Pulse X-ray device for stereo imaging and few-projection tomography of explosive and fast processes

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\textbf{Abstract.} This paper describes the operation principles and design features of the device for single pulse X-raying of explosive and high-speed processes, developed on the basis of a Tesla transformer with lumped secondary capacitor bank. The circuit with the lumped capacitor bank allows transferring a greater amount of energy to the discharge circuit as compared with the Marks-surge generator for more effective operation with remote X-ray tubes connected by coaxial cables. The device equipped with multiple X-ray tubes provides simultaneous X-raying of extended or spaced objects, stereo imaging, or few-projection tomography.

\section{Introduction}

X-ray imaging takes a prominent place among various methods for studying the movement and distribution of materials. In a number of cases, X-ray imaging happens to be virtually the only method that makes it possible to obtain reliable data on the internal structure of the object. In the case of single and fast or explosive processes, one usually applies pulse X-raying. The scientists of the Lavrentyev Institute of Hydrodynamics of the Siberian Branch of the Russian Academy of Sciences have been developing their own pulse X-ray devices of the PPX series (Portable Pulse X-ray) since the inception of the Institute. The PIR-4, PIR-600/1200, and PIR-100/240 devices have been developed for the operating voltages of 100 kV up to 1200 kV [1]. The most recent modern device of the series is PIR-200M (Figure 1).

\begin{figure}[h]
\centering
\includegraphics[width=0.4\textwidth]{pir200m.png}
\caption{General view of the PIR-200M pulsed X-ray device (left); internal layout (right).}
\end{figure}
2. Principals of operation and characteristics

The PIR-200M pulse X-ray device consists of the following functional main components: a high-voltage unit, a remote control panel with a 15-meter long connecting cable, and external radiation head units with up to 10-meter long high-voltage cables. Radiation heads allow for the use of pulse X-ray tubes of the types of IMA6-D, IMA5-320D, IRTP2-240 and IRTP3-D.

The operational principle of the X-ray device is as follows. The PIR-200M pulse X-ray device is based on a non-ferrous oil insulated Tesla transformer (Figure 2), an inhomogeneous forming line with ceramic capacitors, and a high-voltage cables. A nanosecond-long X-ray radiation is generated in a sealed vacuum tube with explosive emission.

![Figure 2. Circuit diagram of PIR-200M based on Tesla transformer.](image)

The X-ray device is controlled via a remote control panel (Figure 3). The device can be started in three ways: manually, by pressing a button on the control panel, by an electric pulse signal of the amplitude from 5 V to 300 V, and by a contact sensor (by contacts short-circuit).

![Figure 3. Control panel for the PIR-200M device.](image)

The the X-ray device generates single bremsstrahlung pulses on the start command. The main power supply of the PIR-200M is ~220 V 50 Hz line. The power consumption rate is not more than 50 W. The device contains a built-in battery of 12 V and 3.2 Ah, which allows for autonomous operation (up to 100 X-ray flashes and 4 hours in a standby mode).
The X-ray device has the following parameters:

- the duration of the X-ray pulse at half-height is 40 ns in the case of an IMA6-D tube and 80 ns in the case of an IMA5-320D tube;
- the delay since the start command until the X-ray radiation is 2 μs with dispersion of 50 ns;
- the output voltage is 200 kV;
- output dose per pulse for an IMA5-320D tube with a kovar window measured at 21 cm from focus is 75 mR;
- the device is powered by the alternate current line of 220 V, 50 Hz or by built-in battery 12 V;
- it is possible to start the device both by a TTL electric pulse of 5 V and a contact sensor;
- delay time from control panel built-in time generator – from 1 to 999 μs;
- the dimensions of the PIR-200M pulse X-ray device are 570×280×680 mm.

The device is designed to be in parallel connection with one to three external X-ray tubes (Figure 4). This technical solution is not available in any other domestic or foreign model. This allows for stereo imaging, few-projection tomography, and simultaneous X-raying of extended or spaced objects.

![High-voltage connector unit of the PIR-200M consist of 3 sockets.](image)

The table compares the characteristics of the PIR-200M device and those of the closest counterparts [2-4] intended for the single-flash radiography of fast processes. The table shows that the PIR-200M device has characteristics comparable to the best other counterparts, while having a number of advantages.

![Table 1. Comparison with analogs.](image)

|                  | Pulserad 43733A | ScFl-300 | Argument 150-200 | PIR-200M |
|------------------|-----------------|----------|------------------|----------|
| 1. Operating voltage, kV | 300             | 100-300  | 150-230          | 100-240  |
| 2. Current, kA   | 5               | 10       | -                | 4        |
| 3. Pulse dose, mR | 8               | 9        | 0.15 ± 1.2       | 1.8 ± 8  |
|                  |                 |          |                  |          |
| 4. Flash duration, ns | 30             | 20       | 4 ± 7            | 20 ± 80  |
| 5. Focal spot size, mm | 5              | 1        | 1.5 ± 2.3        | 2 ± 3   |
| 6. Weight, kg    | 146             | 200      | 6.5 ± 17         | 55       |

- a a distance of 1 m from the anode.
- b for various voltages and different tubes.
- c for different tubes.

**3. Examples of application**

The doses given in the tables can be used to obtain good-quality images per flash on distances of up to 2 meters on standard X-ray film with luminescent intensifying screens, on ImagePlate screens, or solid matrices (Figures. 5 and 6). The objects under control can move with velocities of up to 10 kilometers per second.
Figure 5. X-ray image of the exploding detonator; below is the coin perforated by the fragment of the detonator (a); interaction of the 7.62-mm bullet and the 12-mm steel target; the steel core and the shell expansion are seen (b).

Figure 6. (a) interaction of the copper shaped-charge jet with the aluminum target; (b) diesel fuel injection and spraying inside the combustion chamber.

The PIR-200M device is suitable for the X-raying of low-dense and medium-dense objects. It performed well in the X-raying of shaped-charge jets, the objects of inner, outer, and terminal ballistics, dynamic processes in brightly glowing media, foam, aerosols, and fragmentation fields.

4. Conclusions

This paper describes the development of a small device for the X-raying of single high-speed and explosive processes according to the characteristics not inferior to the best counterparts in the world.

When the device is equipped with several tubes, it is possible to perform the simultaneous X-raying of extended or spaced objects, stereo imaging, and few-projection tomography.

The PIR-200M device is capable for X-raying in a wide range of densities and thicknesses (from 0.1 mm of aluminum to 24 mm of steel).

The objects of X-raying can move with velocities of up to 10 km/s, and the image blurring does not exceed the space resolution of the detectors.
The fields of application of the PIR-200M device are terminal ballistics, wound ballistics, the study of the projectiles and armor of small arms, high-speed impact, the dynamic of shaped-charge jets, and the internal fragmentation dynamics in mine firing.

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