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Mobile x-ray complex based on ironless pulsed betatrons. X-ray complex conception for small-angle tomography

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Abstract. The conception of creating mobile radiographic complex based on ironless pulsed betatrons is proposed for radiography of dynamic objects having large optical thicknesses. Realization of this conception allows: a) optimizing geometry of the hydrodynamic experiment at the expense of the change of the radiation source and recorder position relatively to the test object, located in the explosion-proof chamber(EPC). Thus, it lets the intensity of the x-ray radiation be increased twice in the recorder plane as compared with available Russian complexes; b) creating an efficient environment protection system at the expense of localization of dangerous explosion products, and a shock wave connected with them; c) significantly decreasing the cost of radiographic complexes, if not building heavy protective casemates and their infrastructure. Instead of them it is possible to use cheap rapidly erected constructions. The mobile radiographic complex is described. Its characteristics, obtained during the testing powering were provided. Thickness of the lead test at 1m from the tantalum target at the limiting energy of the betatron electron beam E_{lim}~12 MeV(it is determined by the value of a capacitive storage of the pulsed powering system of the electromagnet) was ~115 mm. Conception of a multibeam complex creation based on ironless pulsed betatrons for small-angle tomography was also considered.

1. Introduction

At optimum spectral composition, high-power radiation sources are necessary for radiography of dynamic objects having large optical thicknesses. Either linear or cyclic electrons accelerators, betatrons in particular, are such generators.

It is possible to increase information value of the radiography by x-raying the object with three beams having independent spatial coordinates. In this case, it is possible to start solving the task of the material distribution restoration in the test object without suppositions of the object symmetry. Realization of similar geometry of the experiment is possible using either several accelerators or electron beam splitting. The electron beam could be generated, for example, by the linear accelerator to a number of targets.

We believe that realization of the first geometry of the experiment is more preferable. Unlike the multibeam variant with the linear accelerator beam splitting, each beam, in this case, is formed by its own accelerator; and general number of information channels increases proportionally to the number of the accelerators.

Nowadays, there are several active radiographic complexes that realize the first geometry of the experiment. These are Chinese complexes Dragon[1], American complex DARHT[1], English complex HRF AWE[2], Russian complexes XRC-B and XRC-B1.

2. Conception of mobile radiographic complex and results of its realization

Creating XRC-B and XRC-B1 complexes, we accumulated a positive experience which allowed proposing of a new concept of modern radiographic complexes based on ironless pulsed betatrons. The concept is the following: (1) it is necessary to use small casemates for location of the radiographic facilities (betatrons) at hydrodynamic experiments with high-explosive charge of more than 25 kg; (2) it is necessary to use mobile radiographic complexes [3] in combination with explosion-proof chamber (EPC) at hydrodynamic experiments with high-explosive charge at least 25 kg. Figure 1 presents a special variant of such an experiment that allows obtaining of up to 9 frames in one experiment.

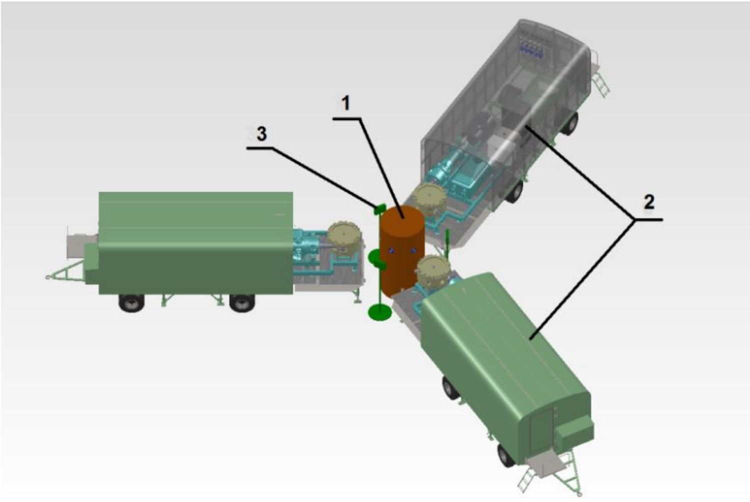

Figure 1. The scheme of the experiment using mobile radiographic complexes in combination with EPC.
1 – explosive-proof chamber; 2 – mobile cyclic accelerators; 3 – system of collimation and registration of shadow images.

In the physical experiment, radiographic facilities and EPC (1) with the test object are located at a test site. Before the experiment, the wall of the cyclic accelerator van (2) is opened and installed horizontally using adjustable supports. The platform with the radiation source is moved on this horizontal surface and stopped at the necessary distance from the EPC. Collimator and shadow image recording systems (3) are located near the EPC. Several mobile cyclic accelerators (MCA) can work with one explosion-proof chamber.

Realization of this concept allows:

1) optimizing geometry of the experiment at the expense of the radiation source and recorder position relatively to the test object, located in the EPC. This allows increasing twice of the intensity of the x-ray radiation in the recorder plane compared to available russian complexes;

2) significantly decreasing cost of the experiment due to lack of expensive heavy casemates and their infrastructure. It is possible to use cheap rapidly erected construction;

3) creating an efficient environment protection system at the expense of localization of dangerous explosion products and shock wave;

4) increasing of the calendar time of hydrodynamic experiments (the experiments are prohibited during the summer period because of fire risks) at the expense of fire safety during the experiments.

3. Experimental prototype of single-beam three-frame mobile radiographic complex

The pulsed ironless betatron of new generation is the basic facility of the mobile radiographic complex. Since 2002, the units and radiation parameters of the betatron have been developed and optimized.

Figure 2 presents a sketch of a single-beam three-frame mobile radiographic complex. It consists of the accelerator (1), unit of pulsed powering of the betatron electromagnet (2), EPC (3), shadow images collimation (4), and recording (5) system. Elements of the radiographic facility are symbolically shown in the accelerator module van. Pulsed powering system of the betatron electromagnet and technological equipment of the complex are shown in another van. The modules and external control system are connected using the cable and fiber optical lines (the links are not shown in the sketch in Figure 2.)

Figure 2. The sketch of the single-beam three-frame mobile radiographic complex.
1 – accelerator; 2 – unit of pulsed powering of the betatron electromagnet; 3 – EPC; 4 – x-ray beams collimation system; 5 – shadow images recording system.

The injector is one of the basic units of the complex. It is designed based on small voltage multiplier [4] and double forming line. This injector allows significantly decreasing (2.5 times) mass-size characteristics of the radiation source as compared with the sources of available Russian complexes [5]. The facility dimensions are 4500×2000×1800, total weight is about 5 t. The main units and systems of the oscillator are similar to those of earlier developed complexes. Figure 3 presents a photo of the MCA with open front panel of the accelerating module.

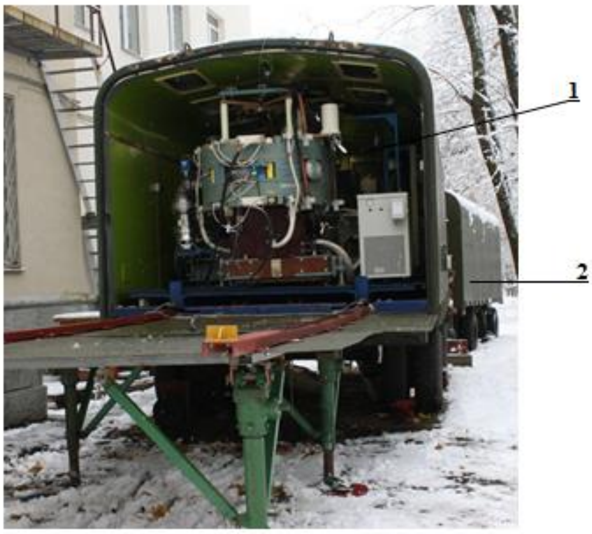

Figure 3. Mobile cyclic accelerator.
1 – accelerating unit; 2 – unit of pulsed powering of the electromagnet.

4. Results of test-activating of accelerating unit

Currently, the accelerating unit and its equipment are assembled. Physical operation of the oscillator powered from the pulsed system of the electromagnet powering (located at the experimental bench) is performed. It was also tested. At the limiting energy of the betatron electron beam E_{lim}~12 MeV (it is determined by the value of a capacitive storage of the pulsed powering system of the electromagnet), thickness of the lead test was ~110-115 mm at 1 m from the target.

Figures 4-5 present signal oscillograms of the MCA subsystem operation. The signals were recorded during the tests.

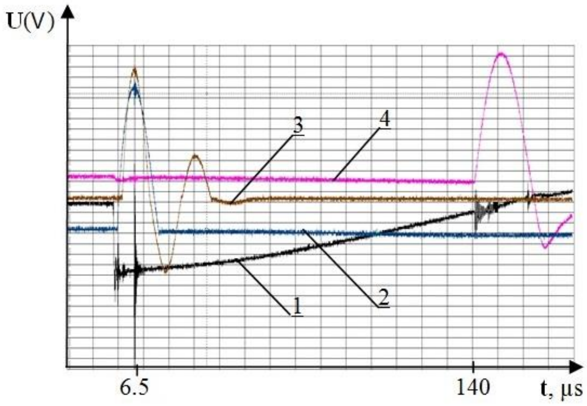

Figure 4. Signals of the MCA subsystems operation: line 1 - 0-field signal; line 2 – solenoid charging pulse; line 3 – magnetic lens charging pulse; line 4 – signal from a slow dumping unit.

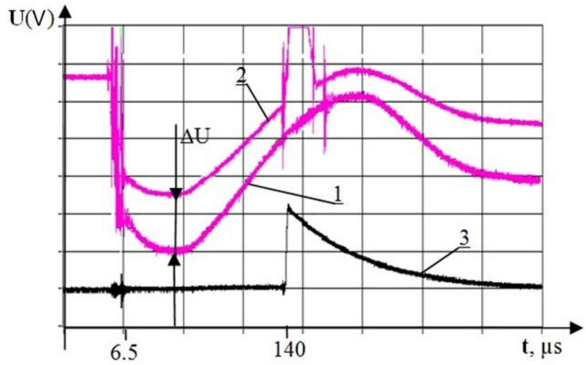

Figure 5. Signals from the betatron probes: line 1 – signal from the Rogowski coil (the current is present in the chamber); line 2 – signal from the Rogowski coil (there is no current in the chamber); line 3 – signal intensity of the x-ray radiation.

Figure 4 presents oscillograms of the signals obtained at operation of the accelerator subsystems in accordance with setup time algorithm. Time reading of some facility subsystems starts with arrival of 0-field signal (line 1) – operation of the electromagnet. The betatron injector operates on t=6.5 µs relatively to 0-field at maximum current in the solenoid windings and magnetic lens of the wiring section [6]. In our case, the pulses of the solenoid charging (line 2) and magnetic lens (line 3) arrive on the 0.5 and 2nd microsecond, respectively. The signal from the slow dumping unit arrives on the 140th microsecond – the electron beam circulating in the betatron chamber dumps to the target (line 4).

Figure 5 presents signal oscillograms from the betatron probes. The current of the electron beam (circulating in the betatron orbit) is estimated with the Rogowski coil, which encircles a toroid of the accelerating chamber. We measure the signals difference ΔU obtained with the current in the chamber (line 1) and without the current (line 2). Using a specially developed method, we recalculate this signal difference into the electron beam current of the betatron chamber. The presented oscillogram shows the recorded current of the electron beam of ~60 A. The x-ray radiation intensity from the tantalum target (line 3) is controlled with special semi-conductor probe.

We continue the assembly, starting-up, and adjustment works with the electromagnet pulsed powering unit. The unit contains the capacitive storage for the energy of ~0.5 MJ for the electromagnet powering system (6 capacitors per 300 µF, 24 kV), high-voltage power source, and switch box. It is necessary to fabricate and locate some technological equipment (oil preparation system).

5. Conception of multibeam radiographic complex for small-angle radiography

Available complexes provide recording of the shadow projections of the studied object in-plane from different angles. To increase information value of the radiography, it is necessary to provide the recording from different angles in space. To solve this task, we have developed the concept of the multibeam radiographic complex of small-angle tomography [7]. The sketch of such complex with horizontal location of the EPC is presented in Figure 6.

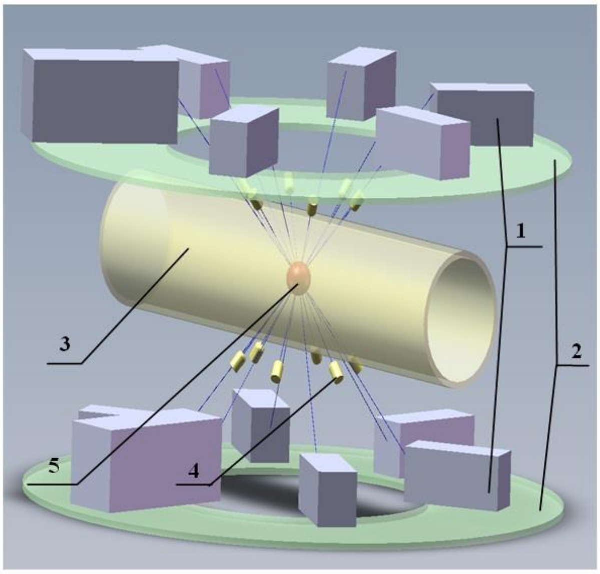

Figure 6. The sketch of multibeam radiographic complex. 1 – small-scale devices; 2 – planes of the devices location; 3 – EPC; 4 – system of collimation and shadow images recording of the object; 5 – test object.

In this geometry of the experiment, we are planning to use 12 small-scale devices of new generation (1). They will be located in two horizontal planes (2) per 6 devices in each plane. With such arranging of the complex, the distance from the radiation source to the studied object (5) is 3 m. The complex is compact enough; its diameter is 20 m including a service area. Taking into account the three-frame recording regime of each accelerator, the complex allows obtaining for up to 36 images. This will significantly increase information value of the radiographic studies.

6. Conclusion

Taking into account the accumulated experience, there is a real possibility of creating mobile radiographic complexes and multibeam radiographic complex for small-angle radiography based on ironless pulsed betatrons, intended for radiography of the dynamic objects of high optical thickness.

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