

On the Use of Radio-Frequency Cables PK50 in High-Voltage Triggering Circuits of High-Power Pulse Generators

S.N. Ivanov

*Institute of Electrophysics, Amundsena Str. 106, Ekaterinburg, 620016, Russia,
Phone: +7(343)2678824, Fax: +7(343)2678794, e-mail: stivan@jep.uran.ru*

Abstract - The synchronization circuit of a RADAN-303 powerful pulse generator and measuring equipment (oscilloscopes, streak cameras) has been described. The circuit is intended for synchronization of experiments on the breakdown in the subnanosecond range. Sections of a thin (the polyethylene insulation 11.5 mm across) radio-frequency cable type PK50-11-11 up to 10 m long were used in the generator high-voltage triggering circuits. This cable was designed to transfer low-voltage r.f. signals and was not intended to pass high-voltage pulses. It is known that the electric strength of insulation materials increases in the subnanosecond range. Our studies demonstrated that these cables can be successfully used for conveyance of ultrashort pulses with the amplitude of up to 150 kV.

1. Introduction

One of the factors that allows a comprehensive analysis of dynamic characteristics of a pulsed electric breakdown in the subnanosecond range is the precision synchronization of the high-voltage pulse generator (PG) and the measuring equipment. This is necessary to record processes, which accompany the breakdown, in the real-time regime with the required precision of their relative and absolute time referencing. Such experiments should provide precision (to within several hundred picoseconds) triggering of measuring equipment with an advance of 10-50 ns relative to the generator pulse [1]. It is necessary also to ensure a stable amplitude of pulses at the discharge gap and, hence, a stable voltage at the PG output. These problems are solved by precision triggering of controlled high-voltage switches and the development of new synchronization circuits for experiments. Very stringent requirements are imposed on high-voltage triggering circuits of PG with respect to stability of the shape and parameters of high-voltage ignition pulses. In this paper we describe a modification of the circuit, which was developed by us earlier [1,2] for synchronization of the PG RADAN-303 and measuring equipment. Sections of the thin radio-frequency cable

RK50-11-11 up to 10 m long were used in the high-voltage triggering circuits of the PG. Circuit for protection of the cable against breakdowns was designed.

2. Block Diagram of the Installation

In our experiments [3,4] the PG supplied a voltage pulse with the FWHM of (0.3-4) ns, the adjustable amplitude of (50-180) kV and the voltage rise time of (5×10^{13} - 5×10^{14}) V/s to the gas discharge gap under study. The value and the shape of the breakdown current were recorded using a C7-19 wideband analog oscilloscope and a Tektronics TDS6604 digital oscilloscope. A streak camera (AGAT-SF3M, Cordin 173) simultaneously photographed the luminescence, which accompanied pre-breakdown and breakdown processes in the discharge gap. The use of the streak camera was responsible in the main for the intricacy of the experiments since it was necessary to provide an advance triggering with precision to within 0.5 ns of the sweep generators of the instruments used, which have dead times from 15 to 50 ns.

The block diagram of the experimental installation is shown in Fig. 1. The first variant of this circuit was published in [1,2]. We used a pulse generator with a controlled switch (a high-pressure nitrogen three-electrode spark gap (SG) with field distortion [5]), which was triggered from an additional generator of triggering high-voltage pulses (TPG). The TPG and the PG were connected through a high-voltage delay line (DL) whose delay time (~ 50 ns) compensated the time lag in triggering of the measuring equipment. The PG was a small-size four-nanosecond generator RADAN-303 [6]. The high-voltage triggering circuit of the PG is enclosed with a dashed line in Fig.1. A pulse slicer with peaking and chopping nitrogen discharge gaps [5] was installed at the PG output. The PG output pulse was fed to the discharge gap with minimum distortions through a short (20 cm) transmission line. In addition to synchronization of the measuring equipment, the SG solves the problem of stabilizing the amplitude of output pulses. For more detailed description of the circuit and the voltage diagrams, which illustrates the operation of the circuit, we refer the reader to Ref. [1,2].

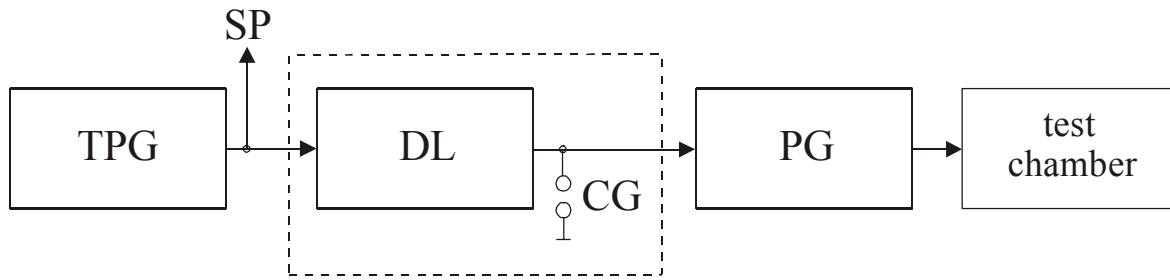


Fig. 1. Circuit for synchronization of PG and measuring equipment. SP – advance triggering pulse of measuring equipment.

3. PG Triggering Circuit

The RADAN-303 nanosecond generator represents a double forming line (DFL) [6] having the output resistance of ~ 50 Ohm, which is charged to the maximum voltage of 200 kV from the Tesla transformer during the time of ~ 8 μ s. The SG serves as the switch of the DFL and is installed between the intermediate potential electrode and the external grounded electrode. Because one of the electrodes of the discharge gap is grounded, the input of the short high-voltage sync pulse is extremely simplified. To ensure the subnanosecond synchronization, it is necessary to provide an advanced development of the subnanosecond breakdown between the starting electrode and the opposite electrode, which bears a positive potential. This situation is possible if the triggering high-voltage pulse has the rise time of several hundred picoseconds. The experiments showed [5] that the SG ensured the maximum triggering precision of up to 300 ps for the RADAN-303 generator.

A high-voltage TPG assembled as the Arkadiev-Marx circuit with a high triggering precision was developed [7] for starting of the SG. At a load of 50 Ohm, the amplitude of triggering pulses was adjusted at 20-70 kV and their FWHM was 0.5 ns (if the synchronization pulse was longer, it was necessary to strengthen the electric insulation of the transmission high-voltage coaxial circuits of the DL, leading to the complication of their design). The leading edge of the pulse was ~ 300 ps long. It was mentioned in the foregoing that very stringent requirements are imposed on the triggering pulse parameters. Even an insignificant increase of the pulse front duration makes it impossible to realize the subnanosecond synchronization of the whole experimental setup. There is a great number of theoretical studies dedicated to the ratio between the bandwidth and the pulse length. Using the formula $f_{up} = 0.4/t_f$ [8] for calculation of the upper frequency limit of the response characteristic, we shall have that the transmission line with $f_{up} = 1.3$ GHz or higher is required to transfer a pulse with the leading edge of 0.3 ns at minimum distortions.

Let us formulate the requirements imposed on the PG triggering circuit. This circuit should provide the

following:

1. The delay of the high-voltage triggering pulse for the time equals the switch-on delay of the measuring equipment (10-50 ns).
2. Distortions of the leading edge of the high-voltage triggering pulse are brought to a minimum.
3. The electric insulation of the triggering circuit withstands the double maximum output voltage of the PG or is protected against the breakdown by high-voltage pulses with the amplitude of up to 360 kV, which are reflected from the load (the discharge gap).

The most complicated element of the PG triggering circuit is the high-voltage DL, which can be realized in different ways. Oil-filled coaxial lines made of metal tubes may be used as the DL. The required electric insulation of this DL is simple to achieve. However, the DL with the delay time of 50 ns will have the length of 10 m, which is not convenient in practical applications. Multisectional delay lines (made up of several single sections) will complicate the construction and make it more expensive due to the use of swivel connectors. We used also a spiral coaxial metal line as the DL. Calibration experiments showed however that this line distorted the leading edge of the subnanosecond triggering pulse and the PG switched to the nanosecond synchronization regime. This circumstance made it difficult to photograph the luminescence, which accompanied the breakdown, at sweeps of 0.5 ns/cm and less.

We made the DL using sections of the radio-frequency coaxial cable type PK50-11-11. This cable was designed for transmission of low-voltage pulses of the radio-frequency range and was not intended for transfer of high-voltage pulses. The PK50-11-11 flexible coaxial cable had a solid insulation of low-density polyethylene with the external diameter of 11.5 mm. The cable had the inner conductor twisted of 7 copper wires 1.18 mm in diameter each and the outer cylinder of symmetric braiding made of copper wires (0.2 mm). According to [9], the cable had the following characteristics:

- the wave impedance of 50 Ohm;
- the nominal attenuation constant for 1 GHz equal to 0.3 dB/m at the nominal input power of 450 W;

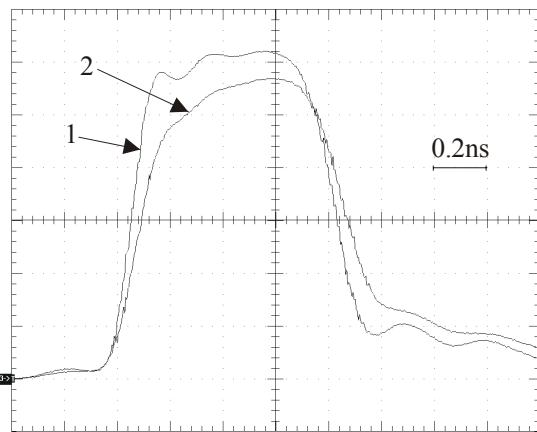


Fig. 2. Test voltage pulse measured with a Tektronics TDS820 oscilloscope. 1 – pulse at the cable input; 2 – the same pulse at the cable output.

- the nominal attenuation constant for 3 GHz equal to 0.5 dB/m at the nominal input power of 200 W;
- the test withstand 50-Hz voltage of the polyethylene insulation equal to 14 kV;
- the initial voltage of internal discharges in the insulation (the “corona initial voltage”) equal to 5.5 kV.

Sections of this cable were used earlier for making of generators of single nanosecond (units and tens of ns) high-voltage (20-30 kV) pulses operating to an unmatched load [10,11]. It is known that the electric strength of insulation materials sharply increases in the subnanosecond range. Considering this fact, we made a test DL of a cable section 10 m long. The distortion of the leading edge of a subnanosecond test pulse passing through this DL is shown in Fig. 2. Such transmission delay lines provided the subnanosecond synchronization of the PG and the measuring equipment, but the lines quickly failed due to the breakdown of the cable insulation.

To determine the applicability limits of the PK50-11-11 radio-frequency cables in triggering circuits of powerful pulse generators, we tested the electric strength of their insulation in the subnanosecond and nanosecond ranges. A voltage pulse from 0.3 to 4 ns long with the amplitude of up to 180 kV was applied to a test cable section 1 m long. It was shown that the cable was fit for transmission of voltage pulses with the amplitude of up to 150 kV and the length of up to 4 ns (the maximum FWHM of pulses produced by the RADAN-303 generator). Its performance was stable at smaller amplitudes and shorter pulses. In other words, the electric insulation of the cable provided a stable operation of the triggering circuit with margin of safety during transmission of subnanosecond triggering pulses having the amplitude of 20-70 kV, but quickly failed if high-voltage pulses, which were reflected from the load (the intermediate spark gaps, the

discharge gap), penetrated to the triggering circuit.

A chopping gap (CG) was installed between the cable and the SG of PG to protect the cable from the breakdown by pulses reflected from the load (see Fig.1). The CG was adjusted to the operate voltage of 50-70 kV. The pulse voltage was controlled by means of wideband capacitive voltage dividers built into the coaxial section of the triggering circuit.

The synchronization circuit made it possible to start the PG and the measuring equipment and begin experiments on the subnanosecond breakdown of overvoltaged gas gaps with the subnanosecond referencing of observed effects to voltage oscillograms [3,4]. The triggering circuit withstood thousands of voltage pulses without the insulation breakdown.

4. Conclusion

It was shown that commercial thin radio-frequency cables type PK50 can be successfully used for transmission of high-voltage subnanosecond pulses. These cables were designed for transfer of low-voltage radio-frequency signals and were not intended for transmission of high-voltage pulses. Our studies demonstrated that the electric strength of insulation materials sharply increases in the subnanosecond range and such cables can be successfully used for conveyance of ultrashort pulses having the amplitude of up to 150 kV. The circuit for high-voltage triggering of a powerful pulse generator, which is described in this paper, is just one of possible applications of these cables in electrophysical equipment operating in the subnanosecond range. We used them also during development and manufacture of flexible X-ray probes with a miniature explosive-emission radiator [12, 13].

Acknowledgements

The author wishes to thank V.G. Shpak, M.I. Yalandin and S.A. Shunailov for the RADAN generator used in the experiments.

This study was supported by the Russian Fund for Basic Research (grant 05-02-16477) and the Presidium of the Ural Branch RAS (a joint project of basic research by UB and SB RAS).

References

- [1] S.N. Ivanov, V.G. Shpak, S.A. Shunailov, et. al., *Prib. Tekh. Eksper.*, 5, 51 (2000) (in Russian).
- [2] S.N. Ivanov, V.G. Shpak, S.A. Shunailov, et. al., *in Proc. XIII Int. Symp. on Gas Discharges and their Applications*, Glasgow, GB, 2000, pp.497-500.
- [3] S.N. Ivanov, *Doklady Physics*, 49/12, 701 (2004).
- [4] S.N. Ivanov, E.A. Litvinov, V.G. Shpak, *in Proc. of the 14th Symp. on High Current Electronics*, Tomsk, Russia, 2006, in press.

- [5] M.I. Yalandin, V.G. Shpak, *Prib. Tekh. Eksper.*, 3, 5 (2001) (in Russian).
- [6] V.G. Shpak, S.A. Shunailov, M.I. Yalandin, et al., *IET* 36, No.1, 106 (1993).
- [7] S.N. Ivanov, V.G. Shpak, S.A. Shunailov, M.I. Yalandin, in *Proc. of the 12th Symp. on High Current Electronics*, Tomsk, Russia, 2000, pp.250-254.
- [8] G.A. Mesyats, *Pulsed Power and Electronics*, Moscow, Nauka, 2004, p.704 (in Russian).
- [9] D.Ya. Galperovich, A.A. Pavlov, N.N. Khrenkov, *Radio-Frequency Cables*, Moscow, Energoatomizdat, 1990, p.256 (in Russian).
- [10] D.I. Proskurovsky, E.B. Yankelevich, *Prib. Tekh. Eksper.*, 5, 108 (1973) (in Russian).
- [11] G.P. Bazhenov, V.I. Manylov, V.G. Shpak, et al., *Prib. Tekh. Eksper.*, 2, 117 (1978) (in Russian).
- [12] G.A. Mesyats, V.G. Shpak, S.N. Ivanov, in *Proc. of the 14th Symp. on High Current Electronics*, Tomsk, Russia, 2006, in press.
- [13] G.A. Mesyats, V.G. Shpak, S.N. Ivanov, in *Proc. of Physics of Extremal Conditions of Matter - 2005*, Chernogolovka, Russia, 2005, pp.48-49.