Design and testing of fluid resistor for repetitive high-voltage pulse generator

A V Poloskov, I S Egorov and M A Serebrennikov

National Research Tomsk Polytechnic University, Tomsk, Russia, (Lenin ave. 30, Tomsk 634050 Russia)

E-mail: poloskow@tpu.ru

Abstract. The paper presents a design and the results of testing of the liquid resistive load for a repetitive high-voltage generator (200 kV, 0.5 ms). The load uses a sealed dielectric case, which is to be placed into a vacuum volume ($5x10^{-4}$ Torr) for electrical strength ensuring. Repetitive testing of the generator with the load (10 pps) caused the electrolyte heating, the load resistance decreasing, and the changing of a generator mode. An expansion tank is used to compensate thermal expansion of the electrolyte, which makes it possible to absorb up to 1 MJ of energy in the load without seals breaking. A generator load curve can be obtained for one experiment with a help of the fluid load without any additional depressurization of the vacuum volume.

1. Introduction

To test the facilities and devices manufactured for research and application purposes, due to their unique characteristics in various research centers, often needs a complicated diagnostic equipment, parameters of which essentially differ from its industrial prototypes. The current paper examines the results of testing of the fluid resistive load, which was designed for an operation in a vacuum chamber of the high-voltage generator of the ASTRA repetitive electron accelerator [1], under residual atmospheric pressure of $5x10^{-4}$ Torr. Such pressure remained in the course of accelerator operation, to provide dielectric strength of the high-voltage vacuum insulator of the generator and to provide the conditions of pulsed electron beam generation. The accelerator has found its application in a wide range of research and application problems [2-5]. The parameters of an electron beam are very significant for the defined applications. These parameters are determined by the characteristics of an accelerating voltage pulse formed by the generator. The generator was designed as a capacitive storage discharge through the high-voltage pulse transformer [1]. According to [6], the pulse parameters depend on matching of the generator impedance ($Z_g \approx 80\ \Omega$) with an abrupt non-linear characteristic of the impedance of the vacuum electron diode [7], which transforms the stored electrical energy into a kinetic energy of beam electrons. Thus, there is a possibility to examine the operation parameters of the high-voltage pulse generator under different values of the load resistance, i.e its load characteristic.

To meet the application conditions, the generator resistive load should provide the pulse dielectric strength over 200 kV [1, 7], and the change in *Zn* load resistance should range from *Zg* to 2*Zg*. The load should provide the energy absorption, using the pulsed power, as high as 500 MW [1] under an average power of 400-500 W. The graphite resistors with a ceramic case (TVO), which are traditionally used to build the low-inductive loads for the generators with a high pulse power, can be used in a series connection, to provide the dielectric strength of a resistor surface. However, the power dispersed by the resistors abruptly decreased when they operate in vacuum making impossible to work with a high pulse repetition rate. It is also not very convenient to replace the resistors to adjust the load resistance that requires resealing of the vacuum chamber and significantly complicating a revival of the load characteristic of the generator.

It seems to be more convenient to use the fluid resistors described in [8]. There, the electrolyte is utilized as a volume resistance, whose initial conductivity can be easily adjusted by a salt concentration. In the current work, the solution KCl (2%) was used as an electrolyte of the fluid load.

2. Experimental setup

Basing on the data described in [8], in terms of the conditions defined before, an original construction of the fluid resistor was developed. The body of the fluid load was made as a dielectric tube, hermetically plugged from the ends by the metal flanges operating as electrodes (Fig. 1). The structure of the fluid load was vertically installed, with a filler neck being directed upward. The length of the body over the insulator was 400 mm. The volume of water was 3.38 l.

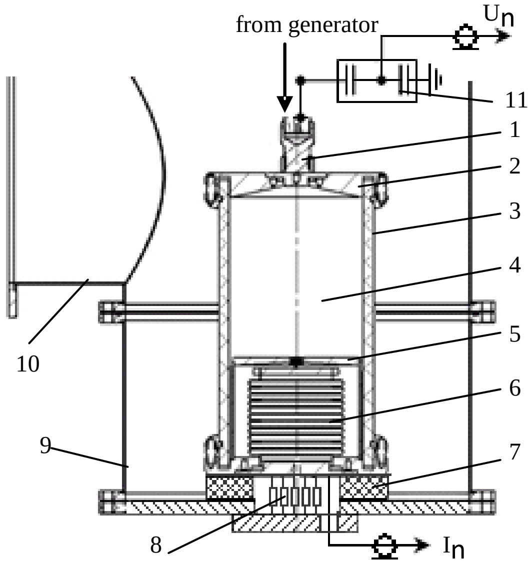

Figure 1. A structure of the fluid load with pressure damper and a scheme of testing of the generator with a load. 1 – a high-voltage output of the generator; 2 – a potential electrode, a filler neck; 3 – a dielectric tube (a glass fiber plastic); 4 – a volume with an electrolyte; 5 – a grounded electrode; 6 –a pressure damper; 7 – a base insulator; 8 – a low-inductive shunt (0.05 Ω); 9 – a body of the vacuum chamber; 10 – a pumping branch; 11 – a capacitive voltage divider.

The load was supplied with a pressure damper of the electrolyte. The grounded electrode was made in such way that when changing the volume of the damper, the geometry of the gap between electrodes remained unchanged. The estimated calculation of the heat expansion of the electrolyte showed that about 1 MJ could be released in the load without a considerable increase in pressure inside the body, due to the volume compensation. The structure of seals enabled to use the fluid load under residual atmosphere pressure of 5x10-4 Torr.

To carry out the tests, the load was installed into the vacuum chamber and connected to the high-voltage output of the generator. The grounded electrode was installed on the insulator base and connected to the generator body, using a low-inductive shunt allowing us to control the current, passing through the load (Fig. 1). The voltage applied to the load was controlled using a capacitor voltage divider (Fig. 1).

3. Results and discussion

At the moment of assembling, the load resistance *Zn*=226.5 Ω was determined using the immittance device (E7-21). During the experiment, we assumed that the load resistance over pulse duration remained unchanged. In the course of experiment, the load voltage *Un* and the current *In* oscillograms were recorded (Fig. 2). They were employed to determine the *Zn* load resistance at the moment of maximum current using Ohm's law.

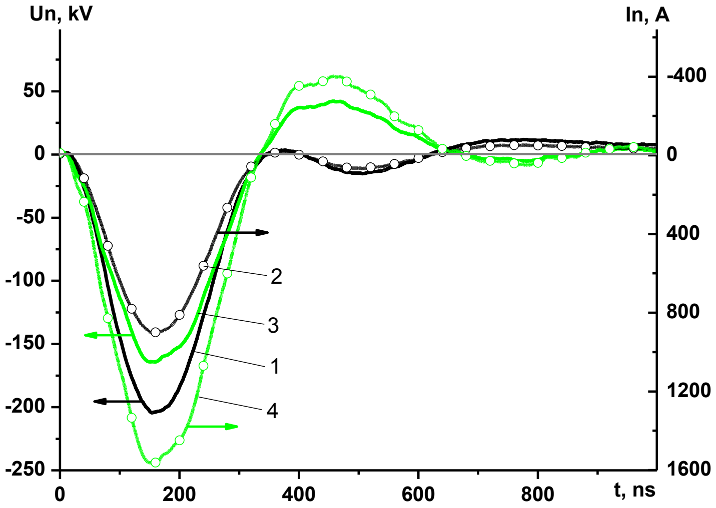

Figure 2. Waveforms of the voltage (1, 3) and the current (2, 4) of generator under the load resistance 226.5 Ω (1, 2) and 105 Ω (3, 4).

The curves given in Fig. 2 were also used to estimate the energy released in the load *En* per pulse duration:

$$Pn\,(t) = Un \cdot In;$$

$$En = \int Pn\, dt,$$

where *Pn* is a pulse power developed in the diode;

To determine the load characteristic, the high-voltage generator loaded on the high-voltage fluid resistor was tested at a constant value of the energy stored in the storage under pulse repetition rate 10 pps for 20 minutes. The voltage and current curves were recorded for 2400 pulses. The energy absorption by the electrolyte increased its temperature and, as a result, decreased the load resistance.

The load current and voltage curves recorded for 12000 pulses enabled to build a variation diagram of the resistance load (the load characteristic) and the energy released in it (Fig. 3). The diagram in Fig 3 is confirmed by a computational model described in [9].

The change from 226.5 Ω to 105 Ω in the generator resistance caused a mismatching of the generator and load impedances. It was exhibited in a change of the energy amount released in the load (Fig. 2-2). It should be noted that reasoning from the purpose of the generator, the energy released for duration of the first voltage pulse can be treated as useful (Fig. 2-3). The energy of electrons generated during an afterpulse is not enough for its practical use. Besides, when the load resistance is lower than $2Zg \approx 160\ \Omega$, the discharge process of the generator is periodical, that negatively affects the lifetime of the high-voltage vacuum insulator of the generator [10].

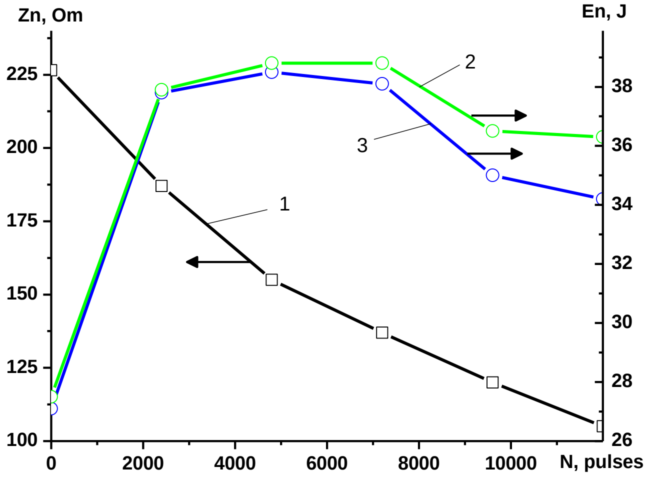

Figure 3. Diagrams of the load resistance (1) and the energy released in the load per pulse (2, 3) with an increasing number of pulses, at a pulse repetition rate of 10 pps.

The temperature of the fluid load before and after the experiment was recorded using a thermal imager (Fluke Ti10); it was 20°C and 53°C, respectively.

The energy, released in the load for the whole time of the experiment procedure E_{Σ}, was estimated as:

$$E_{\Sigma} = c \cdot m \cdot \Delta T = 460.7\ \text{kJ},$$

where c was the specific heat capacity of the electrolyte (2% KCl concentration), $c \approx 4046$ kJ/(kg·°C);

ΔT was an electrolyte temperature variation, $\Delta T = 33°$;

m was the mass of electrolyte, m=3.45 kg.

Using the data of the diagram in Fig. 3, we obtained the calculated value of energy $E_{\Sigma P}$ released in the load for the whole time of the experiment procedure:

$$E_{\Sigma P} = \int En\, dN = 441.4\ \text{kJ}.$$

So, the measured and calculated values of the energy released in the load during the experiment differ by 5% that can be explained by the inaccuracy of measuring instruments.

4. Conclusion

The suggested structure of the fluid resistive load and the described method of its application enabled to design the load for the generator operating under changing load resistance resulting from its heating. We used high-voltage pulses (over 200 kV) with 10pps pulse repetition rate. In the course of the experiment, the load remained leak-proofed under a residual atmosphere pressure of $5\text{x}10^{-4}$ Torr. Due to this load, 450 kJ ± 5% of energy was released that caused its heating by 33°.

Acknowledgements

This work was partially supported by RFBR grant #16-32-00287mol_a.

References

[1] Egorov I., Esipov V., Remnev G., Kaikanov M., Lukonin E., Poloskov A. 2012 *Proceedings of the IEEE International Power Modulator and High Voltage Conference*, art. no. 6518845, pp. 716-719.2.

[2] Mostovshchikov A.V., Ilyin A.P., Azanov A.A., Egorov I.S. 2016 *Key Engineering Materials*, **685**, pp. 639-642.

[3] Egorov I.S., Esipov V.S., Lukonin E.I., Poloskov A.V. 2015 *Instruments and Experimental Techniques*, **58** (1), pp. 64-66.

[4] Mostovshchikov A.V., Ilyin A.P., Egorov I.S., Ismailov D.V. 2016 *Key Engineering Materials*, **712**, pp. 60-64.

[5] Poloskov A., Egorov I., Ezhov V., Remnev G. 2016 *Key Engineering Materials*, **685**, pp. 667-671.

[6] Remnev G.E., Furman E.G., Pushkarev A.I., Karpuzov S.B., Kondrat'ev N.A., Goncharov D.V. 2004 *Instruments and Experimental Techniques*. V. **47**. № 3. C. 394-398.

[7] Egorov I.S., Ezhov V.V. Poloskov A.V. *Fundamental research*. – 2014. – № **9-9**. – C. 1964-1968 (in Russian).

[8] Gerasimov A.I. *Instruments and Experimental Techniques*. 2006. V. **49**. № 1. C. 1-26.

[9] Egorov, I. 2014 *Review of Scientific Instruments*, **85** (6), art. no. 066112.

[10] Egorov, I. 2016 *IEEE Transactions on Dielectrics and Electrical Insulation*, **23** (4), art. no. 7556492, pp. 2174-2180.