PORTABLE PULSE X-RAY APPARATUS WITH GAS INSULATION

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There are presented the data on development, investigation and application of a pulse X-ray apparatus with gas insulation. There are described circuit and design solutions for a 90 kV apparatus to be used in medical X-ray diagnostics and a 200 kV apparatus to be applied for the researches of high-speed processes. There are demonstrated the advantages of using gas under pressure as insulating medium.
There are presented basic output characteristics of the devices.
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1 INTRODUCTION

At VNIIEF a large experience on development and application of portable pulse X-ray apparatus (PIRA) is accumulated. Under a close collaboration with our Institute a science and production association "Burevestnik" has produced a large number of portable X-ray apparatus of IRA, RINA, DINA, MIRA, ARINA types. The main areas of such devices application are a study of fast processes, nondestructive materials testing and medical diagnostics.

Traditionally transformer oil is used as a main dielectric in PIRA. To the advantages of the transformer oil one can refer a high electric strength at a sufficiently high value of dielectric constant, common availability, low cost. Among other widely spread dielectrics there are gases under pressure: nitrogen, hydrogen, SF_6 gas at al. Gases are often used to fill the switches, high-voltage switch-pickers and more rarely as the main dielectric in high-voltage generators.

In the X-ray devices developed at VNIIEF gas is applied as main dielectric. Due to gas insulation one has managed to create PIRA with much smaller weight and overall parameters than those of devices with oil insulation.

2 ADVANTAGES OF GAS INSULATION

In the developed devices a mixture of nitrogen and SF_6 gas was_used as dielectric. As directly in the medium of SF_6 gas and nitrogen there did not occur high-volt breakdowns, when composing a mixture creators were limited by requirements of devices temperature operation only. The pressure of saturated SF_6 gas vapors at temperature -25^{0}C was 0.6 MPa, at -30^{0}C – 0.5 MPa. These temperatures were specified in task orders on creation of a medicine device and a device meant for study of fast processes, correspondingly.

Mixture of SF_6 gas and nitrogen in relation of 25% and 75% (0.5 MPa SF_6 and 1.5 MPa N_2) applied when developing devices possessed the electric strength approximately two times higher than that of the transformer oil. Measurements were performed at a pulse duration of charging voltage in the range of 0.5÷1mcs. This allowed to make a gap of 2.5 mm in the medicine apparatus jig, operating at voltage of 90 kV and frequency of 400 Hz, and in the device for study of fast processes at voltage of 200 kV the gap was 6 mm. A disadvantage of gas insulation by the value of dielectric constant as compared to the oil insulation was compensated through this.

An important positive factor of gas employment as a main dielectric is simplification of the device design as there is no need to develop special channels for air bulb removal from hidden cavities and a temperature compensator, as in the case of the transformer oil. There is no necessity in evacuation of high-voltage unit active volume for a careful impregnation of transformers and capacitor. Oil insulation devices operating at high pulse-repetition rate often fail due to a breakdown. This occurs due to accumulation of gases in the high-voltage unit, formed as a result of micro-breakdowns and corona discharges. Gas insulation devices are deprived of this demerit.

3 BASIC PIRA ELEMENTS

The medicine X-ray apparatus structurally consists of two units: a high-voltage unit and a control desk connected by a high-voltage cable.

The electrical scheme of device is traditional for such type devices [1]. The main elements of the high-voltage unit are X-ray tube, high-voltage switch-picker, pulse transformer.

The X-ray tube represents an advanced variant of IMA-6 [2] serial tube. The new tube is made with regard to two factors.

The first one is high requirements to the service personnel safety. Due to introduction of a special protective shield of heavy metals into tube's design, one has managed to minimize the rate of spurious radiation exposure dose.

The second consists in that operating tube's insulator experiences gas pressure up to 2 MPa. The conducted tests of the new tube have shown that its insulator bears pressures of 4 MPa without destruction. Besides, even if the insulator breaks under a strong mechanical effect on the high-voltage unit, there does not occur its loss of sealing. The output tube window is made of 50 mcm thick titanium and bears the pressure of 2.4 MPa. A high-voltage pulse transformer represents a resonance transformer on disconnected ferromagnetic core operating on the second half-wave of high-voltage pulse oscillations occurring in the second winding of transformer at generator operation. Transformer's efficiency is 40%. The relation of amplitudes of the first and the second half-waves is 2. This is quite enough for a safe operation of the gap-peaker to be discussed later.

The X-ray power supply unit of 1.5 kg mass is manufactured in a plastic body with 190x140x80 mm overall dimensions on whose face desk there is placed a light diode indicator of X-ray pulses number and control buttons. High-voltage resonance transducer of microprocessor control system power supply unit charges the primary high-voltage unit capacitor by quasi-constant current [3] and provides the X-ray pulse repetition rate equaling approximately to 400 Hz.

The next device with gas insulation is PIRA meant for study of fast processes. Employment of gas insulation in it is conditioned by a wide range of temperatures from -30C^0 to +50C^0 and small mass-dimension parameters. A resonance transformer is also applied in the device operating on the second half-wave. The relation of half-waves is 2.45, the efficiency is 60%.

The X-ray tube is an in-house design. It is meant for work under high pressure. Provided that the primary voltage polarity is changed and the X-ray tube is replaced for the electron one, the device can be used for emission of electrons with energies up to 200 keV.

In the new PIRA with gas high-voltage unit insulation there are used metal-ceramic pickers of high pressure Rim 100/35 and Rim 200/50 [4]. The comparative characteristics of these gaps and production specimens (P-48, P-49) are given in Table 1.

Table 1. Swith-pickers comparative characteristics.

Type of a switch	Breakdown voltage, kV*	Switched current, kA	Switched energy, J	Time of switching, ns	Operation resource, pulses	Dimensions, mm	
						diameter	length
P-48	100±20	3	3	0.5	10^3	30	36
	120±10	1	0.5	0.5	10^6		
P-49	150±30	4	4	0.5	$5\cdot10^3$	50	66
	200±15	1	1	0.5	10^6		
Rim 100/35	120±6	3	3	0.5	10^4	35	43
	130±5	1	0.5	0.5	10^6		
Rim 200/50	150±5	4	4	0.5	10^5	50	68
	220±5	2	1	0.5	$>10^6$		

* Averaged over 100 pulses with a confidence level of 0.98

A significant improvement of properties of Rim 100/35 and Rim 200/50 is achieved due to:

- a change of working gas - nitrogen for hydrogen what has allowed to deprive of insulator's contamination by tungsten nitrides formed in the spark discharge under electrodes fusing. This has increased the resource;
- application of annular superficial grooves located circularly onto the working surface section of a cathode electrode and formation of annular asperities being sources of autoemission electrons that in the pre-breakdown phase give rise to electron avalanches that stabilize a discharge [5].
- employment of computations of electric fields distribution along the surface of insulator and a gap between electrodes what has allowed to select an optimal form of an isolator, electrodes and overall dimensions of the gap according to its operating voltage and electric strength of insulator's material.

It is necessary to note that switches Rim 100/35 and Rim 200/50 are meant for operation in the transformer oil medium. These gaps being used in gas medium, the uniformity of distribution of electric field along insulator's surface would be somewhat broken. This leads to the lowering of its electric strength by 20÷30% and to the resource reduction. There has been correspondingly corrected a shape of switch high-voltage outlet in order to avoid this process.

It should be underlined that at 0.3÷1J energy storage of accumulative circuit the use of cermet high-pressure switches with hydrogen filling in generators with gas insulation will permit to raise the frequency of switching repetitions up to 1000 Hz, to lower a spread in amplitude of voltage pulses formed by the gap on the load up to 3-5% and to increase the resource by several times.

The medical X-ray apparatus has the following basic technical characteristics:

- 90kW operating voltage;
- 2 mm focus spot;
- 7 ns duration of X-ray pulse at half-height;
- 5 mP X-ray exposure per 100 pulses at 1m distance from the anode;
- overall dimensions of high-voltage unit: 50 mm diameter, 380 mm length;
- 2 kg mass.

The resource is not less than 1 million pulses what provides about 5000 pictures of thorax.

The basic technical characteristics of the apparatus meant for high-speed process study are the following:

- 200 kW operating voltage;
- 1.5 mm focus spot;
- 4 ns duration of X-ray pulse at half-height;
- X-ray exposure per 1 pulse at 1 m distance from 1.5 mP anode;

- 510x135x300 mm overall dimensions of high-voltage unit;
- 12 kg mass.

The device allows to get a shadow pattern at a distance of 2÷2.5 m from the anode and to X-ray 5 mm steel at 1m distance from the anode.

4 CONCLUSION

The medical X-ray apparatus has passed clinical tests and is already used in some medicine establishments. The X-ray apparatus meant for study of fast processes is applied for different investigations held in RFNC-VNIIEF. Particularly, with the aid of such apparatus there was conducted X-ray radiography of ponderomotive unit of magnetic explosion generator at a study of liner’s implosion in Russian and American experiments held in 1999 and 2001 years.

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