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CONCEPT OF RADIOGRAPHIC COMPLEX BASED ON IRONLESS PULSED BETATRONS FOR SMALL-ANGLE TOMOGRAPHY

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Abstract

The active research complexes intended for the radiography of dynamic objects with a high optical density are reviewed. The concept of a multi-beam radiographic complex for a small-angle tomography based on ironless pulsed betatrons is proposed. It is possible to use up to 18 compact facilities in a complex; they are located in three horizontal planes. The test object is placed in the explosion-proof chamber. Each facility consists of two typical units: an accelerator unit, and a unit of the electromagnet pulsed powering system. The output parameters of the facility are the maximum transmission ability of 200 mm of the lead at 1 m from the betatron target, the resolution of less than 1 mm, the gamma-pulse full width at half maximum of 100 ns in a single-frame mode, the gamma-pulse full width at half maximum of 150 ns in a three-frame mode. The complex will be able to obtain up to 54 frames in one hydrodynamic experiment at the operation of each facility in a three-frame mode. The complex is compact. Its diameter with a service area will be 20 m.

INTRODUCTION

Powerful pulsed radiation sources of optimal spectral composition are required for the radiography of dynamic objects with the large optical thickness. The generators of such radiation are either linear or cyclic accelerators.

The information content of the radiography can be considerably increased in case when an object is X-rayed by several beams with independent spatial coordinates. In this situation it is possible to start solving the task of the distribution material recovery in the test object without making an assumption of the object symmetry. The realization of this experiment geometry is possible by using several accelerators or an electron beam distribution to the necessary number of targets. The electron beam in the second case might be generated for example by a linear accelerator.

According to the authors’ opinion the realization of the first case scenario is more preferable. It has an advantage with respect to the variant of the distribution of the linear accelerator beam. The first case makes every X-ray beam be shaped independently by its accelerator and the total number of information quanta increases proportionally to the number of accelerators.

REVIEW OF ACTIVE RADIOGRAPHIC COMPLEXES

Nowadays there are several active radiographic complexes based on the linear accelerators. It is worth mentioning the well-known USA complexes such as DARTH-I, DARTH-II, FXR, the Chinese complexes such as DRAGON-I, DRAGON-II, the French complex AIRIX, and others [1]. The main characteristics of these radiographic complexes are presented in Table 1.

The ironless pulsed compact betatrons of the BIM type [2,3,4] have been used in FSUE “RFNC-VNIIEF” and FSUE “RFNC-VNIITF” for a long time in radiographic complexes to conduct hydrodynamic investigations. In particular, there have been the investigations of the substance behaviour in extreme conditions [5]. The complexes of FSUE “RFNC-VNIIEF” and FSUE “RFNC-VNIITF” are called X-Ray Complex based on the Betatron (XRCB) and X-Ray Complex based on the Betatron-1 (XRCB-1). These complexes contain three and two accelerators of BIM 234.3000 type respectively. The main characteristics of the Russian radiographic complexes based on betatrons are provided in Table 2.

Table 1: Characteristics of the Active Radiographic Complexes

Parameters	AIRIX, France	FXR, USA	DARTH-I, USA	DARTH-II, USA	DRAGON-I, China	DRAGON-II, China
Electron energy, MeV	20	18	19.8	18.4	19.2	20
Beam current, A	3500	2300-3400	2000	2000	2540	2500
Pulse width, ns	60	65	60	4×(20-100)	70	3×60
Beam diameter, mm	1.6-2.0	3.2-3.5	1.9-2.1	1.9-2.1	1.0	1.0

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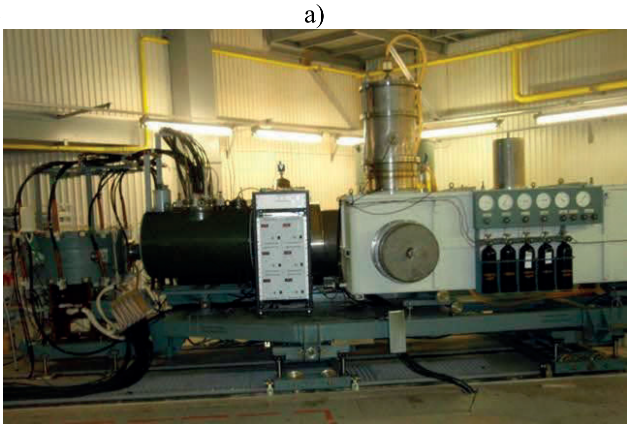
Table 2: Characteristics of the Russian Radiographic Complexes

Parameters	XRCB	XRCB-1
Boundary energy of γ-quantum, MeV	53	65
Exposure dose per pulse at 1 m, R	30	35
Pulse width in a single-frame mode, ns	120	150
Pulse width in a three-frame mode, ns	220,160, 120	250,180, 150
Focal spot dimension, mm^2	2×4	2×6

Photographs of the radiographic complexes of XRCB and XRCB-1 are shown in Figure 1.

a)



b)

Figure 1: Photographs of the radiographic complexes of XRCB (a) and XRCB-1 (b).

At the present moment the new complexes construction works are in progress. In general, those are the complexes that are based on linear accelerators with advanced output parameters: Scorpius [6], LIA 20 [7].

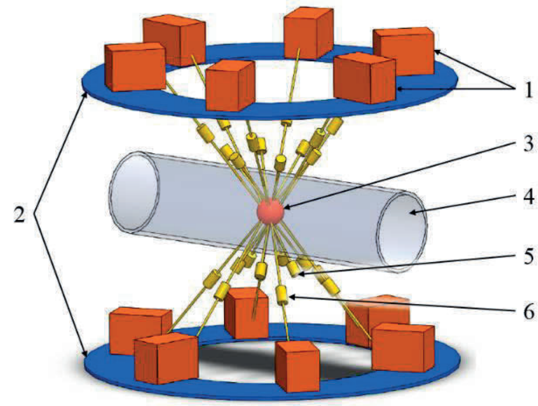


Figure 2: The sketch of a radiographic complex with a horizontal arrangement of the EPC: 1 – cyclic accelerators; 2 – horizontal planes for accelerators arrangement; 3 – test object; 4 – EPC; 5 – shadow image recording system; 6 – X-ray collimation system.

DESCRIPTION OF RADIOGRAPHIC COMPLEX FOR SMALL-ANGLE TOMOGRAPHY

The concept of a multi-beam radiographic complex based on ironless pulsed compact betatrons of a new generation for a small-angle tomography was proposed in 2011 in FSUE “RFNC-VNIIEF” [8]. A sketch of the complex with a horizontal arrangement of the explosion-proof chamber (EPC) is presented in Figure 2. There is a variant with a vertical arrangement as well.

Twelve facilities (1) in two horizontal planes (2) (six facilities in each plane) are supposed to be arranged in this experiment geometry. The test object (3) is located in the EPC (4). The X-ray collimation systems (6) and shadow image recording systems (5) are used. Each facility consists of two typical units: an accelerator unit and a pulsed powering unit of the betatron electromagnet. There is the equipment of the X-ray radiation source in the accelerator unit; the elements of the pulsed powering system of the betatron electromagnet are located in the other unit. The connection between the units and external automated control system is performed via cables and fiber-optic lines.

The parameters of each facility are as follows. The transmission ability of the radiation source is up to 200 mm of the lead at 1 m from the betatron target. The resolution is less than 1 mm, the full width of the γ-pulse at half maximum is 100 ns in a single-frame mode and 150 ns in a three-frame mode. The testing powering of the accelerator prototype was carried out in 2018 and it revealed the possibility of the declared parameters achievement.

The complex is compact. Its diameter with a service area is about 30 m. Considering that a complex can obtain up to three frames, it allows recording up to 36 images in one hydrodynamic experiment.

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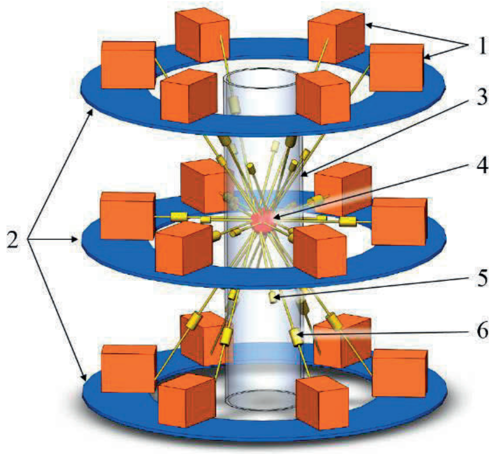

Figure 3: A sketch of the radiographic complex with facilities arrangement in three horizontal planes: 1 – cyclic accelerators; 2 – horizontal planes for accelerators arrangement; 3 – EPC; 4 – test object; 5 – shadow image recording system; 6 – X-ray collimation system.

During the discussions with the specialists of recording and image processing in 2017, it was decided to develop the conception. The variant of the complex with the facilities arrangement in three horizontal planes was proposed. A number of facilities in this concept is varied from 15 to 18. A sketch of the complex for a small-angle tomography with three horizontal planes is shown in Figure 3. It is also proposed to use compact pulsed betatrons of a new generation in this complex. This case makes it possible to obtain the information from 15 to 18 different angles that corresponds to a number of X-ray images from 45 to 54 respectively. The complex is compact as well. Its possible dimensions with a service area are $10\times40\times40$ m^3.

CONCLUSION

Nowadays there is a real possibility to construct multi-beam complexes based on ironless pulsed compact betatrons for a small-angle tomography of dynamic objects with the large optical thickness. These complexes will considerably enhance the information content of hydrodynamic investigations.

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