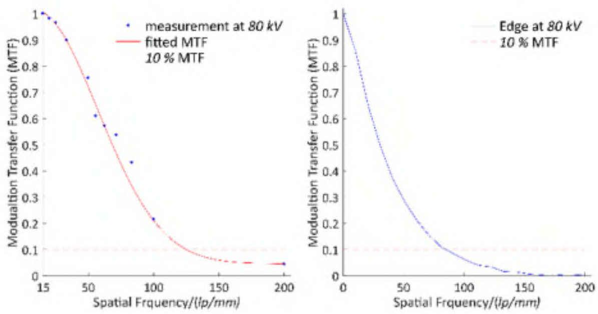

Figure 3. Comparison between test-chart and edge measurements obtained for 40 and 80 kV and a fixed power of 6 W.

It can be noticed that the two curves have slightly different slopes; a possible explanation is that the MTF of the edge incorporates all spatial frequencies, whereas the MTF of the test-chart is only sampled at distinct spatial frequencies and thus does not contain values down to spatial frequencies close to zero. The Results reported in Table 1 show the focal spot sizes measured by the two adopted methods: a difference of 3.8 µm was found in the investigated case.

4.2. Comparison between test-chart and JIMA

The test-chart method was further compared to a third method, which is normally used for a fast visual inspection of the resolution limit. Table 1 includes also the results obtained with a JIMA resolution chart, by applying the same computational approach used for the new proposed test-chart ($\mathrm{JIMA_T}$) and a visual inspection ($\mathrm{JIMA_E}$). It can be noticed that the JIMA results have the same difference (i.e. around 2 µm in absolute value) with respect to the results obtained with the other two investigated methods.

Table 1. Focal spot sizes determined at 10 % MTF for test-chart method, compared with results obtained with slant edge and JIMA. $\mathrm{JIMA_T}$ denotes the values obtained using the same evaluation method of the test-chart, $\mathrm{JIMA_E}$ indicates the values determined visually.

	Measured spot size			
Voltage	**Test-chart**	**Edge**	$\mathbf{JIMA_T}$	$\mathbf{JIMA_E}$
80 kV	8.0 µm	11.8 µm	9.2 µm	10 µm

5. Conclusions

In conclusion, the preliminary results reported in this work show that the newly proposed test-chart can be successfully used to evaluate the focal spot size of micro-focus X-ray sources. The new approach was compared with other well-established methods, such as the slanted edge method and the JIMA resolution chart. This first comparison shows the discrepancy between the different methods and the necessity of a conversion factor. The future developments of this work will be addressed at determining the conversion factor between the different tested methods, in order to obtain a more accurate evaluation of the actual focal spot dimensions. Furthermore, the MTFs obtained with the radial features will be compared to the linear pattern and the other methods to gain more knowledge about the shape of the focal spot.

Acknowledgements

This work has received funding from the European Union's programme PAM[2] within Horizon 2020 under grant agreement No 721383.

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