EXPERIENCE OF USING SMALL-SIZE BETATRON MIB-5 IN THE STRUCTURE OF INDUSTRIAL COMPUTED TOMOGRAPH BT-500XA

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Abstract: The report describes characteristics of an industrial tomograph with the maximal tomogram diameter 500 mm when used together with a small-size betatron of the maximal radiation energy 5 MeV. It is shown that such a source yields a high spatial resolution with less output, compared to X-ray devices and linear accelerators.

Introduction: X-ray computed tomography is a high-quality method of non-destructive testing of a complex internal structure of critical products of the modern machine building. In Russia a series of industrial tomographs BT-50, BT-500, BT-800 and BT-1500 are developed and produced. The figures in model designation correspond to the maximal tomogram diameter expressed in millimeters.

These tomographs are a result of a long-term work of scientists and engineers under the direction of E. I. Vaynberg. In his opinion, further improvement of metrological characteristics of industrial tomographs is restrained by a lack of suitable X-ray sources.

The following three parameters of a radiation source are the most important for industrial tomographs: energy of accelerated electrons, size of a focal spot and power density of an electron beam that falls at a focal spot unit area or a unit of its linear size.

Let us call this size a focus width and indicate it W_f. Then the power density of a source can be defined as $P_d = \frac{P_M}{W_f}$, where P_M is total power of an electron beam falling onto a source target. For industrial tomography it is desirable to have a source with the following parameters: energy of accelerated electrons within the range from 2 to 10 MeV, focal spot width W_f 0.1…0.2 mm, power density about 1000 W/mm. However, such sources are not produced nowadays. The best X-ray devices have voltage not higher than 420…450 kV at the minimum focus width 0.8…1.0 mm, and the specific load on a target about 1000 W/mm.

Linear electron accelerators that are the most widespread in the computed tomography of thick products (such as Linatron) overlap the necessary energy range from 2 to 15 MeV and have a typical focus width W_f=1…3 mm at the load on a target about 200 W/mm. Therefore, the main drawbacks of the modern radiation sources for tomography are related to an insufficiently small size of the focal spot; for X-ray devices – small thickness of test products.

Due to the absence of a universal source that would satisfy all requirements, a trend of using two interchanging sources in industrial tomographs is evident. This is the principle of industrial tomograph BT-500XA that comprises a 450 kV X-ray device and a 2 MeV linear accelerator, which raises the price and complicates the maintenance of the tomograph.

Results: Lack of a considerable progress in modernizing conventional radiation sources for industrial tomography over many years stimulates the search for alternative sources.

One of such sources can be a rather simple and inexpensive radiation source on the basis of small-size pulse betatrons that are developed in Research Institute of Introscopy at Tomsk Polytechnic University. Such betatrons are manufactured jointly with the firm “JME Ltd.”. A separate report is devoted to these radiation sources within the framework of this conference; that is why there is no need to focus on their characteristics.

Nominally a small-size betatron satisfies two of the three requirements: such betatrons are produced for energies from 2 to 10 MeV; the focal spot width of all models is unique – 0.2…0.3 mm.

However, low load of about 20 W/mm to the target is a serious disadvantage of the small-size betatrons. That is why during a long period of time it was believed that small-size betatrons are not good for industrial tomography. Nevertheless, in 2003 experiments on application of the small-size betatron as a radiation source for industrial tomograph BT-500XA were performed in 2003.
A prototype of MIB-5 with the maximum energy 5 MeV and the dose rate about 2 cGy/min was used in the experiments. The distance from the target was 1 m, the focal spot width was 0.2 mm. This betatron was intended for another purpose and was installed on the tomograph unchanged. By the way, no changes were made in the tomograph itself except for a simple support for the betatron.
The appearance of tomograph BT-500XA and betatron MIB-5 is presented in Fig. 1. Metrological characteristics of the tomograph were estimated with the help of standard samples and simulators, whose tomograms are shown in Fig. 2.

Fig. 1. Tomograph BT-500XA and betatron MIB-5.

The main metrological characteristics of tomograph BT-500XA in combination with various sources are given in Table 1.

Table 1

Radiation source	Isovolt 450 HS 450 kV focus 0.8x1 mm	Linatron 200A 2 MeV focus width 2 mm	Betatron MIB-5 5 MeV focus width 0.2 mm
Effective thickness of a tested layer, mm	0.5…3.5	1…3.5	1…3.5
Limit of spatial resolution, pair/mm	3	1	5
Measuring inaccuracy of linear sizes inside a test object, mm	0.05	0.1	0.05
Sensitivity to local defects in the shape of: pores, mm^3 metallic inclusions, mm^3	 0.1 0.03	 0.3 0.03	 0.4 0.05
Sensitivity to arbitrarily oriented cracks, mm	0.05	0.05	0.05
Maximum thickness of a test object in steel, mm	50	120	150
Duration of testing, min	4…8	4…8	10…60

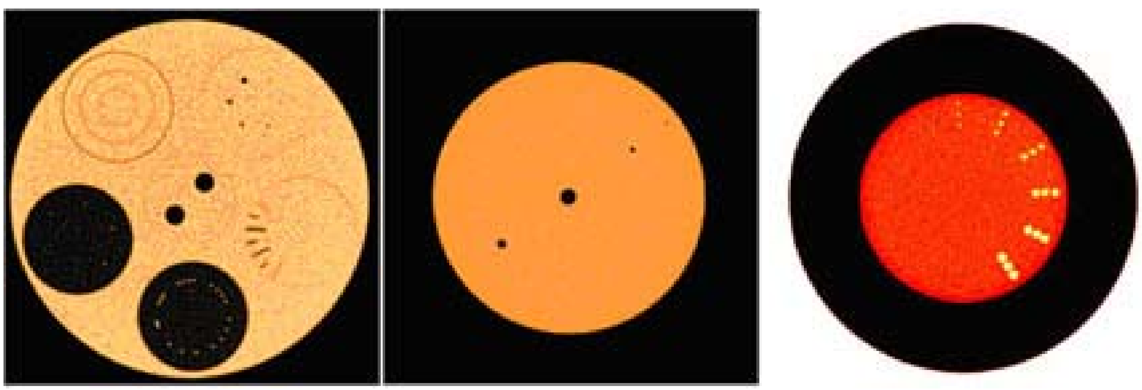

Fig. 2. Tomograms of standard specimen CO-1-A of a steel cylinder of 150 mm diameter with holes Ø 8, 4, 2 and 1 mm, and a hollow steel cylinder of 150 mm external diameter and 30 mm wall thickness, filled with dielectrics with a group of holes Ø 3.5…1.0 mm.

Thus, if the control duration is not critical, application of betatrons such as MIB-5 as a radiation source in the structure of computed tomographs such as BT-500XA allows spatial resolution more than 5 line pairs/mm, which is 5 times more than the resolution of the same setup equipped with a linear accelerator of Linatron type. Problems of technical maintenance being comparable, the price and dimensions of the portable betatron are many times lower than of a linear accelerator, and even lower than the price of industrial 450 kV X-ray devices whose penetration is three times worse than that of MIB-5.

Discussion: Figs. 3 and 4 present tomograms of some complex products of a automotive and aerospace purpose, whose testing by conventional X-ray devices is impossible because of a great radiation attenuation of these sources.

Each of the tomograms confirms advantages of MIB-5 high radiation energy and small focal spot width. For instance, the left side of Fig. 4 presents a group tomogram of simultaneously X-rayed 13 cooled turbine blades made of a high-temperature nickel alloy. According to this tomogram obtained over 10 minutes, one can clearly see remainders of unmelted material in two blades; wall thickness of each blade can be measured with 0.05 mm inaccuracy. Thus, tomograph BT-500XA with MIB-5 provide control productivity of more than 1 blade per minute. The same tomograph together with a conventional 450 kV X-ray device can X-ray only one blade over 3-4 minutes. In case of a group tomography, high bremsstrahlung energy of the betatron compensates disadvantages of a long exposure, especially in control of dimensions.

Fig. 3. Tomograms of a cylinder block head, a steering tube of a lorry and an internal-combustion engine.

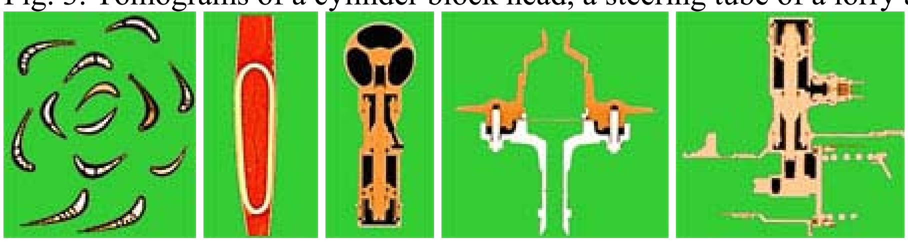

Fig. 4. Group tomogram of 13 cooled turbine blades, tomograms of a helicopter blade and rocket valves.

Tomograms of real products of electrical engineering and machine building obtained with the use of betatron MIB-5 are shown in Figs. 5-6.

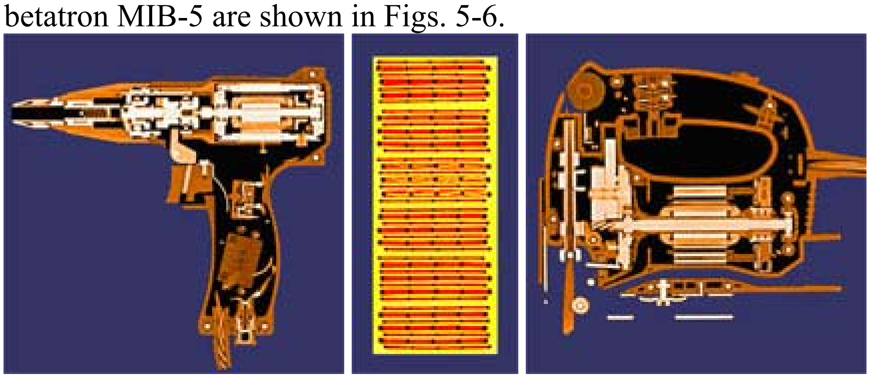

Fig. 5. Tomograms of a power drill, accumulator and electric fletsaw.

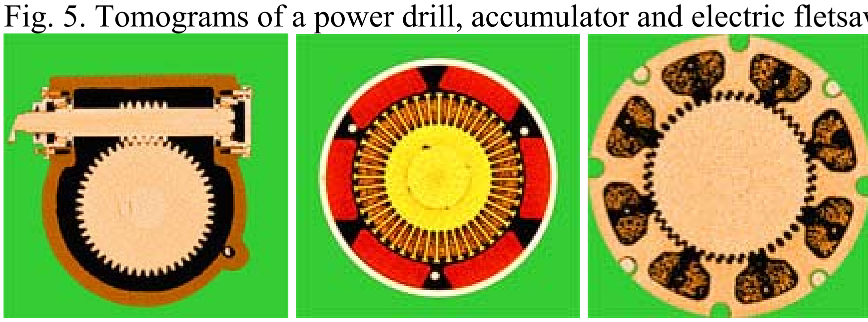

Fig. 6. Tomograms of a worm-and-wheel gearbox, direct-current motor and step motor.

Conclusions: Thus, we have experimentally shown a practical possibility and efficiency of using small-size betatrons of MIB series produced by Institute of Introscopy at Tomsk Polytechnic University in computed tomographs of BT series with the purpose of technology development and non-destructive testing of critical industrial products if there is no need in high productivity.

In conclusion, we would like to point at some facts relating to application of small-size betatrons in tomography.

RII performed works testifying that the betatron allows any small size of the focal spot but the size reduction relates to the radiation dose rate decrease. The focal spot width can be reduced to 0.1 mm at a slight decrease of the dose rate not more than 10%.

Betatron MIB-5 was produced in 1985. In the modern betatron samples, the dose rate is twice more, the dimensions and the weight being the same. If the test duration is critical, it is possible to increase the weight and radiation output as well.

The betatron has a unique capability of inertialess adjustment of the radiation energy. For instance, if a given impulse is obtained at a rated energy of accelerated electrons, then the energy of the next impulse can easily be two or three times reduced. This allows obtaining two combined tomograms at different energies.

The betatron radiation pulse is rather short, 2…5 microseconds usually, and can be accurately synchronized. This opens up a possibility of receiving dynamic tomograms when a controlled mechanism is in real operating conditions and its elements are subjected to the corresponding loads.