A PULSE GENERATOR OF X-RAY QUANTS FOR REMOTE RADIATION MONITORING

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Abstract

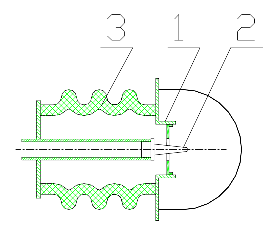
The report presents the development of compact UT, which improved definition x-ray image is ensured by using a diode system with a coaxial geometry acceleration of electrons to the anode electrode internal target and explosive emission cathode. UT used to run a specially designed high-voltage pulse transformer-based "Tesla" with surge sharpener. Describes the design and block diagram interface generator X-ray quanta. Feature is the high stability of the generator is not dependent on the voltage, battery charge. Presented the results of experimental testing of the generator X-ray quanta. Also shows the waveform duration x-ray pulses in the presence of the lead filter and without it.

Modern complex industrial facilities (nuclear reactors, elements of pipeline and rail transports, power plants turbines, heat exchangers, aircraft, etc.) require the implementation of remote penetrant monitoring. At the same time, such monitoring systems are subject to the increased requirements for transportation, portability, expressness of changes.

The best solution for this kind of problems is the application of portable mono-block instruments based on pulse x-ray acceleration tubes (AT). The weight and dimensions of mono-block radiator, the power supply and control panel allow to transfer them easily and quickly mount to take effective measurements. Such radiation sources concerning small dimensions should provide the average exposure rate as ~10 mR/s within the distance of ~m from the target with the minimum area of target's radiating surface. Given parameters are obtained by generating the x-ray quants in the vacuum diode AT operating in the pulsed-periodic mode with the current amplitude of accelerated electrons ~kA, the pulse duration ~(1-10) ns and the maximum energy of electrons with several hundred keV. For this purpose, the Experimental Plant of Pulse Technique (EPPT) - the subsidiary of OOO «SPECTR»-IMS, with the assistance of Institute for Nuclear Research of the National Academy of Sciences of Ukrainian and NRNU MEPhI, has designed a small-sized AT in which the enhancement of the x-ray image clarity was provided by the diode system with the coaxial geometry of an electrons' acceleration to the internal anode electrode - target [1-2].

This electrodes' geometry allows to produce a cathode plasma spreading to the anode and acting as an intensive source of electrons. The electric field intensity in the anode region can reach up to ~108 V/m.

While operating pulse generators of x-ray quants in the field, high requirements are imposed on the mechanical and dielectric strength of AT. And therefore in order to enhance these indicators, the special high voltage ceramic insulator was suggested to be used. By means of computer simulation and physical modelling at a demountable vacuum stand information has been received on optimal geometrical dimensions of a diode acceleration system [3] that formed the basis for designing AT. Fig.1 shows its schematic section and general view.



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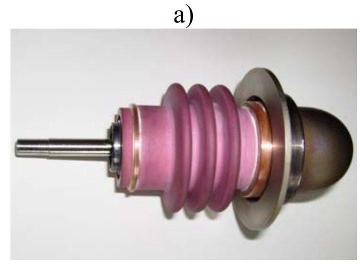

b)

Figure 1: Acceleration tube and its triggering circuit: a) the schematic section of AT. 1- cathode; 2- anode; 3- ceramic corrugated insulator; b) the general view of AT.

Obtained relations of geometric dimensions for a diode system are defined by the following system of inequalities [4]:

$5.10^{-4}\text{m} \le \rho \le 10^{-3}\text{m}$, $5\rho \le r_K \le 10\rho$, $0.2\ r_K \le r_A \le 0.5\ r_K$, $0.4\ r_K \le h \le 1.4\ r_K$,

where ρ- the rounding radius at the anode end, r_K– the radius of a hole in the cathode, r_A- the radius of an anode circular section with the plane passing through the

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front end of a cathode, h- the distance from the front end of a cathode disk to the front end of an anode.

The special pulse high voltage source based on the Tesla coil with a spark gap-peaker was used for triggering AT. It was mounted with AT in a sealed pressure-resistant case filled with the insulating gas under the pressure of 15-20 atm. The basis for an insulating medium was the elegas (SF_6).

Fig. 2 depicts the switching diagram of a high voltage circuit.

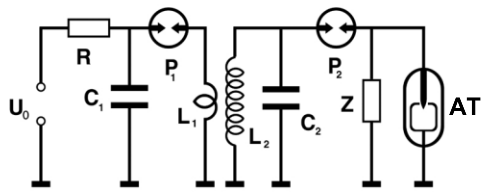

Figure 2: The triggering circuit of AT: R- the charging resistance; C_1- the tank capacitor; P1- the spark gap of primary circuit; $L_{1,2}$- the inductance of primary and secondary windings of Tesla coil ; C_2- the capacitor of secondary circuit of Tesla coil; P_2- the spark gap; Z- reactance for initial galvanic coupling of the spark gap - peaker with the ground and matching the primary and secondary windings of Tesla coil.

The tank capacitor charges via a specially designed by EPPT small-sized source of direct-current voltage U_0. Fig.3. shows the block diagram of generator interface. The distinctive feature of this generator is a high stability, regardless of the line voltage or of the battery charge. This is achieved by the division of a voltage increase into two stages. Due to the feedback there is no-load loss protection and short circuit protection in a generator.

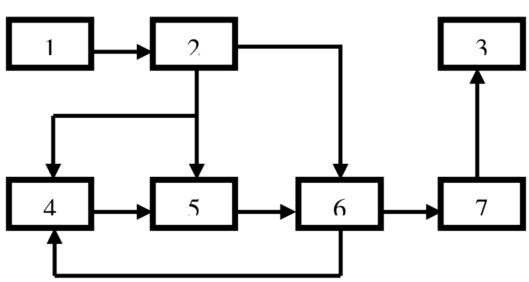

Figure 3: The block diagram of x-ray quants generator. 1- the supply-line filter, 2- the power supply unit, 3- the high voltage unit , 4- the control unit, 5- the pulse generator, 6- the power amplifier, 7- the voltage multiplier.

The pulsed-periodic launch of AT could be performed in both the auto generated mode and armed mode with a given frequency. In the latter case instead of an uncontrolled gas-filled double-electrode spark gap P_1 there can be used a controlled vacuum or gas-filled spark gap provided with an additional ignition electrode.

When launching AT in the auto generated mode, the tank capacitor C_1 is being charged. Reaching the breakdown of the spark gap at the voltage capacitor, the circuit is closed and the capacitor is discharged into the primary winding of a transformer. Due to the current flowing through the primary low-inductive winding, in the secondary winding there arises a high voltage which increases to the response voltage ($U_м$) of a spark gap - peaker P_2. As a result, the anode of AT acquires potential $U_м$. To ensure the galvanic coupling of the right electrode of the spark gap - peaker with the ground in a circuit, the resistance Z is introduced which also ensures to maintain the voltage on the anode of AT during the generation of x-ray quants owing to the inductive component. In addition parameters of resistance are selected so as to provide the optimal conditions for power transmission to the accelerated electron stream .

The enhancement of a primary discharge circuit in the part of the tank capacitor and the spark gap was carried out during the development of the instrument. The original design of the capacitor with three plates was suggested, i.e. consisting of two combined capacitors in series.

Tests of AT working model have shown that with the amplitude of accelerating voltage of 300kV the amplitude of electron current and the pulse duration at half maximum comprised about 2 kA и 2ns respectively that is in agreement with estimated data and the dose at 0.5 m away exceeded 1mR per pulse .

The obtained radiation-monitoring performance of the instrument provides an opportunity for operating it both in the mode of exposing films and in the mode of using the photoelectric converters with subsequent encoding in the analog-to-digital converter and computational signal processing .

Fig. 4. shows experimental dependencies of the dose rate in the air on the distance R between the target and the observation point and on the power W stored in the tank capacitor.

Given dependencies are built using the least squares method according to measurements data of an exposure rate taken for 50 pulses of AT response at a response frequency 10Hz in different places at different values of W. There was also the enhancement of the AT triggering circuit parameters. The average percentage error of approximation measured by the residual principle did not exceed 15%.

Also in collaboration with All-Russia Research Institute of Automatics (VNIIA) named after N.L. Dukhov investigations of the lead screen influence on the x-ray radiation pulse form were carried out using a semiconductor detector with a temporal resolution of at least 1,5 ns. Fig.5 shows oscilloscope pictures of voltages from the detector.

The sensor was positioned 2 sm away from AT. The sensor was connected to the digital oscilloscope.

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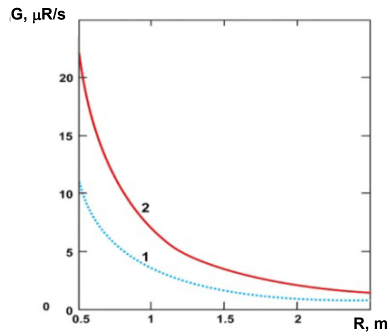

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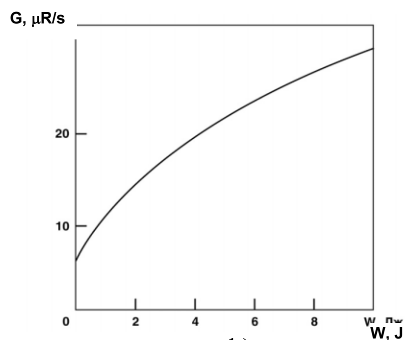
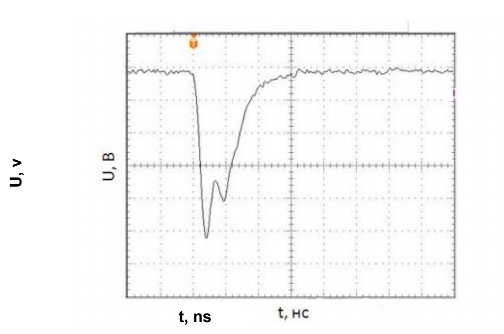


b)

Figure 4: The measurement results of the dose rate of generated radiation – G: a) dependencies G(R), taken for values W=1 J- curve 1 и W=7 J- 2; b) dependence G(W).



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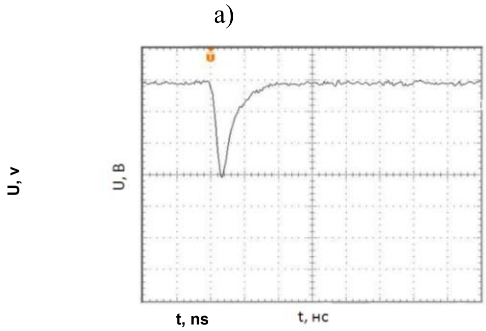

b)

Figure 5: a) The oscilloscope picture taken without the screen. b) The oscilloscope picture taken with the lead screen of 1mm thick.

From oscilloscope pictures it can be clearly seen the reduction of a signal amplitude with the lead screen at AT. In addition pulse durations at half maximum do not exceed 3ns. This fact allows to use designed pulse sources of x-ray radiation analizing high-speed processes.

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