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Betatron radiography and tomography of steel castings with large thickness

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Abstract. Steel castings with large thickness are widely used in different areas of industry and the control of steel castings with large thickness is becoming more and more important in order to detect defects and ensure the reliability. In this paper, we carry out betatron radiography and tomography to control the steel castings with large thickness and check the potential ability of Inspection and Examination System (IES) for a high-energy betatron tomography. The results of betatron radiography and tomography of steel castings with large thickness are presented and compared with precedent work, which shows that the IES is considered a promising high-energy tomography system.

1 Introduction

Steel castings of a large thickness are widely used in machinery, shipbuilding, aerospace, oil and gas industry, etc. The conditions for applying steel castings with large thickness are critical: high temperature, extreme pressure, corrosive media, etc. These requirements put restrictions on production.

The examination of steel castings with large thickness is a very important work in order to detect defects and ensure the reliability. In order to detect possible shrinkage porosity, shrinkage shells, inclusions and other defects, it is necessary to set up examination by a high-energy x-ray tomography, which returns complete information of the inspected object with a large thickness. One of the key tasks of the steel castings inspection is the identification of the defect generation mechanisms. Such identification helps with producing optimization, improvement in technology of steel casting production, system reliability and hardware lifetime. Meanwhile non-destructive high-energy x-ray testing is necessary for assessment of the change in density and recognition of detrimental defects in newly produced steel castings with large thickness.

Now many companies produce and develop high-energy tomography to test the thick-walled, large-sized steel castings and products of complex construction. Foreign companies such as Fraunhofer IIS [1], Empa [2], Jesse Garant Metrology Center [3], GRANPECT [4], CZST [5], and domestic companies like PromIntro [6] and JSC "FNPTs Altai" [7]. In our case, the betatron radiography and tomography of steel castings with large thickness were carried out with the help of the Inspection and Examination System (IES) [8] at the Tomsk

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Polytechnic University. The IES was used to inspect a steel castings with large thickness as well a high-energy betatron tomography. By this work, we studied the potential ability of IES working as a reliable tomography system.

2 Materials and Methods

During inspection of the steel castings with large thickness, we conducted experiments of radiographic and tomographic scans with the help of IES as high-energy tomography in Russian–Chinese Laboratory of Radiation Testing and Inspection of the Tomsk Polytechnic University. The general view of the IES and the inspected object are presented in Fig. 1 below.

(a) (b)

Fig. 1. General view of the IES system (**a**) and the inspected object (**b**).

The source of high-energy x-ray radiation is a betatron with 9 MeV energy. The dose rate is 18-21 R/min at 1 meter from the focal spot. The betatron is equipped with a vertical collimator. The width of the collimated beam is approximately 25 mm in the plane of the detector. The size of the focal spot in the vertical direction does not exceed 2 mm.

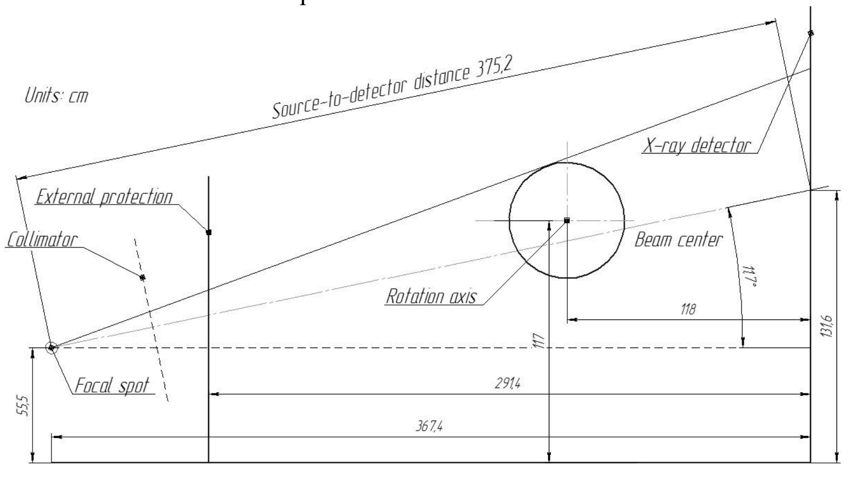

Fig. 2. Scheme of installation for betatron radiography and tomography.

The installation scheme for betatron radiography and tomography is shown in Fig. 2 on the next page. The inspected object was placed on a stand associated by a rotary shaft. The rotator is mounted on a frame with an electric drive for longitudinal displacement of the inspected object in a direction perpendicular to the radiation beam. Using the rotator allows one to shoot from different angles, as well as to collect data for the tomography examination.

For x-ray detection, we use a linear detector manufactured by TSNK-Lab (Moscow). The scintillation material of this linear detector array is $CdWO_4$ and crystal size is 5×6×30 mm^3. The detecting unit contains 608 detectors.

3 Results

Fig. 3 shows a radiogram of steel casting with large thickness and the positions of the tomography slices. Reconstruction was carried out in two programs: INKCT (developed by TPU) and Nrecon (developed by Bruker microCT, Belgium) [9]. In tomographic experiments, the number of projections for each section was 1800 with an angular pitch of 0.2 degrees. The pixel size of the tomograms is 1.72 × 1.72 mm^2. The size of the tomogram is 280 × 280 pixels. Below are the results of tomographic cross sections obtained in the experiments (Fig. 4).

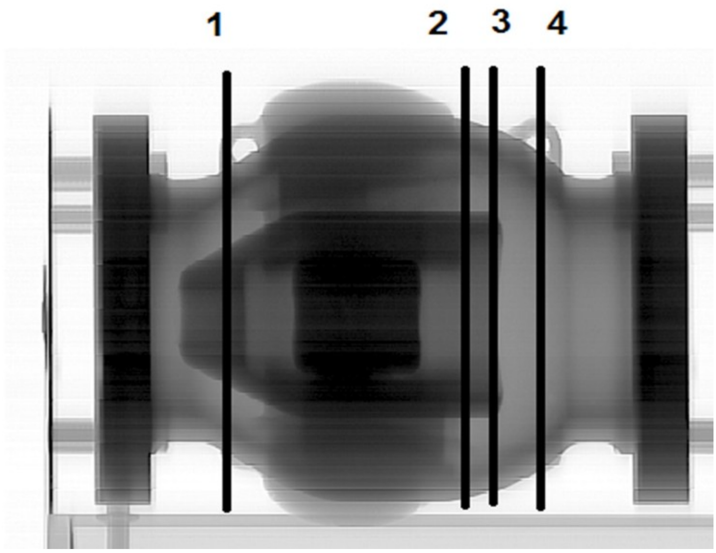

Fig. 3. Radiogram with the extraction of details at a large thickness and the position of the tomography slices.

The presented tomograms in Fig. 4 show that the inspected object is sufficiently transparent for imaging. However, as in the case of radiography, the resolution of the tomograms is insufficient to analyze the presence of defects. In addition, the experiments are burdened by the non-optimal geometry of the tomographic setup. In this case, there is a reason to state that correcting the shortcomings of the installation will provide spatial resolution at the level of 1-2 pixel sizes of the tomograms.

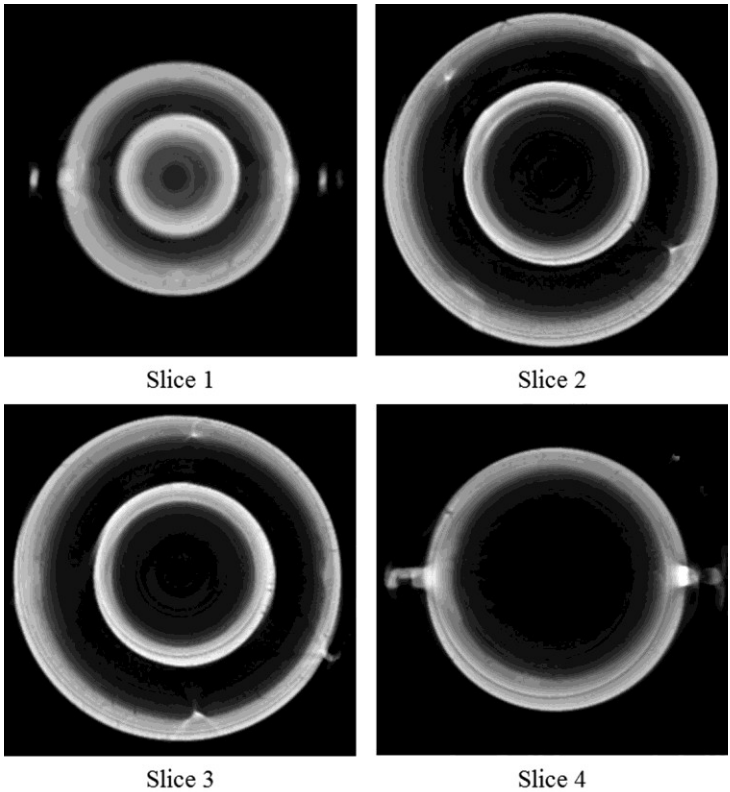

Fig. 4. Tomograms of the selected sections.

4 Discussion

As the results in [10-12] showed, it is difficult to choose a powerful source to penetrate a steel object with very large thickness. Even a linear accelerator can hardly reach a high resolution of a steel casting with such large thickness.

This work can be considered as a continuous research study of [13] and [14]. With a significant increase of thickness of the inspected object, as stated in previous section, the resolution of the tomograms become insufficient to analyze the presence of defects as the experiments are burdened by the non-optimal geometry of the tomographic setup, which indicates the shortcomings of IES to be improved. Take into consideration of the thickness of steel casting is bigger than 100 mm, the experiment results in Fig. 3 and Fig.4 can be thought as with good quality and high resolution.

5 Conclusions

The purpose of the experiments was to investigate the possibilities of using the betatron as an X-ray source for examination of the large-sized cast products. It is shown that a 9-MeV betatron possesses sufficient quantum energy to produce a signal at the declared radiation thickness. It is also shown that radiography and tomography of steel castings with large thickness are possible in principle. However, when designing an installation, it is necessary to strive to increase the resolution of the obtained images by including as many possible elements of the detector as possible. At the same time, the volume of the scintillator should not decrease significantly. In spite of the shortcomings of IES, this work shows the potential ability of IES working as a promising high-energy tomography system.

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