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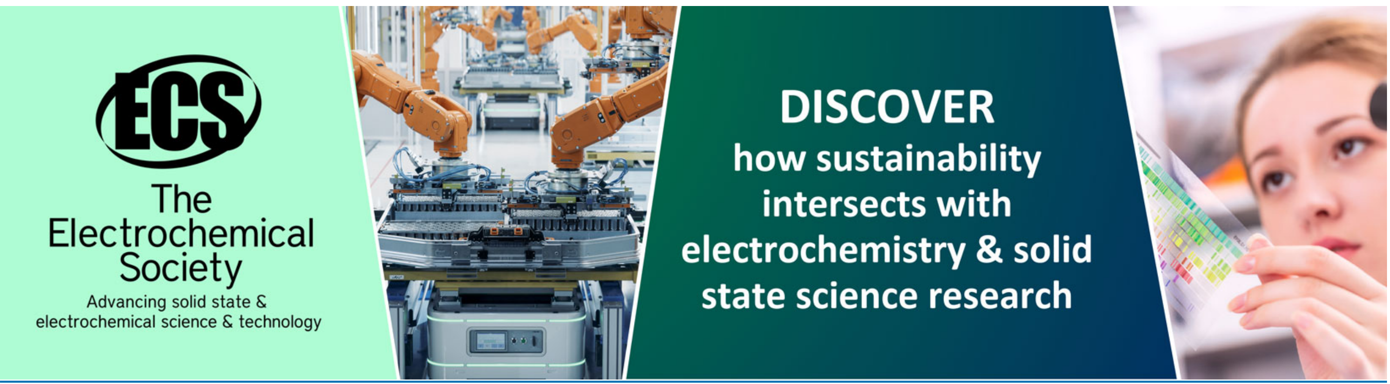

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Determination of the modulation transfer function in betatron tomography

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Abstract. Spatial resolution of high-energy computed tomography is experimentally studied on the basis of X-ray inspection of a steel cylinder to assess the operability of the system [1, 2]. To determine the spatial resolution in the energy range of X-ray radiation from 1 to 4 MeV, the modulation transfer function with a preliminary filtering of radiation by a copper plate of 4 mm thickness was measured. The effect of beam hardening and correction of ring artifacts is studied. The modulation transfer function is determined using the Brucker microCT software. Experimental studies were conducted in the Russian-Chinese scientific laboratory for X-ray control and inspection of the Tomsk Polytechnic University [3, 4].

1. Introduction

Currently, there is an increased interest in high-energy X-ray sources due to the emergence of new areas of application. Especially the need in small betatrons with a maximum energy of X-ray radiation from 1 to 10 MeV does not weaken. These betatrons are manufactured in Tomsk Polytechnic University and are used in many fields of science and industry.

Small-size betatrons have a number of unconditional advantages, which include:

- mobility;
- high penetrating ability (up to 430 mm of steel), which makes it possible to control industrial thick-walled hollow articles, large-sized objects in industry, transport and large-sized cargoes in inspection check out;
- possibility to carry out control at reduced radiation dose rates;
- relatively low instability of radiation parameters from pulse to pulse;
- small size of focal spot;
- the possibility of forming sequences of X-ray pulses with different maximum energy, which leads to the lack of an alternative to small-size betatrons as sources of high-energy X-ray radiation, with regard to mobile inspection check out systems with the recognition of materials of control objects and their structural fragments.

In the last decade the computed tomography (CT) is widely used not only as a means of visualizing the internal structure of research objects (RO), but also as a powerful tool for solving various measurement problems [5-7]. Such measurement tasks include, for example, the estimation of coordinates, linear dimensions, areas, volumes and masses of RO structural fragments, measurement of porosity, moisture distribution by RO, etc. In particular, in the building materials industry, CT is used to assess the uniformity (by density, porosity) of building materials for various purposes. Tomography makes it possible to estimate the specific surface area of the grain material, the filling

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factor of the volume and the specific contact number, which makes it (CT) an indispensable tool in the development of technologies for the production of promising materials, including porous ones, for building, aircraft construction and rocket construction [8].

Along with capillary and various realizations of optical monitoring methods, CT is acquired a special place in the investigation of surface and near-surface layers, as a result of the methods combination the degree of confidence in the testing results increases. Tomography makes it possible to detect and evaluate the opening of cracks in various objects subjected to various physical influences at an early stage of the development of cracks. Analyzed method becomes an essential tool for research in the theory of compression, mass transfer, destruction, etc.

From the above mentioned it follows that the issues related to the resolving power of CT systems acquire a special significance [9, 10]. The resolving power is characterized by the functions of scattering of a point, a line, and a modulation transfer function (MTF) [11-12]. These functions are evaluated experimentally in accordance with the standards for determining the metrological characteristics of the systems: Standard E1441 – 11, Standard E1570–11, Standard ISO 15708–1, ISO 15708–2, Standard ASTM E1560-11.

2. Methods of measurement

The spatial resolution of CT systems with a conical beam is measured with the correction of the tightening of the beam according to the standard [13]. A steel cylinder with a diameter of 50 mm is used as a test phantom. The cylinder is placed in the CT system at the center of the rotation stage. Three-dimensional CT slices with the beam hardening artifact are reconstructed from the unprocessed projection data. The MTF measurement is based on a set of three-dimensional CT slices (Figure 1).

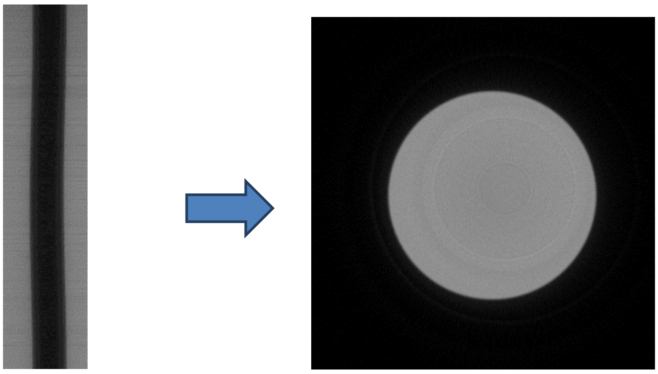

Figure 1. Sinogram and reconstructed slice of the cylinder.

As a result of the reconstruction, the section of the test object, which is a circle, is restored. From this circle holding the rays in different directions (Figure 2.a). For each ray, the μ (linear attenuation coefficient) versus the radius is constructed - the edge response function (ERF) (Figure 2.b).These functions are averaged to reduce the noise level, then the final function is differentiated. The result of differentiation is a function called the line spread function (LSF) (Figure 2.c). The application of the Fourier transform to the line scattering function leads to an estimate of the MTF (Figure 2.d).

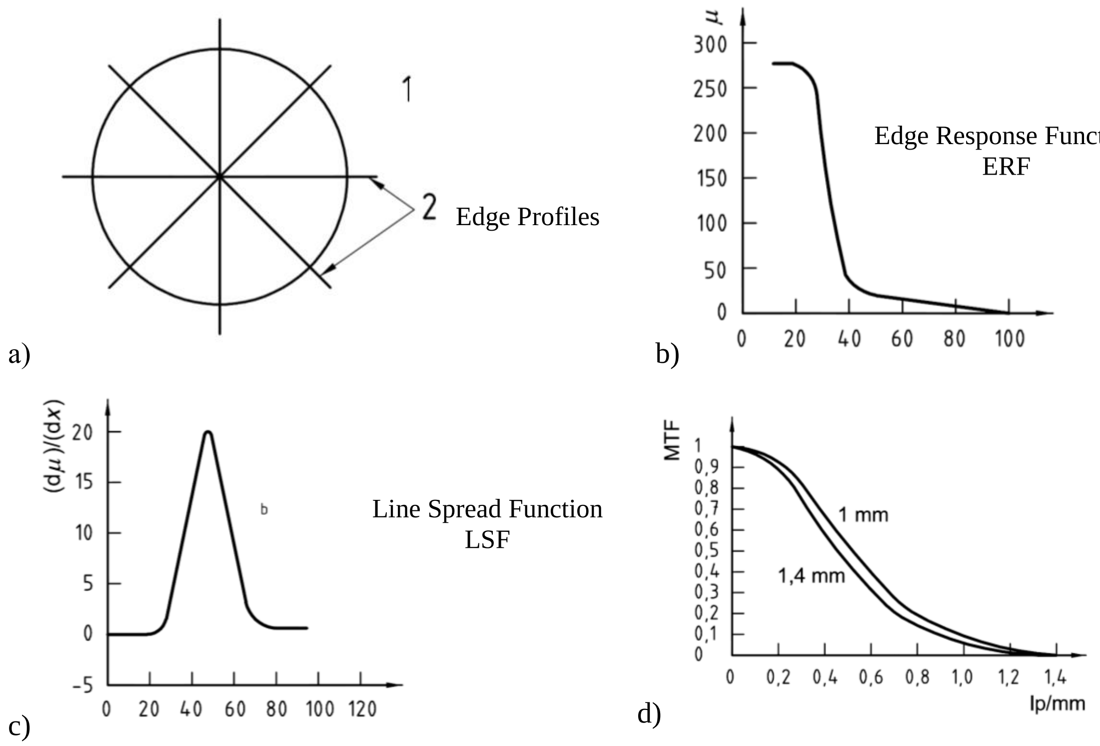

Figure 2. Procedure for estimating the MTF on a cylindrical test object according to the standard.

3. Experiment

The experiment was performed on CT system based on the source of high-energy X-ray radiation with maximal energy of 4 MeV. The scanning geometry for the conic beam model is realized. The system was developed and implemented by scientists from Tomsk Polytechnic University. The main components of the system are: the flat panel detector, the small electronic accelerator - betatron and the rotation table. The detector - the IHe2 panel (Perkin Elmer, USA) has a size of 2048×2048 pixels. The pixel size of the detector is 200 μm. The betatron (MIB 4, TPU, Russia) has a focal spot with dimensions of 0.3 mm horizontally and 3 mm vertically.

4. Correction of beam hardening

In order to increase the effective energy, the radiation was preliminarily filtered with a copper plate 4 mm thick. Figure 3 shows the distribution of the linear attenuation coefficient (LAC) of radiation along the central part of the image of the object without filtration (a) and with filtration (b).

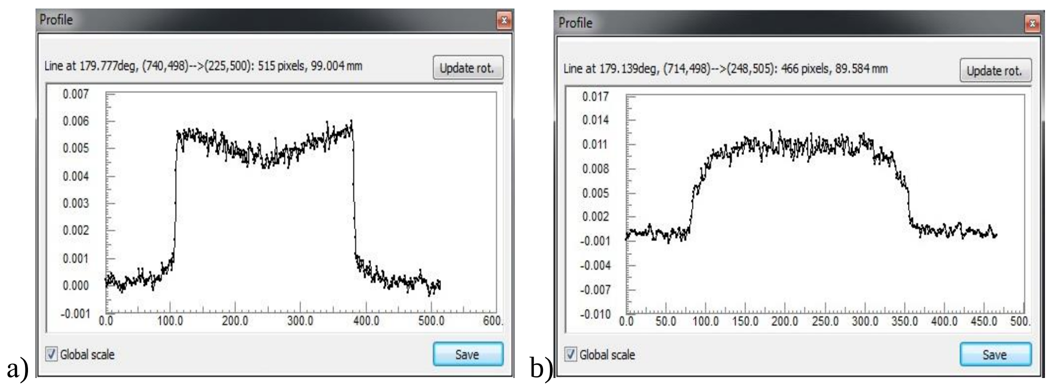

Figure 3. LAC of radiation distribution a) - without filtration, b) - with filtration.

From the analysis of the data shown in Figure 3, it follows that the preliminary filtration of radiation leads to an equalization of the LAC value along the cross section of the object and to increasing the image uniformity.

5. Estimation of spatial resolution

Figure 4 shows the MTF estimations for various values of the maximum X-ray energy, which varied from 1 to 4 MeV. The determination of the MTF was carried out using software from Brucker micro CT.

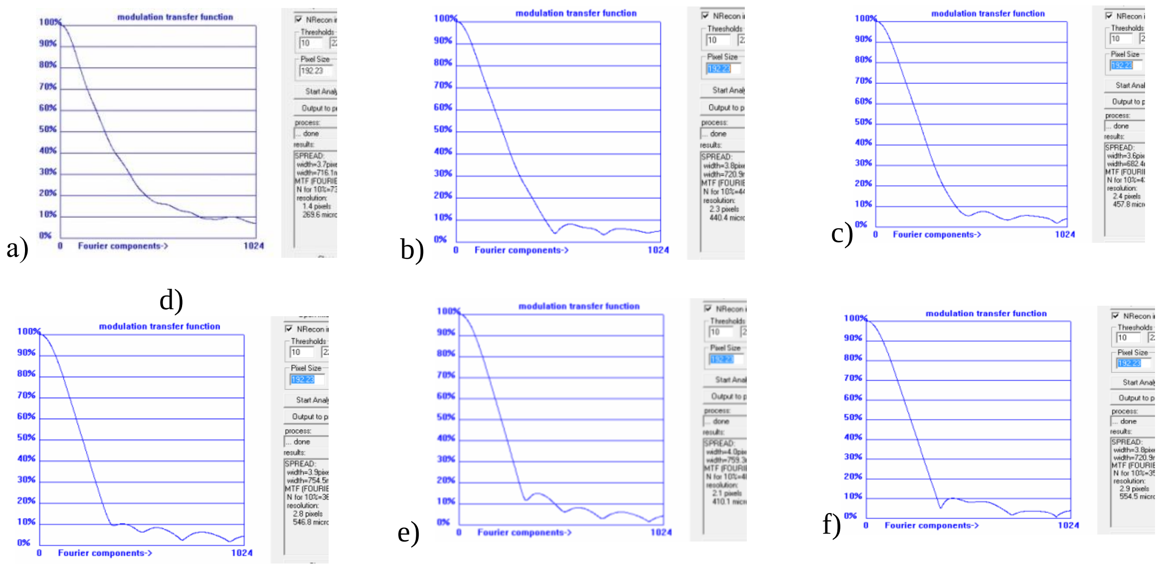

Figure 4. MTF: a) – 1 MeV; b) – 1,5 MeV; c) – 2 MeV; d) – 3 MeV; e) – 3,5 MeV; f) – 4 MeV.

Analysis of the obtained MTFs allows us to conclude that the highest spatial resolution of the high-energy CT system is achieved for a maximum energy of 1 MeV X-ray radiation and preliminary filtration of radiation by a copper plate 4 mm thick and was 269.6 μm. This means that the minimum detectable defect size is 270 μm for steel of 50 mm thickness.

6. An example of using a high-energy computer tomography

A computer tomography based on the betatron MIB-4 was used to detect cracks in reinforced concrete products (Figure 5) exposed to electropulse effects. The analysis of the valid section, shown in Figure 5, testifies to the high probability of opening microcracks in concrete. Despite the relatively low resolution of the CT system, it was possible to detect cracks in the concrete by opening less than 50 μm. The actual crack opening was measured from the optical images of the tested sample.

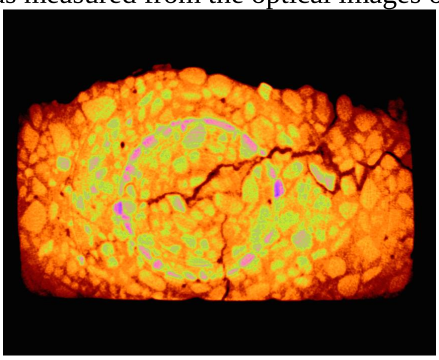

Figure 5. Cross section of reinforced concrete product.

7. Conclusion

A set of theoretical and experimental studies on the evaluation of the modulation transfer function of a high-energy computer tomography of the Tomsk Polytechnic University was carried out. The modulation transfer function was evaluated in a plane recovered cross section. To reduce the influence of nonmonoenergetics, preliminary filtration of X-ray radiation was used.

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