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Design and Performances of High-Current Modular Pulsed Power

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Abstract: A design of the high-current modular pulsed power generator and results of the test of this generator are presented. The generator is based on two capacitors each of 2.5 μF and 50 kV maximum charging voltage. Two multi-gaps gas spark switches with capacitive coupled triggering are used to discharge stored energy into the load. The triggering pulse with amplitude up to 70 kV and rise time of ~50 ns is supplied by three-stage Marx-generator. The output of each capacitor with multi-gaps spark switch is connected to the load by eight coaxial cables ~1 m in length. The total inductance of the generator does not exceed 200 nH. At 40 kV charging voltage this generator produces 180 kA with a quarter of period of 1.6 μs at short circuit load of ~15 nH. The generator has been used in the research of underwater electrical wire explosion. The space separation of the load and modules of generator allows one to avoid possible damages of the generator by shock waves produced during the wire explosion. In addition, this modular generator design allows to increase easily the number of modules and to reach several hundreds of kiloamperes in the load.

Key words: Pulsed power, high current, high voltage.

1. Introduction

One of the promising methods in research of warm dense plasma [1, 2] is underwater electrical single wire or wire array explosion by a current pulse with amplitude of several tens-hundreds of kiloamperes and duration in the range 10^{-7}-10^{-6} s. Due to small compressibility of water which prevents expansion of exploding wire and large value of breakdown electric field in water one can deliver extremely large energy density into wire reaching several hundreds of eV/atom. Carried out experiments [3] showed that up to 90% of the stored in capacitor bank energy can be delivered to the exploding wire and around 20% of this energy is transferred to the energy of SSW (strong shock waves) generated in water by exploding wires [3, 4]. Generation of SSW is accompanied by formation of a large pressure in the range 10^{9}-10^{11} Pa in experimental chamber filled by water [5, 6]. Thus, in order to avoid the damage of the pulsed generator, the latter should be decoupled from the load, i.e., experimental chamber where underwater wire/wire arrays electrical explosion occurs. However, this requirement contradicts to necessity to deliver to the exploding wires a current pulse with large amplitude in ns-μs timescale because of increased inductance of the discharge circuit in the case when the generator is decoupled from the load by additional transmission lines. Indeed, one of the main parameters of high-current generator is the output current amplitude which for fixed charging voltage and capacitance of the generator is determined by the total inductance of the discharge circuit.

In this paper, the design and parameters of the high-current modular generator which consists of several separate generators operating in parallel and delivering current to the load by coaxial cables is described. The application of separate generators allows one to keep relatively low-inductance of each generator [7] and the use of multi-cable connection of these generators to the load provides low inductance of

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the total system and allows to avoid damage of the generator from the shocks produced by wires explosion in water-filled chamber.

2. Design of the Generator

The pulse generator is based on two low-inductance pulsed generators each consisting of high-voltage Maxwell type capacitor (capacitance of 2.5 μF, maximum charging voltage of 50 kV), operating in parallel on a single load. An experimental chamber with exploding wire is installed on separate base at the distance of ~1 m from the generators. The separate location of the load allows one to minimize the shock wave damage of the generator, especially multi-spark switches which are used for discharge of the capacitors, as well as to apply this generator to different loads. The main parameters of the pulsed generators are listed in Table 1.

The high-voltage and high-current pulse was delivered to the load using eight coaxial cables RG-213 connected in parallel. This design allows one to minimize the inductance of the connections between the generator and load keeping almost the same the rise time and maximal amplitude of the discharge current similar to the case of application of a strip line. In addition, this design allows one to develop several generators operating simultaneously on the one load placed at some certain distance from these generators. Moreover, this design allows one to use these generators with several loads with additional mechanical switches which will connect the generators to the certain load.

An external view and scheme of the experimental setup and design of the generator are shown in Figs. 1 and 2, respectively. An external view of the high-current generator consisting of two modules operating on single load is shown in Fig. 3.

In order to avoid electromagnetic noise produced during gas spark switch operation, a screening aluminum box was used. A delrin insulator was installed between the grounded and high-voltage electrodes of the gas switch. The latter is consisted of

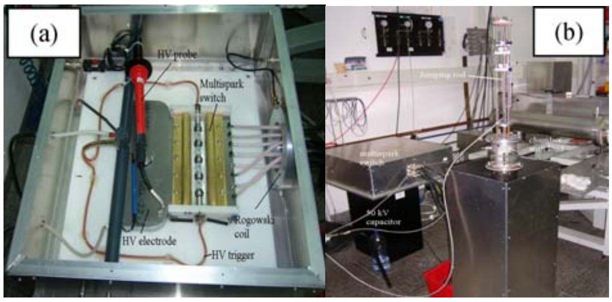

Fig. 1 External view of the experimental setup: (a) Block of the multi-spark switch with the removed cover; (b) experimental setup with one pulsed generator.

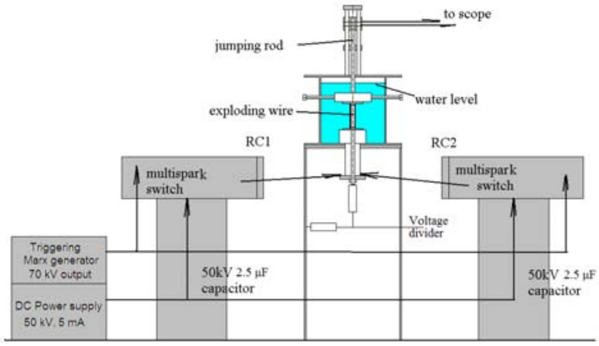

Fig. 2 Experimental setup for two generators operating on joint load. RC1 and RC2 are Rogowski coils.

Fig. 3 Double module setup outside of the laboratory hall for experiments with underwater electrical wire explosion.

two brass electrodes and five ball-like electrodes placed in the middle of the interelectrode gap. Such design of the gas switch allows one to decrease significantly the switch self-resistance and self-inductance. In addition, application of such multi-gap spark switch for each capacitor allows one to decrease additionally the discharge circuit resistance and inductance. The potential of the ball-like electrodes was fixed as a half potential difference between the electrodes using high voltage and high resistance resistor divider (200 MΩ: 200 MΩ). In addition, these ball-electrodes are decoupled from each other by 100 MΩ high-voltage resistors. A triggering pulse, produced by Marx generator, is applied to short-circuited loop made of high-voltage cable which is placed inside the balls through the holes made in these electrodes (Fig. 1a). When a high voltage pulse produced by the triggering generator is applied to this cable, potential differences between the ball electrodes and the high-voltage and grounded electrodes are changed due to capacitive coupling between the wire of the triggering electrode cable and the ball electrodes.

The discharge current and voltage were measured using calibrated self-integrated Rogowski coil and voltage divider, respectively. The charging voltage was measured using Fluke voltage divider placed in one of the generators and connected to the high-voltage electrode.

To charge the generator, high-voltage dc power supply with output voltage up to 50 kV and current up to 5 mA was used. The gas spark switches of the 2.5 μF Maxwell capacitors were triggered by specially developed 3 stages Marx generator, based on 40 nF, 50 kV Maxwell high voltage capacitors charged to 23 kV and discharged by spark gap switches with middle distortion electrode (Fig. 4). For charging of high-voltage trigger generator a 30 kV and 10 mA dc power supply produced by Glassman High Voltage Inc., series ER was used. To trigger the Marx generator a spiral generator [8] charged to 3 kV was used. The spiral generator produced high voltage pulse of 40 kV in amplitude which was applied to the 2nd and 3rd stages of the Marx generator. The spark gap of the spiral generator was triggered by 3 kV pulsed transformer which was supplied by a 300 V pulse produced by the SCR (silicon-controlled rectifier) which triggered the discharge of 1 μF capacitor charged to 300 V.

3. Results of the Test and Summary

Results of the pulse generator test with the short circuit load are shown in Fig. 5.

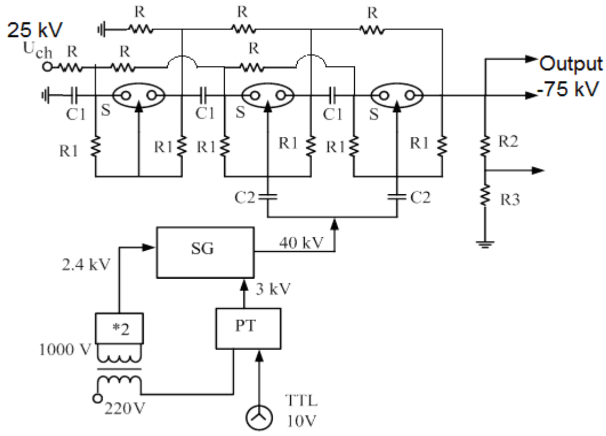

Fig. 4 High-voltage trigger generator scheme. C—40 nF, 50 kV Maxwell capacitors; C2—130 pF 40 kV capacitors, S—spark gap switches, Resistance R1 = 200 MΩ, R2 and R3 are resistances of the voltage divider: R2 = 50 Ω, R3 = 1 Ω, SG—spiral generator, PT—pulse transformer, *2—voltage multiplier and rectifier. R = 10 kΩ–charging resistors.

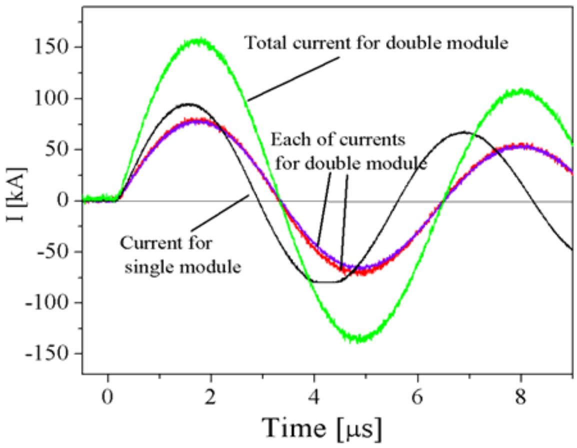

Fig. 5 Short circuit current wave forms.

The main parameters of the generator for one and two modules are presented in Table 1. One can see that this generator allows one to achieve at the load current amplitudes of several hundreds of kiloamperes, with less than 1.6 μs quarter of period. This generator was successfully used in the series of experiments with underwater wire and multi wire array electric explosions showing its excellent reproducibility and reliability in operation.

Features of the modular pulse power generator:

- Multi spark gap switch allows one to decrease current density in each spark channel that results in the absence of visible detectable erosion of electrodes;

Table 1 Parameters of the generator.

	One generator	Two generators
Capacitance (μF)	2.5	5
Charging voltage (kV)	38	38
Short circuit current (kA)	95	155
Maximal current in operating regime (kA)	75	150
Current rise time (μs)	1.35	1.55
Short circuit inductance (nH)	300	200

- A common high-voltage triggering of several modules decreases the time jitter between the beginnings of the generators operation down to 10 ns;
- Common high-voltage charging and control simplified significantly experimental setup;
- Application of current monitors for each generator allows one to effectively control operation of each generator as well as to obtain the total current in the load;
- Application of multi-coaxial cable connection between the modules and load (in the present case, eight coaxial cables for the each module) provides flexibility of the generator, does not lead to the increase in the inductance as compared with strip line connection and allows on to avoid almost completely electromagnetic noise;
- Modular type of the generator allowed one to avoid shocks produced in the experimental chamber to influence on the generator operation;
- Modular type of the generator allows one to use rationally the laboratory space and to easy maintain the generator;
- Modular type of the generator allows one to increase the total discharged current by the increase in number of modules.

4. Conclusions

High-current pulsed power generator based on modular sections was developed and successfully tested. At charging voltage of 38 kV and short circuit load, the amplitude of the discharge current is 155 kA with rise time of ~1.55 μs. The time jitter in operation of two modules is ±15 ns. This design of the pulsed power generator allows one to increase the number of modules and separate the generator and load, thus avoiding mechanical vibration which could accompany experiments.

Acknowledgments

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References

[1] N. Goldman, E.J. Reed, I.F. William Kuo, L.E. Fried, C.J. Mundy, A. Curioni, Ab initio simulation of the equation of state and kinetics of shocked water, J. Chem. Phys. 130 (2009) 124517-6.

[2] R.P. Drake, Perspectives on high-energy-density physics, Phys. Plasmas 16 (2009) 055501-7.

[3] Y.E. Krasik, A. Fedotov, D. Sheftman, S. Efimov, A. Sayapin, Underwater electrical wire explosion, Plasma Sources Sci. Technol. 19 (2010) 034020-8.

[4] A. Grinenko, S. Efimov, A. Fedotov, Y.E. Krasik, Efficiency of the shock wave generation caused by underwater electrical wire explosion, J. Appl. Phys. 100 (2006) 113509-8.

[5] S. Efimov, V.T. Gurovich, G. Bazalitski, A. Fedotov, Y.E. Krasik, Addressing the efficiency of the energy transfer to the water flow by underwater electrical wire explosion, J. Appl. Phys. 106 (2009) 073308-8.

[6] S. Efimov, L. Gilburg, A. Fedotov-Gefen, V.T. Gurovich, J. Felsteiner, Y.E. Krasik, Aluminum micro-particles combustion ignited by underwater electrical wire explosion, Shock Waves 22 (2012) 207-214.

[7] B.M. Kovalchuk, A.V. Kharlov, V.B. Zorin, A.A. Zherlitsyn, A compact submicrosecond, high current generator, Rev. Sci. Instrum.80 (2009) 083504-6.

[8] F. Ruhl, G. Herziger, Analysis of the spiral generator, Rev. Sci. Instrum. 51 (1980) 1541-1547.