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The selection criteria elements of X-ray optics system

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Abstract. At the design of new modifications of x-ray tomography there are difficulties in the right choice of elements of X-ray optical system. Now this problem is solved by practical consideration, selection of values of the corresponding parameters – tension on an x-ray tube taking into account the thickness and type of the studied material. For reduction of time and labor input of design it is necessary to create the criteria of the choice, to determine key parameters and characteristics of elements. In the article two main elements of X-ray optical system – an x-ray tube and the detector of x-ray radiation - are considered. Criteria of the choice of elements, their key characteristics, the main dependences of parameters, quality indicators and also recommendations according to the choice of elements of x-ray systems are received.

1. Introduction

In the modern world, the most widespread systems for the industrial nondestructive control are x-ray tomography, which are divided on several types: the sizes of the studied quantity, technical characteristics, a scope, etc. As a popular direction of systems' development can be considered microtomography [1]. These systems allow investigating internal structure of objects with micron sizes. These systems are characterized by tension on an x-ray tube from 10 to 160 kV, the small size of a focus spot - from 1 to 10 microns [2, 3]. As betatrons belong to another class of x-ray systems due to other principle of realization and technical characteristics they aren't considered in this article.

At the moment four companies Matrix (Great Britain), SkyScan (Belgium), Feinfocus (Germany), Fraunhofer (Germany) which offer the micro tomography meeting the modern advanced requirements in the field of energy saving, functional characteristics, the accuracy of measurement and a bunch of x-ray radiation are presented at the market [4].

By the creation of new systems of the x-ray tomography the design stage is one of fundamental. At this stage key parameters of technical system according to the specification pay off, essentially new technical solutions are developed [5, 6], configuration of system is made [7].

The activities for development and design of x-ray systems have a skilled character, the choice of a complete set and parameters of system is made by means of theoretical formulas and also intuitive selection of accessories which correspond to these parameters [8]. Before the research scientists and engineers there is always a sensitive issue about the choice of elements of an X-ray optical system [9].

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At design of new systems first of all are guided by the following components: technical parameters of system's elements, a exterior and operating modes of the detector, the size and a type of the studied material [10], requirements to accuracy [11], prime cost, admissible working conditions [12], energy consumption [13–15].

Therefore, it is extremely important to define and mark out the main choice criteria of elements of X-ray optical system.

2. Methodology

The X-ray optical system intended for nondestructive control consists of four elements: an X-ray tube, the detector of X-ray radiation, the system of positioning of a desktop, the studied material [16].

In this article bigger attention is paid to two key elements of X-ray optical system – to an X-ray tube, the detector of X-ray radiation and also the geometrical and spatial sizes of the most X-ray optical system. The final quality of the shadow image, in particular, its sharpness, clearness, optimum scale, an opportunity to recreate the three-dimensional image depends on the choice of the correct distance.

As it has been marked above, a basic element of X-ray optical system is the x-ray tube. We will consider her in more detail. An X-ray tube – the electric vacuum device with a source of radiation of electrons (cathode) and a target in which they are braked (anode) [16]. The main technical characteristics of sources of X-ray radiation are: type of an X-ray tube; range of tension; step of the choice of tension; range of currents on the anode; the maximum power on the anode; power of a x-ray tube; size of a focal spot, mm; radiation angle of emergence, degree.

The key characteristics of X-ray tubes defining them opportunities:

•The focusing elements are electromagnetic or other elements in a tube which "squeeze" the accelerated electrons into so small point on a target as far as it is possible. This point on a target is called a focus spot. The less focus spot, the better permission of the final image is.

•By the size of a focus spot the tubes a is divided into two types: microfocus and nanofocus. The size of a focus spot in microfocus tubes is 3 mkm.

•Exterior and type of a target. The type of a target exerts the direct impact on the size of the shadow image [17]. It also should be noted that the minimum distance between a focal spot and the studied material for various types of targets it is various.

•The target material and material thickness. for increase in service life the good density of a stream of x-ray radiation and at the same time its weak absorption when passing through a target is necessary. Most often the tungsten is used for a target.

Wavelength of X-ray radiation defines his energy, i.e. ability to get into the object. The X-ray radiation with shorter wavelength formed at higher value of kW has bigger penetration in comparison with X-ray radiation with the bigger wavelength (less energy radiation). It should be taken into account as an important nuance that in X-ray tubes with tension to 60 kV only 0.1% of energy will be transformed to energy of X-ray radiation. At a voltage of 100 kV the efficiency of a tube increases to 1%.

We will consider the behavior of X-ray radiation. An object of a research is the most important data source for determination of such parameters as energy of X-ray radiation (tension on a tube), type of a source of X-ray radiation, thickness of protective lead screens (from disseminated) and the scheme of raying. All these parameters are chosen depending on the geometrical sizes of a controlled product that the sensitivity of control didn't exceed a half of the size on depth minimum of unacceptable defects. In the Figure 1 the dependence of thickness of the illuminated material on tension on an X-ray tube is represented. The studied material in this case is iron, an X-ray tube of Hammatsu. These values are received in the empirical way. It is extremely important.

Activities for determination of system's optimum parameters have a skilled character, the choice of a complete set and the modes of system is made by means of theoretical formulas and also intuitive settings. These calculations characterize only a situational (static) condition of X-ray optical system and don't allow estimating the fully behavior of system (change of output parameter) at change of factors' values. The problem is solved with the help of mathematical dependence. As it is shown in the Figure 1 this dependence has the form of a curve and is described by $y = 0.0005x^2 + 0.01x + 0.278$ equation. The share of this factor is 99.68%. It says that the equation has very high rates of accuracy.

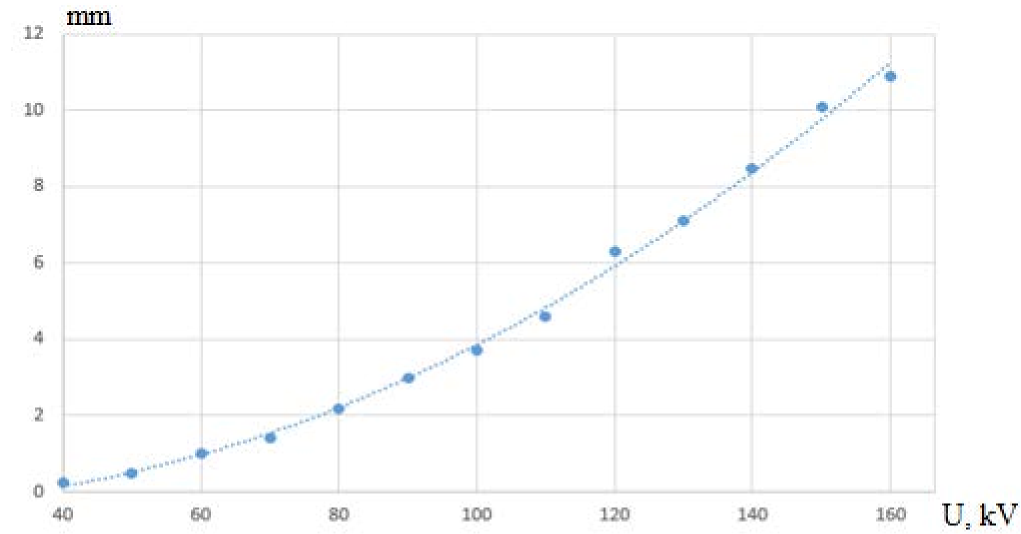

Figure 1. The dependence of thickness of the illuminated material on the tension.

An important role in X-ray optical system it is allocated for the detector of the X-ray radiation and also the distance between an X-ray tube investigated by material and the detector. In the majority of computer X-ray tomography the digital detectors are used. The X-ray digital detector is a device which is intended for obtaining digital X-ray images.

Digital detectors for X-ray have the following main technical characteristics:

- Size of active area of the detector.
- Factor of optical susceptibility of the detector's surface.
- Size/step of a point (pixel) of digital images.
- Extreme spatial resolution.
- Matrix size of the image.
- Graded resolution.

Key parameters of quality of the image, received by means of digital detectors are:

- Unsharpness of the received pictures. This property is characterized by the relation of geometrical unsharpness on projective increase and unsharpness of the detector which are described by the main spatial resolution.
- A contrast ratio to noise. The given characteristic is based on the relation of a signal and noise and also depends on the coefficient of effective absorption of a research object.
- Ratio of a signal to noise. The given characteristic is based on the rated relation of a signal to noise as a dependence of radiation quality and an exposition dose).
- Basic spatial resolution. It exerts impact on the size of effective pixel of a matrix.
- Contrast sensitivity. The characteristic is described by the size equal to the contrast relation to image noise level. Calculates taking into account coefficient of dispersion and coefficient of absorption μ. The characteristic influences the sizes of the studied material and size of an error of measurements.
- Spatial resolution. The increase in the physical sizes of detectors leads to increase in the size of a semiconductor photosensitive matrix, and it always influences the price. Producers differently try to resolve this contradiction. For example, the detector sometimes moves along a sample [16]. The received parts of the image "are sewed" in a common 3D model by means of specialized software. Despite seeming simplicity, it is connected with some technical difficulties. The successful stitching of

the image requires the precision system of the detector's movement. And again it should be noted that the equipping the tomography with the similar system of the detector's movement doesn't lead to reduction of its cost at all.

For the analysis nine digital X-ray tomography, which are presented, at the market have been chosen: Hammatsu, GEDXR250, GE DXR250RT, Perkin Elmer XRD0840, Varian PaxScan 1313, Toshiba E5877J, Toshiba E5876J, SkyScan 210, RadEye200.

The possible to define that the dependence of width of an object on distances on a tube to an axis of rotation of an object changes under the linear law. As a result, the more the value of length of an object at the fixed distance, the broader the range of the studied sizes is that does detectors with these parameters better than competitors [18].

Mathematically projective increase in M can be calculated on the following relations:

$$M = \frac{D_F}{D_O} = \frac{d_f}{d_O},$$

where d_0 is a distance from a focus spot of an X-ray tube to an object, d_f is distance from a focus spot of an X-ray tube to the detector, D_o– the research object size; D_f– projective increase in an object of a research.

From the Figure 2 it is seen that geometrical increase decreases under the hyperbolic law with increase of values of distance from a tube to an object axis.

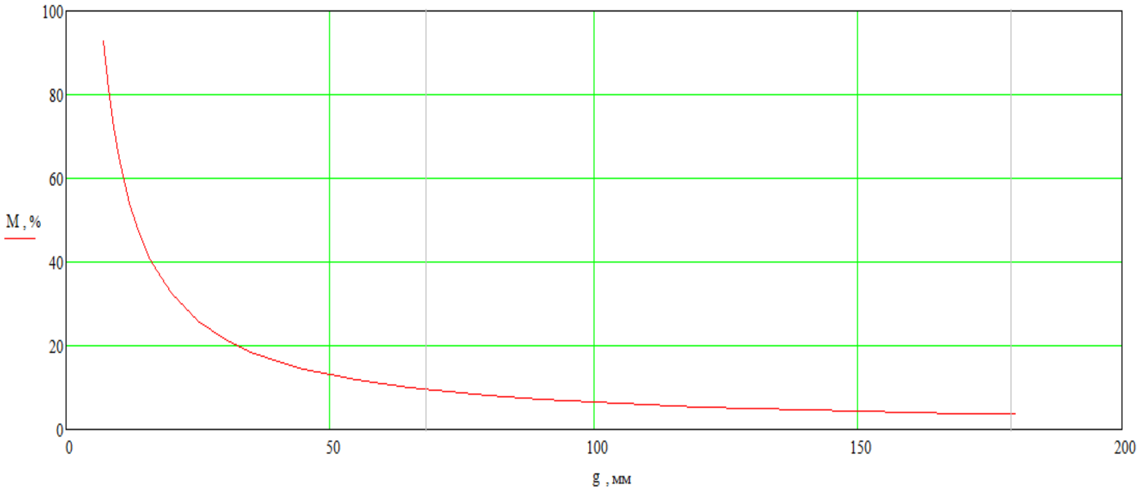

Figure 2. The schedule of geometrical increase from distances from a tube to an object.

The size of voxel calculates as the relation of the pixel size to the geometrical increase of M

$$\left(M = \frac{H}{g}\right): \nu = \frac{p}{M} = \frac{pg}{H}.$$

The size of voxel is an important characteristic of the detector for obtaining the shadow tiff-images and the subsequent three-dimensional reconstruction. She determines the quality of the picture, its specification. Therefore, it is very important to design and choose the sizes of X-ray optical system correctly. The focus length should be chosen so that the geometrical unsharpness was commensurable with value of internal unsharpness. Increase in focus length allows to reduce unsharpness, but at the same time the intensity of radiation decreases and exposition time increases. In X-ray tubes the small focal spot allows to get better permission. The bigger the spot is, the more indistinct contours are and permission of the received image is more limited.

From the Figure 3 it is possible to define, that the size of the detector's voxel changes under the linear law depending on changes of values of distances from an X-ray tube to an axis of an object rotation. The best indicators from the detectors given in this calculation were shown by SkyScan and Hammatsu.

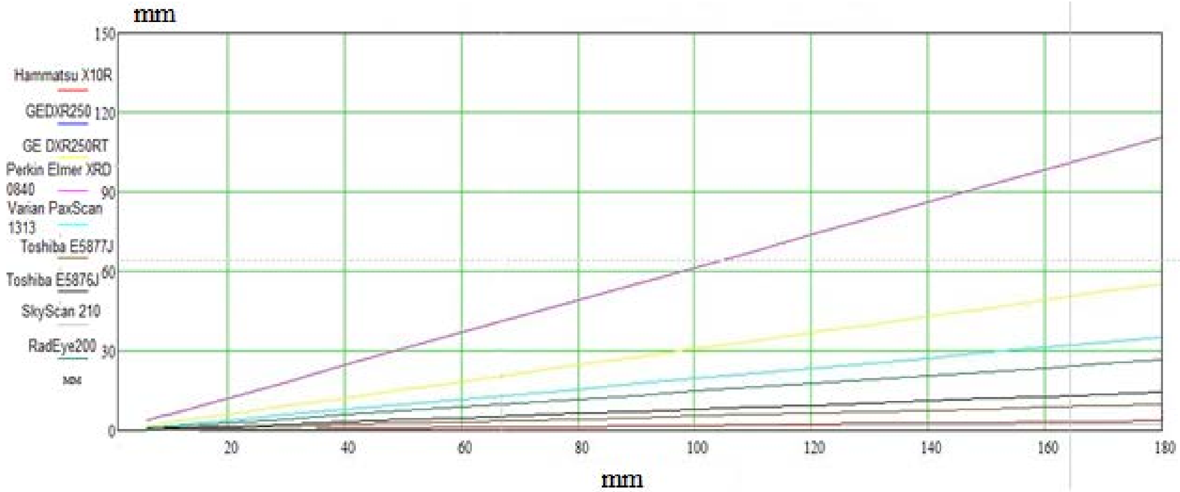

Figure 3. The schedule of dependence of the size of voxel from distances to a rotation axis.

The possibility of reliable reconstruction of the dose field and, therefore, structure of an object of diagnostics significantly depends on the mode of carrying out a tomography. The quality of the received image and the resolution of system depend on the choice correctness of such parameters as distance, tension, current, etc. For example, the image removed at a voltage of 80 kV, noisier, than the removed one at 140 kV. It's extremely important in the choice of elements of X-ray optical system to rely on the criteria offered in the article.

3. Summary

In the conclusion, there is a wish to note that in the article the choice criteria of the elements, their key characteristics, the main dependences of parameters, the quality indicators and also recommendations after the choice of elements of X-ray systems are received. Knowing behavior, the dependences of parameters of X-ray optical system received in the empirical way, it is possible to predict easily and quickly the size of output intensity, tension, current on the anode, the size of a focal spot and voxel. Knowing the dependence obtained from practical data, can accurately and fully describe the system. This fact distinguishes this mathematical dependence on the available theoretical means of calculation. This model has the importance in practice as it allows to receive better shadow images for the creation of three-dimensional images and also facilitates work of engineers and constructs on development of new modifications of X-ray systems. The offered criteria not only will facilitate a set of works on design of X-ray systems, but also it will become useful at the choice of necessary parameters of system for a concrete X-ray research.

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