DEVICES AND SOME METHODS OF PULSED RADIOGRAPHY OF HIGH-SPEED PROCESSES

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The basic design of the PIR pulsed x-ray systems developed at the Institute of Hydrodynamics, of the Siberian Division of the Russian Academy of Sciences is described and their parameters are compared with those of the well-known Hewlett-Packard and Scanditronics devices. Some methods of increasing the resolution of radiography using the great spectral width of radiation of the PIR pulsed devices are described. An example of extraction of the density distribution in several sections of a cavitating liquid utilizing simple methods of computer processing of images is given.

1. PIR PULSED X-RAY SYSTEMS

To provide simple, powerful, and inexpensive sources of pulsed x-ray radiation for scientific studies, a series of pulsed devices called PIR (the abbreviation in Russian of “transportable pulsed radiograph” [1, 2]) was designed at the Laboratory of Pulsed Electrophysics of the Lavrent'ev Institute. A carefully designed, pulsed, high-voltage resonance transformer, low-inductive secondary circuit, and a sealed x-ray tube with a cold cathode are combined in these devices to produce a short and intense pulse of radiation and to make the system suitable for pulsed radiography. The PIR voltage ranges from 100 to 1200 kV.

Two main modifications of the transportable pulsed systems were designed to study high-speed processes in materials of low and medium densities (PIR-100/240) and in materials of medium and high densities (PIR-600/1200). Each of them allows assembly for several working voltages and actually represents a family of devices: PIR-100/240 is intended for voltages of 100, 150, and 240 kV, and PIR-600/1200 for voltages of 600 and 1200 kV. PIR-600 devices were produced in quantity by the “Sevkavrentgen” plant, and the output satisfied the majority of explosion and ballistic test sites of the USSR. PIR-100/240 devices were batch-produced by the Scientific Research Institute of Introspect (Moscow) and were used in many research centers from Moscow to Krasnoyarsk.

Studies of the energy conversion and generation of x-ray radiation in pulsed cold cathode x-ray tubes made it possible to declare the following new principles, which turned out to be basic for the design and production of highly efficient pulsed x-ray sources.

1.1. Compensation of Electric Charges on the Secondary Winding of a Pulsed Transformer. Each turn of the winding has both the intrinsic interturn capacitance and the turn–earth capacitance \( C_{T-E} \). Because of the short commutation time of the cathode–anode gap of the tubes by the plasma jet, only the capacitances \( C_{T-E} \) of turns that are nearest to this gap can discharge. Most of the turns cannot discharge through the inductance of the winding, and a considerable portion of the charge remains on the turns. In this case, breakdowns between turns usually occur both due to the sudden voltage drop at a short distance and due to multiple reflections of the generated electromagnetic wave from the winding...
ends. To avoid this, we used two coaxial electrodes $E_a$ and $E_w$ connected to the winding ends. This gave rise to an additional capacitance of each of the turns with the high-voltage electrode $C_{HE}$. With appropriate change in coil-winding density (in a first approximation $\propto r^{-3}$), this made it possible to compensate, in each turn, the charge arising on the capacitance $C_{TE}$ by an equal but opposite charge on $C_{HE}$ and to match the capacitance distribution of voltages on the turns and the induction emf in them. Thus, it was possible to solve the above-mentioned problems of charge compensation on the secondary winding and to design a highly efficient shock transformer that matches a pulsed x-ray cold cathode tube [3].

Furthermore, the apparatus design takes into account that all the electrodes of the coaxial capacitor in which the secondary winding is located must be transparent to a magnetic field. The corresponding technical solutions are presented in a number of inventor's certificates [4] and patents [5-7].

1.2. Increasing the Coupling Coefficient of the Transformer Winding and the Energetic Efficiency of the Circuit by Introducing Special Elements in the Design of the Transformer to Decrease Dispersion of the Magnetic Flow. The density of the energy accumulated per unit mass of a ferromagnet (~0.2–0.5 J/kg) is considerably lower than the energy density for capacitor banks. The requirement of a minimum delay time between the starting pulse and the x-ray flash (usually not larger than 1–2 $\mu$sec) sets the upper bound of the oscillation period in inductively coupled primary and secondary circuits and, hence, restricts their induction. Thus, the use of ferromagnetic cores is undesirable because of high-speed operation and the requirements of compactness and small weight. On the other hand, the abandonment of the use of ferromagnetic cores decreases catastrophically the coupling coefficient and, hence, the efficiency of transformers, because, to ensure high-voltage insulation, it is necessary to locate windings at a significant distance from one another.

These difficulties can be eliminated by using the ability of conducting shells under strong skin-effect conditions to change significantly the spatial distribution of a magnetic field. The normal component of a magnetic field near such a shell is close to zero. Shaping the surface to a required form by using cuts, superposition, and holes, it is possible to form a magnetic flow in the transformer over wide ranges and to control its parameters, such as the coupling coefficient and the voltage distribution between the windings.