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CALCULATION OF STRUCTURAL PARAMETERS AND DESIGN OF A PROTECTIVE SHIELD FOR AN X-RAY SYSTEM

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The need to calculate the radiation protection of the radiation system is the basis in which diagnostic, design or assembly activities are carried out as part of non-destructive testing. The paper provides an analysis of the design features of x-ray systems and their technical characteristics, operating conditions, diagnostic capabilities of modern tomographic systems. The dependences of the distribution of X-ray radiation and voltage on the thickness of the protective screen are given. The calculation of the thickness of the protective screen is presented, which will allow you to design the body of the protective screen of the x-ray system. The above studies will facilitate the work of specialists in the development of new modifications of x-ray systems.

Keywords: model, control, design, x-ray radiation, characteristic

Introduction

Any corporation needs a system of non-destructive testing to view the penetration of the internal structure of an object without damaging it. This technology is used in the nuclear, gas, shipbuilding, ship repair and other industries [1, 2]. Detection of defects in a controlled product and its internal structure can be carried out by various types of non-destructive testing, one of which is x-ray tomography. This type of tomography fully controls the geometry and nature of the volume distribution of density, and also allows to see the elemental composition of the product without destroying it. This type of tomography allows to control in detail the geometric structure and nature of the volume distribution of density and elemental composition without destroying the product [3]. In addition, this provides fundamentally new opportunities, especially, the ability to reproduce the internal structure of thick, heterogeneous industrial products of complex shape without overlapping shadows of various elements.

Nowadays with the rapid development of x-ray control systems [4] designers solve a problem with design of the x-ray systems' filter for the restriction of the x-ray radiation exit from working area, for the purpose of personnel protection against the radiation. Often before the team of designers there is a dilemma between reduction of mass of a system and the system effectiveness of protection [5, 6]. Safety of the personnel that work at this system depends on the exact calculation of constructional parameters. The matters are resolved due to the calculation of constructional parameters for the purpose of formation of the most effective system parameters [7], to carrying out skilled tests [8, 9]. Modern requirements for x-ray safety when carrying out nondestructive control and the rule demand that any system based on radiations of big power has to have a specially developed system and the certified protection against x-ray radiation [10-12].

When creating a new x-ray tomograph systems the design stage is fundamental [13]. At this stage the key parameters of technical system according to the specification pay off, essentially new technical solutions are developed [14, 15], configuration of system is made [16, 17]. Activities for the development and design of x-ray systems have a tested character; the choice of the constructional parameters is made by means of theoretical formulas of weakening of x-ray radiation when passing through the material and also the intuitive selection of the accessories which correspond to these parameters [18]. These calculations are very labor-consuming and characterize only a situational (static) condition of x-ray optical system within the specifically chosen values of factors which don't allow to estimate fully behavior of system (change of output parameter) at change of factors values. This fact significantly complicates the work on the development and design of x-ray optical system. In this regard the decision to define and create a method of determination of mathematical dependence which will allow to model the process and to analyze the behavior of the system has been made, will significantly reduce temporary expenses and will increase the quality and also accuracy of the developed systems.

1. Samples and Research Methods

The most wide spread systems for the industrial non-destructive testing (NDT) is x-ray tomographs [19]. X-ray tomographs are divided into several types: by the sizes to the studied sizes, technical characteristics, a scope etc. [20]. Now the most popular direction of development of these systems for the NDT can be considered microtomographs [21]. These systems allow to investigate internal structure of the 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 focal spot - from 1 to 10 microns [10]. The X-ray optical system which is intended for the NDT consists of the following elements [12, 22]:

– a source of x-ray radiation – an x-ray tube;

– detector of x-ray radiation [12];

– the system of positioning with a working surface;

– the software for processing of shadow images and formation of two or three-dimensional images, depending on a type of the x-ray tomograph [23];

– a control system – a hardware and software system on management of system mechanics [24];

– power supply unit;

– filter.

One of the most difficult and responsible sections of x-ray systems' design for nondestructive control is calculation of radiation protection – the filter. In all cases the main room for holding actions within the nondestructive control is the workshop in which diagnostic, design or assembly actions are carried out and in which the x-ray radiator as a source of ionizing radiation is placed [12]. From here the necessity of carrying out the calculation of system radiation protection, i.e. definition of lead or other equivalent of stationary means of radiation protection follows [25, 26]. Having decided on parameters and the sizes of x-ray optical system and also a source of x-ray radiation, there is a task of calculation of the lead screen of protection against x-ray radiation for safe work on this system according to the international standards [27].

The calculation of the lead screen from x-ray radiation consists of three actions:

– determination of necessary coefficient of x-ray radiation weakening which shows in how many times it is necessary to reduce the dose power to the admissible size;

– determination of lead protection thickness that is necessary for the deceleration of power of the dose absorbed in the air that is created by a source of x-ray radiation to the admissible size [8];

– recalculation of the found lead protection thickness on that material from which there are designed the building constructions or other devices;

– choice of the quality of filter material and its structure.

– The shortcomings of the applied methods of calculation of radiation protection are:

– physically incorrect expression of the key calculated parameter – coefficient of weakening of radiation,

.

– lack of accounting of orientation of primary bunch of radiation and the movement of the last one during the research (the panoramic tomographs, x-ray computer tomographs that can scan devices),

– the outdated list and working loadings of the x-ray diagnostic devices used in practice, including devices with digital receivers of the image, outdated standards and units of measure of maximum permissible radiation levels.

A special role when calculating the constructional parameters of system is played by such parameters of material as quality and uniformity of material of the filter (availability of foreign particulates, susceptibility to wear), existence of places of deformation [12], sutural and welded connections. The requirements to the systems:

– The system of the x-ray tomograph' filter has to be completely certified according to the ROV standard.

– All systems have to correspond to the local rules and resolutions. For example, in Great Britain it "Rules of the address with sources of ionizing radiation".

– The maximum admissible value of level of the filter radiation leakage shouldn't exceed 5 mSv/h (in the USA), 1 mSv/h (in the other countries).

– After the installation and obtaining the certificate all the x-ray systems undergo the final testing in order to avoid casual radiation of personnel.

The main settlement parameter is a physically correct coefficient of frequency rate of weakening. The coefficient of frequency rate of easing represents the relation of power of the x-ray radiation absorbed dose in this point of air in lack of protection of D_0 to the admissible power of the absorbed dose in air N_D [5]. For the calculation of coefficient of x-ray radiation weakening when determining power of a dose in air in x-rays for an hour use Equation

$$K = \frac{I}{R} \cdot N_D ,$$

where I - is the standard anode current of a x-ray tube; R - is the distance from an x-ray tube to the place of protection, m; N_D - is the admissible power (exposition) dose of radiation absorbed in air, P/hour.

Size of N_D is found by means of help tables. Necessary thickness of lead protection depends on the coefficient of easing and tension on an x-ray tube and is found in special help tables, which depends on coefficient of x-ray radiation weakening and also tension on an x-ray tube. As it was already noted, passing through the substance, x-ray radiation is absorbed. Materials with a high density most strongly absorb the x-ray radiation therefore the case of x-ray installation is often manufactured of lead, and in some x-ray generators for additional protection against radiation the copper is used. For a start we will designate the key parameters at design of the filter: tension of an x-ray tube; tube power; angle of distribution of an x-ray bunch; distance of an x-ray tube from filter walls; thickness of lead material; level of an x-ray bunch after passing of the filter; existence of sutural connections.

For obtaining dependence of key parameter of an x-ray tube, i.e. the tension and thickness of the filter for creation of mathematical model the following parameters have been determined:

— power of an x-ray tube should be 10 W.

— the angle of distribution of an x-ray bunch should be 90 degrees.

— distance of an x-ray tube from filter walls should be 0.03 mm.

— range of the considered tension should be from 60 to 160 kV.

— the radiation size when passing the filter shouldn't exceed the size of 1 mSv/h, according to the international standards of safety.

2. Results and discussions

In general, a large number of experiments have been made for increase in accuracy of mathematical model, with a step of the tension of the x-ray radiation of 5 kV. The results of an experiment are presented in the Figure 1. In this figure two lines are presented, the line 1 shows the results of theoretical calculations by means of the formulas given above, and the line 2 shows the results of empirical researches at what thickness of the filter, the system completely conforms to the requirements for x-ray safety.

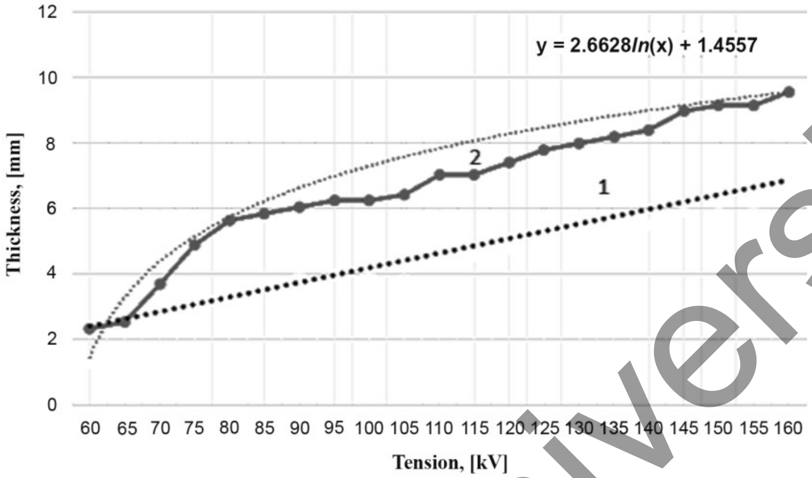

Fig.1. Dependence of tension on filter thickness

On the basis of empirical data, the mathematical model is defined. It submits to the logarithmic law and it is equal to

$$y = 2.66628 \cdot ln(x) + 1.4557 .$$

Proceeding from this schedule it is visible that theoretical calculations don't allow with the required accuracy to count the constructional parameters of the filter and here it is nothing to do without the manual selection. The created mathematical model solves this problem and allows to determine the required parameters of the x-ray system filter with high precision.

For obtaining the dependence of thickness of the filter in a lead equivalent from the angle of distribution of x-ray radiation (parameter of an x-ray tube) for the mathematical model creation the following parameters have been determined:

1. power of an x-ray tube should be 10 W.
2. tension should be 120 kV.
3. distance of an x-ray tube from filter walls should be 0.03 mm.
4. range of an angle of distribution of an x-ray stream should be from 15 to 170 degrees.
5. the radiation size when passing the filter shouldn't exceed the size of 1 mSv/h, according to the international standards of safety.

In general, a number of experiments, with a step of an angle of distribution of an x-ray bunch, that are equal to 5 degrees have been produced. The results of an experiment are presented in the Figure 2. In this figure the empirical results which display the dependence of filter thickness on a radiation bunch angle are presented. At this thickness the system completely conforms to the requirements for x-ray safety. On the basis of empirical data, the mathematical model which submits to the polynomial law of the 3rd degree

$$y = -0.0051 \cdot x^2 + 0.095 \cdot x^2 - 0.73311 \cdot x + 12.133$$

The created mathematical model solves a problem of the automated calculation of constructional parameters within these system parameters and allows to determine the required parameters of the x-ray system filter with high precision, without resorting to the means of manual selection which is not easy, isn't safe and also is temporarily expensive. Excerpts for various modes and parameters of the protective lead screen for the x-ray system, intended for the designed rooms for constant stay of personnel are presented in the Table 1. For this purpose, we will take R=0.3 m.

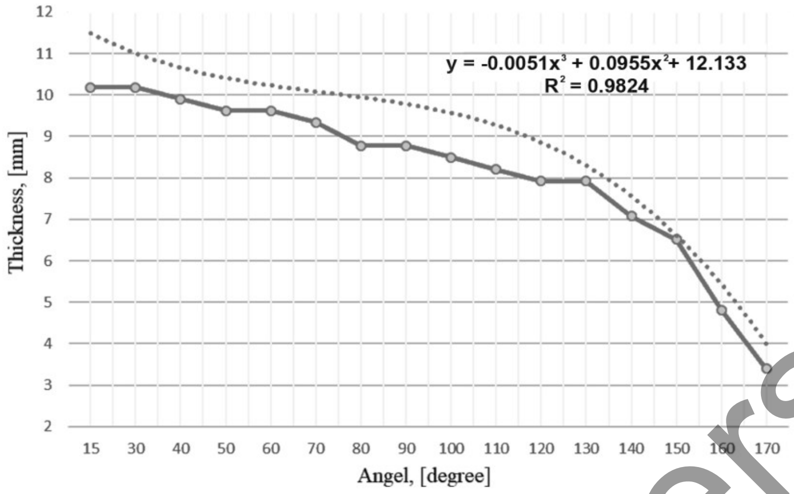

Fig.2. Dependence of an angle of distribution of x-ray radiation and filter thickness

Table 1 presents the empirical model of the dependence of the thickness of the protective screen of an x-ray tomograph on various combinations of parameters of the x-ray optical system. As can be seen from Table 1, when identical parameters are set on the x-ray tube (power, current strength, scattering angle) and, changing only the voltage value, a gradual increase in the thickness of the protective shield is observed, the size of which is achieved at 12.1 mm at a voltage of 140kV. But it is worth noting one behavioral feature of the x-ray protection system. With a progressive increase in the scattering angle and output voltage of the x-ray tube, a progressive increase in the thickness of the protective screen is no longer observed.

Table 1. Calculation of filter thickness

No	Current, [мA]	Angle of dispersion	Tension	Thickness of protection, not less than, [mm]
1	0.1	30	80	8.9
2	0.1	30	120	10.8
4	0.1	45	160	10.7
5	0.1	60	180	11.2

On the contrary, the magnitude of the screen once increases, then decreases in comparison with the previous empirical indication and the entire distribution of the obtained values. This is due to the properties of the intensity value of the output x-ray beam, the propagation model, as well as the value and influence of this or that parameter on the thickness of the protective screen of the x-ray optical system. The most problematic places in the design of the protective shield of an x-ray optical system are places in which different blocks of materials are interconnected. Much attention has to be paid to the sutural and welded connections in case filter layer as the data of the place are the most problem at design of these systems [28]. A big role at design of the filter of x-ray system plays a room type in which it will be applied. During the applying the same values that were in the second series of experiments, it has been found out that in places where the sutural or welded compounds of lead material are observed, holes in the filter are observed where the values of intensity of x-ray radiation exceeds the established norms. The size of excess in many aspects depends on a type and quality of sutural connection, the more professionally this seam is executed, the less the value is. This result is presented in the Figure 3.

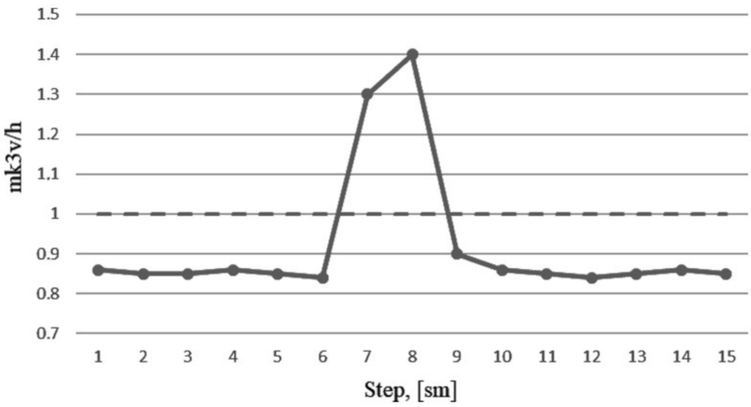

Fig.3. Level of an x-ray radiations

In the situations considered in the Figure 3 it is necessary to accept additional patches over the main material in order to avoid the radiation of personnel. The size of an additional patch is often equal to 1.6 from the main thickness of a leaf.

Conclusion

In the conclusion there is necessary to note that in this article the mathematical models for design of the x-ray systems filter are received, their key characteristics, the main dependences of parameters and also recommendations about design of the x-ray system filter are defined. The unique capabilities of the method of industrial X-ray computed tomography can most effectively be used in the development of technological processes, the development of new products and materials, the control of critical components and mechanisms. Knowing the dependence that was received from the practical data it is possible to calculate precisely constructional parameters of system, and it means that it isn't required it is required additional actions, such as manual selection of material thickness, etc. This fact favorably distinguishes this mathematical dependence on the available theoretical means of calculation. This model has the importance in practice as it allows to design the case of the x-ray system filter that facilitates the work of engineers and constructs on development of new modifications of x-ray systems.

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