

Experience of Pseudospark Switch Operation in Pulse Power Applications

N V Voitenko¹, A S Yudin¹, N S Kuznetsova¹ and V D Bochkov²

¹Tomsk Polytechnic University, 30 Lenina ave., Tomsk, 634050, Russia

²Pulsed Technologies Ltd., 5 Yablochkova str., Ryazan, 390023, Russia

E-mail: tevn@hvd.tpu.ru

Abstract. The paper demonstrates the results of TDI1-200k/25SN-P pseudospark switch (PSS) developed by Russian company "Pulsed Technologies Ltd" application. PSS was used in pulsed power unit intended for electric-discharge fracture of rocks and concrete blocks and splitting off from monolith. The pulsed power unit has a pulse current generator with the capacity of 560 μF , stored energy of up to 63 kJ, operating voltage of up to 15 kV, current pulse amplitude of up to 200 kA and pulse duration more than 200 μsec . The study also shows the current waveforms determined in the short-circuit experiment of the pulse current generator and in the experiments of the electric-discharge fragmentation of concrete at the charging voltage of 13 kV. PSS was operated in ringing single-pulse mode with the exceedance of more than two maximum permissible parameters: current pulse amplitude, current pulse duration and maximum pulse energy. Internal electrode erosion of PSS is shown and possible reasons of asymmetric current feed are discussed.

1. Introduction

The recent decades demonstrate increasingly growing interest to the development of new environmentally friendly technologies, which is due to severe complication of environmental problems. In most cases, the green technologies are preferred, even though they are less effective than conventional technologies. Such technologies are especially in demand, if their usage reduces the amount of manual labor and operating staff risks. Electric-discharge technologies are considered to be a promising option for their application to various processes in mining and building industry. Therefore, many large laboratories in the developed countries are working on the research and implementation of electric-discharge technologies for fragmentation of large rocks, splitting off blocks from monoliths of natural and artificial origin, digging or expanding tunnels, electric-discharge drilling in hard rocks, crushing and grinding ore, etc. [1-5].

The development of electric-discharge technologies and their successful application in industry depend on the availability of durable, reliable and affordable equipment and its components. A high-voltage switch is one of the basic component in the majority of electric-discharge facilities. The high-voltage switch shall meet a number of strict requirements that are determined by operating parameters of the equipment. The progressive types of switches are TDI and TPI thyratrons with cold cathode, also known as pseudospark switches operating on the left-hand branch of the Paschen's curve in a wide range of anode voltages between 1 kV and 150 kV and the switched current of up to 200 kA [6-9]. The article describes the experience of pseudospark TDI-type switch operation that was developed by the Russian innovation-industrial company "Pulsed Technologies Ltd".



2. Experimental

The specialists of the Department of High Voltage Engineering and Electrophysics of Tomsk Polytechnic University have designed and built a mobile unit for high-voltage and high-current studies. The main application of the mobile unit is electric-blast splitting off from monolith and fragmentation of rock and concrete lumps. The unit is based on a high current pulse generator (HCPG) with the operating voltage of up to 15 kV and the stored energy in the capacitor bank of up to 63 kJ, the current in load can be increased up to 200 kA [10]. In the initial design of the HCPG a custom high-pressure trigatron switch was used. The switch had flat graphite electrodes kept in argon-krypton gas mixture, which enabled the switching currents of up to 500 kA. Despite a considerable operating current, the switch had relatively low triggering stability and required constant pressure monitoring, which affected to productivity of rock destruction.

In order to increase the efficiency of power transmission and reduce resistive losses in discharge circuit, the high-voltage trigatron switch was replaced by TDI1-200k/25SN-P thyatron. PSS TDI1-200k/25SN-P is designed for pulse switching of capacitive energy storage in submicrosecond and microsecond duration range. In the operating state, the switch is filled with a buffer deuterium gas at the pressure of 20–60 Pa. This modification of thyatron has a hollow anode and it is intended for ringing mode operation. The operating and maximum permissible electrical parameters of PSS are shown in Table 1.

Table 1. Electrical parameters of TDI1-200k/25SN-P switch

Parameter description	Optimum value	Maximum permissible value	Actual operating value
Anode voltage, kV	3–20	3–25	5–13
Amplitude of anode current, kA	150	200	150–250
Pulse repetition rate, Hz	0.5	300	≤0.5
Switched energy, kJ	10	40	45–47
Duration of anode current pulses, μsec	0.1–100	0.1–1000	250–500
Amplitude of reverse anode current, kA	up to 90% of I_a	up to 98% of I_a	up to 90% of I_a

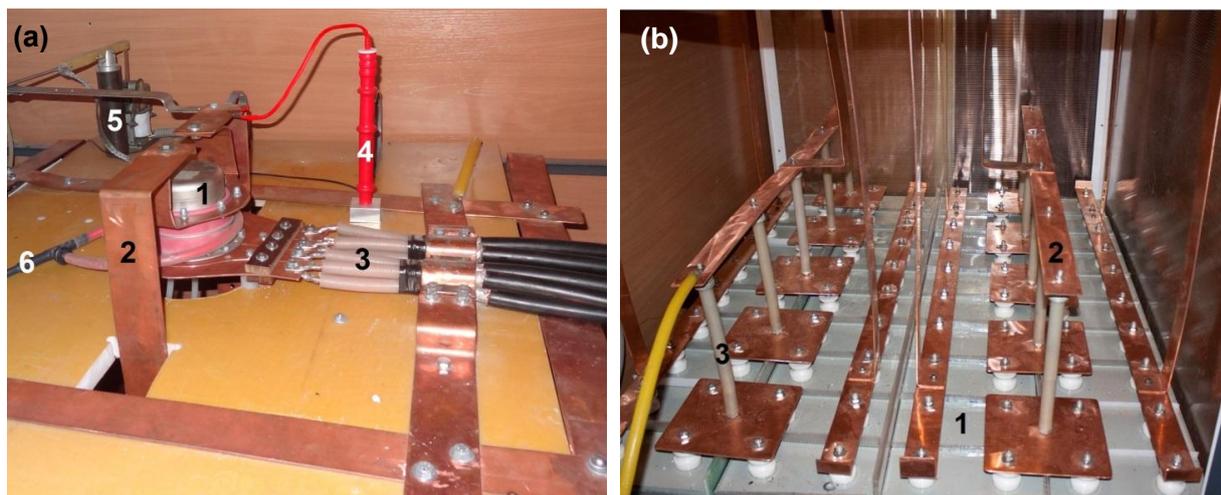


Figure 1. Components of High Current Pulse Generator. (a) arrangement of the thyatron: 1) TDI1-200k/25SN-P; 2) copper buses; 3) coaxial cable; 4) high voltage divider; 5) automatic grounding device; 6) Rogowski coil. (b) capacitor bank: 1) K75-01-15kV-14mkF capacitor; 2) copper buses; 3) fuse.

The High Current Pulse Generator includes a capacitor bank that consists of ten modules. The modules were connected by copper buses in such manner that the current path length from each module to the high voltage switch was practically equal. For reliable operation during the service life of PSS, the manufacturer recommends to provide balanced and symmetrical current feed to the flange of the switch. If the current distribution is asymmetric, then this promotes electrode erosion, which leads to early failure of the device [11]. The arrangement of pseudospark switches and capacitor bank is shown in Fig. 1.

The stored energy was transferred to load by RK50-17-17 coaxial cable. To reduce the equivalent inductance and equivalent resistance of cable the parallel connection of eight cables was used. All cables were divided into two bundles with 4 cables in each. The busses were connected in parallel to reduce the resistance and inductance of the circuit. The symmetrical electric current feed was implemented by connecting two equal sections of capacitor bank from opposite sides to the high-voltage switch (Fig. 2a). For the purpose of balanced current division, in the lower copper flange an incision was made, which divided the flange into several current feed elements (Fig. 2b).

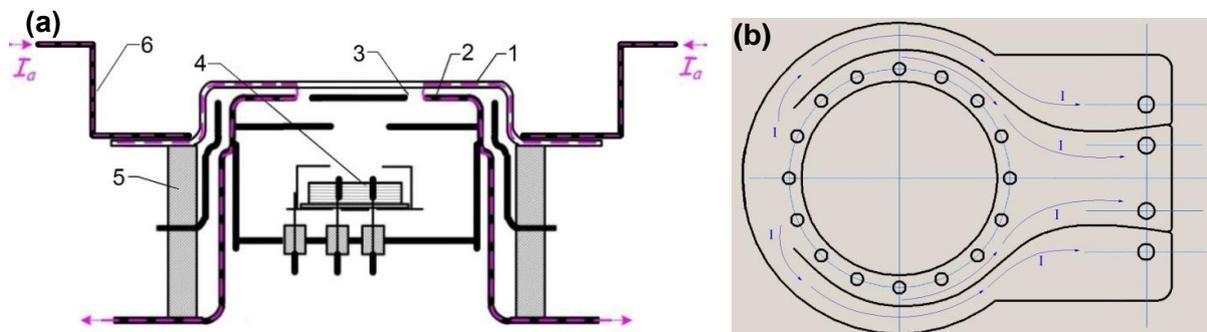


Figure 2. Connection of the pseudospark switch with bus bars. (a) PSS structure: 1) anode; 2) cathode; 3) injection holes; 4) trigger unit; 5) insulator; 6) copper buses. (b) copper flange for current feed.

3. Equipment Testing

The amplitude of current pulse is the most important parameter of electric discharge. Its value directly depends on the resistance and inductance of discharge circuit that are determined by the design parameters of the HCPG. The inductance and resistance of the electrode system can vary according to the configuration and length of the electrode. The values of inductance and resistance were determined in short-circuit experiment by the damping decrement of the current waveform at the charging voltage of 4 kV (Fig. 3a); the operating current was determined in the experiment of concrete monolith splitting at the charging voltage of 13 kV and the electrode length of 50 cm (Fig. 3b).

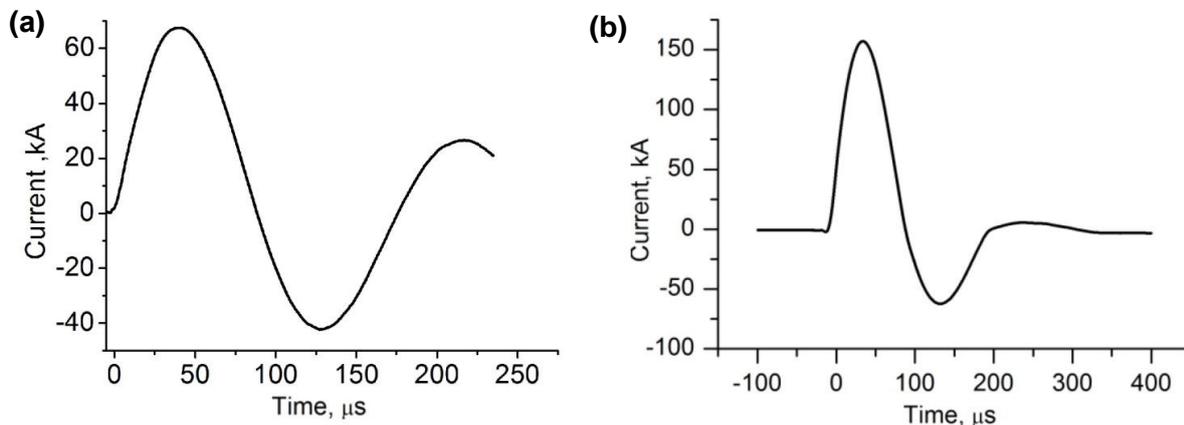


Figure 3. Current waveforms. (a) short-circuit experiment, (b) operating mode.

After a short running life, less than 50 pulses, the pseudospark switch failed to start, while there was no external visible damage. Maintenance work did not lead to the restoration of PSS normal operation. The manufacturer guarantees the satisfactory operation of the PSS and the running life of at least $5 \cdot 10^4$ coulomb of total switched charge, when the thyatron operates in modes without exceeding the maximum permissible parameters. According to Table 1, the actual values of electrical parameters significantly exceed the maximum permissible values. In the experiments of electric-discharge blast of rock and concrete, the PSS worked in the mode with the exceedance of two or more electrical parameters, which probably caused the early failure of the device.

4. PSS Internal Structure Analysis

To detect the internal damage and determine the cause of the failure, PSS was disassembled. The surface condition of the electrodes is shown in Fig. 4. Both electrodes demonstrate the surface erosion of the central region. Fig. 4a shows the cathode; Fig. 4b depicts the anode. In our opinion and according to the information from the manufacturer, this is a normal effect [11].

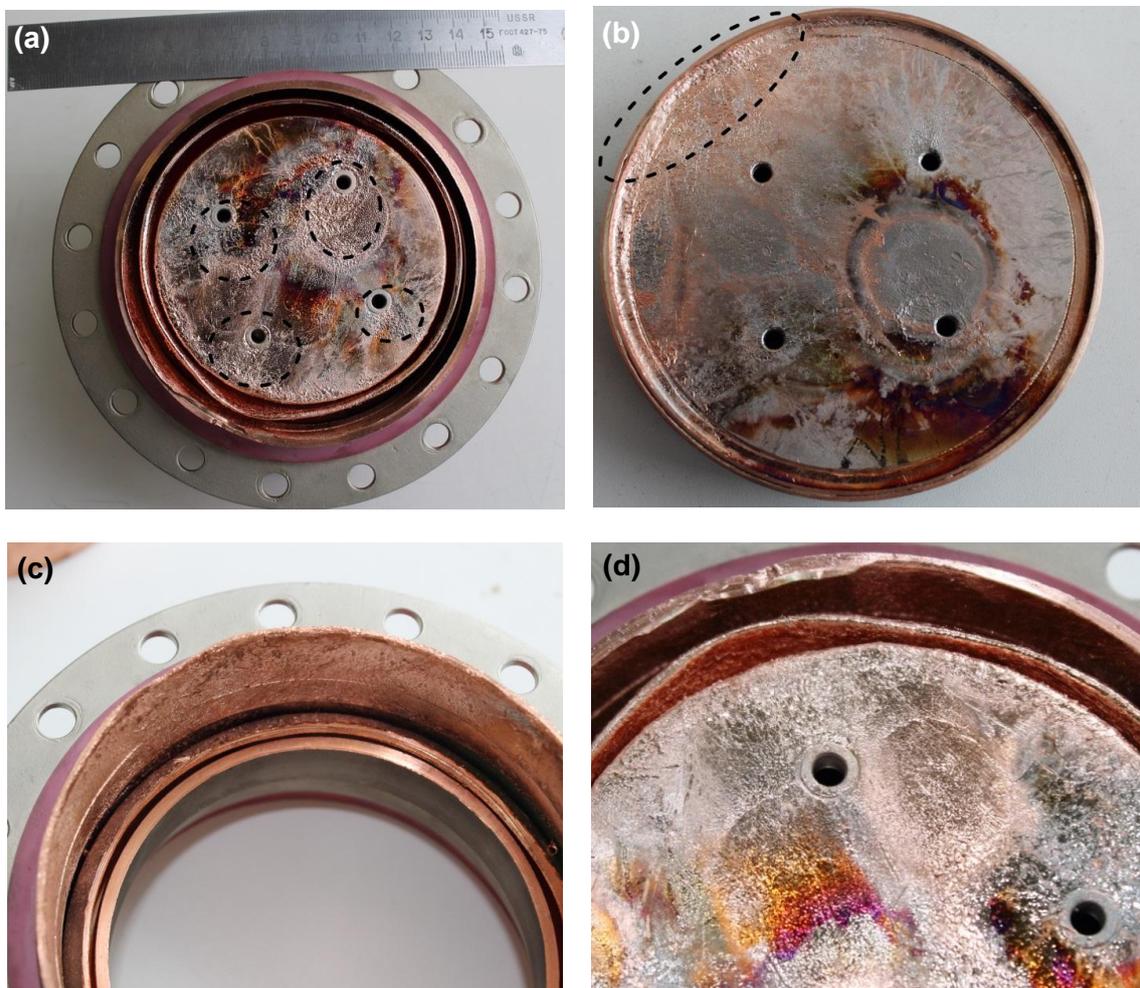


Figure 4. Internal structure of TD11-200k/25SN-P

Although the energy of a single pulse was 47 kJ, which is 17.5% higher than the maximum permissible value, and the duration of current pulse was about 200–300 μsec , the overheating or deep surface melting was not observed. "Linking" of the discharge to a certain injection hole (outlined by dashed lines in Fig. 4a) also did not occur. Thus, the excess of three electrical operating parameters,

current amplitude, switched energy and pulse duration in one-pulse mode could not be the reason for the early failure of the thyatron; however, this can seriously reduce the service life of the device.

Turned out, the actual reason of the thyatron failure was an asymmetric current feed. A significant damage of the wall (Fig. 4a and 4c), the gradient electrode (Fig. 4d) was identified, which were caused by the effect of electric arc. Localization of the discharge on periphery of the electrodes near the lateral surface led to its thinning and the depressurization of PSS. These processes were conditioned by the Lorentz force that pushes the discharge channel out from the central part to the periphery. Thus, the actions taken to implement the balanced current feed and uniform current collector occurred to be ineffective. Hence, this testifies the demand of more buses connected circumferentially to the thyatron's flange as shown in [11]. In future work, we will use the coaxial inclusion of PSS with the application of external conductive screens.

5. Conclusion

We have replaced the high-voltage trigatron switch that was implemented in the mobile electric-discharge blasting unit for splitting and breaking rocks and concrete blocks by TDI1-200k/25SN-P pseudospark switch. The main parameters of the discharge circuit were determined in short-circuit experiment by the damping decrement of the current curve. Due to the operation of the PSS in the mode with the exceedance of two or more electrical parameters, the lifetime of the switch reduced. As a result of the exceeding current pulse amplitude, the current pulse duration and maximum pulse energy, the electrodes of thyatron were subjected to increased erosion. However it was not the reason of such early failure of the thyatron. Damage of the switch occurred because of the concentration of discharge in the periphery of electrodes due to the asymmetric and unbalanced current feed, which ultimately lead to the depressurization of the thyatron.

Acknowledgements

This work was supported by the Federal Target Program, project No. 14.575.21.0059 (RFMEFI57514X0059).

7. References

- [1] Inoue H, Lisitsyn I, Akiyama H, Nishizawa I, Drilling of hard rocks by pulsed power 2000 *IEEE ELECTR. INSUL. M.* **3** pp.19-25
- [2] Silva C C M, Stellin A, Hennies W T, Costa E G Electrohydraulic Rock Blasting: An Alternative for Mining in Urban Areas 2002 *INT. J. MINING ENG.* pp.261-269
- [3] Hofmann J, Th Weise H G G Pulsed Power Technologies for Commercial Material Reduction and Crushing Applications 1997 *Digest of 11th IEEE Pulsed Power Conf.* (Baltimore) pp. 203-207
- [4] Bluhm H, Frey W, Giese H, Hoppe P, et al Application of pulsed power HV discharges to material fragmentation and recycling 2000 *IEEE T. DIELECT. EL. IN.* **7** pp 625-636
- [5] Kuznetsova N, Lopatin V, Burkin V, et al Theoretical and experimental investigation of non-conducting materials 2011 *Pros. 17th IEEE Int. Pulsed power Conf.* (Chicago) pp 267-273
- [6] Bochkov V D, Dyagilev VM, Korolev Yu D and Ushich V G High-power low-gas-pressure current switches 1998 *Instruments and Experimental Techniques* **41** No.5 pp.676-680
- [7] Gribkov V A, Scholz M, Bochkov V D, Dubrovsky A V, Miklaszewski R, Karpinski L, Lee S, Lee P 2004 *J. Phys. D: Appl. Phys.* **37** pp. 2107-2111
- [8] Frank K, Petzenhauser I, Blell U Multi-gap Pseudospark Switches for High Voltage Applications 2007 *IEEE T. DIELECT. EL. IN.* **14** (4) pp. 968-975
- [9] Bochkov V D, Djagilev V M, et al Sealed-off pseudospark switches for pulsed power applications (Current status and prospects) 2001 *IEEE T. Plasma Sci.* **29** No.5 pp. 802-808
- [10] Yudin A, Kuznetsova N, Lopatin V and Voitenko N 2014 *J. Phys.: Conf. Series*, **552** 012028
- [11] Slough J, Pihl C, Bochkov V D, Bochkov D V, Panov P V, Gnedin I N Prospective pulsed power applications of pseudospark switches 2009 *IEEE Pulsed Power Conference* (Washington) pp. 255-259