Methods of triggering for the cold-cathode thyatron with nanosecond operation stability

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Abstract. The sealed-off cold-cathode thyatron TPI1-10k/50 type with a newly developed trigger unit based on auxiliary glow discharge is investigated. As distinct from the commercially produced sealed-off thyatrons, in the thyatron under investigation the high-emissivity tablet is not used. Different triggering circuits are tested. Circuit for which a delay time to breakdown does not depend on auxiliary discharge current is proposed and tested. A capability of the thyatron operation with a stability in delay time not greater than 4 ns is demonstrated.

1. Introduction

Since the end of 1980s, considerable interest has been generated in the high-current low-pressure switching devices with the hollow cathode (pseudospark switches) for different applications [1-7]. The design and principle of operation of these switches are close to those of the classical hot-cathode hydrogen thyatrons. However, these devices do not have a hot cathode. Therefore, pseudospark switches are often named as the cold-cathode thyatrons or the thyatrons with a grounded grid [1, 5-7].

Under certain conditions, it is possible to achieve very short delay time to breakdown of the main gap of a cold-cathode thyatrons relative to the trigger pulse, the jitter in delay time being within a few nanoseconds [6, 8]. This allows using such thyatrons in complex electrophysical systems consisting of a large number of devices operating in parallel. As an example, thyatrons are used in the scheme of a pulsed modulator of a linear inductive accelerator with the maximum voltage of 2.5 MV [9, 10]. The scheme uses 96 cold-cathode thyatrons TPI1-10k/50 with the maximum current of 10 kA and an anode voltage up to 50 kV, which are switched in parallel.

A range of operating pressures of the switch corresponds to the conditions of the left branch of Paschen's curve. Under such conditions the electron free path for ionization is much in excess of the electrode separation. For both self-breakdown in the main gap of the switch and for external discharge triggering a considerable pre-breakdown electron current is required [5, 6]. In the case of external triggering, this current is provided due to a special trigger unit [1-4, 11-17].

Various types of the trigger units are used in the switches. One type of the trigger unit is based on an auxiliary low-current hollow-cathode glow discharge [6, 12, 18, 19]. In the sealed-off thyatrons of TPI type, that are commercially produced in the Pulsed Technology Ltd. (Ryazan, Russia, www.pulsetech.ru), the trigger units consist of a hollow cathode and a ring anode located inside the
cathode cavity. To assist the ignition of the auxiliary discharge and to reduce the discharge burning voltage a special high emissivity tablet is used.

Our previous experiments have shown that the tablet composition influences to parameters of the auxiliary discharge and on rating characteristics of the switch itself [18-20]. In particular, depending of the tablet composition the different regimes of the auxiliary glow discharge in the trigger unit can be realized. In some cases these regimes are temporary unstable, i.e. the spontaneous transitions from one regime to another may occur. In turn, the conditions of the auxiliary discharge burning influence to the delay time to breakdown in the main gap of the switch. Then the problem of nanosecond triggering for the device from pulse to pulse arises.

To overcome the problem, we have developed the novel trigger unit in which the high-emissivity tablet is absent. This unit has been incorporated in the main electrode system of the sealed-off thyratron TPI1-10k/50. Thus, the results of the investigations of different triggering methods as applied to the new version of the thyratron are presented in this paper. Data on the delay times to breakdown in the trigger system and in the main gap are discussed. The ability of the switch operation with a nanosecond stability at a high anode voltages is demonstrated.

2. Experimental results and discussion

Figure 1 shows a schematic of the thyratron with the new trigger unit and one of the possible trigger circuits. Here, the thyratron is connected in the electric circuit for commuting the capacitance \( C_0 \) (charged to a voltage \( V_0 \)) to the load \( R_0 \).

The outer diameter of the thyratron ceramic case is 95 mm. The main discharge gap, to which the initial voltage \( V_0 \) is applied, includes in itself the anode \( A \) and the grounded hollow cathode \( C \). In this device, a two-section design of the main gap with the gradient electrode \( G \) is used. The design of the main electrodes is the same as that in the standard version of the thyratron TPI1-10k/50. As figure 1 shows, the trigger unit electrodes are built in the grounded cavity of the main cathode.

Similar to the classical hot-cathode thyratrons, the working pressure in the device is maintained due to hydrogen reservoir. A voltage \( V_T=(4-6) \) V at a current of about 2 A is applied to the heater of the hydrogen reservoir.

Inside the cathode cavity the trigger unit is located. As noted above, the trigger unit is based on an auxiliary glow discharge. As distinct from the commercially produced thyratrons, the trigger unit electrodes \( A_1 \) and \( C_1 \) represent two cups, faced to each other by the open sides. Thereby discharge initiation occurs over the “long path” and the acceptable discharge ignition and burning voltages are provided. The inner diameters of the cavities \( A_1 \) and \( C_1 \) are 26 mm and 30 mm respectively. The distance between the bottoms of the cavities is 80 mm. The trigger unit communicates with the cavity \( C \) via the aperture in the electrode \( C_1 \) whose diameter is 5 mm.

The electric circuit, presented at the figure 1, corresponds to the circuit with a grounded grid. The hollow cathode \( C \), which plays a role of a grid of classical hot-cathode thyratron, is grounded. At initial conditions in the trigger unit an auxiliary discharge with the current \( i=(10-30) \) mA is sustained and the high voltage \( V_0 \) is available at the anode \( A \). At certain instant of time the negative trigger pulse \( V_T \) is applied to the trigger resistor \( R_T \) through the ballast resistor \( R_B \). Under the action of this pulse, a trigger discharge between the electrodes \( C \) and \( C_1 \) with a pulsed current of about 20 A develops. As a result, a high-density plasma arises in the cathode cavity \( C \) so that electrons are extracted from the plasma into the main gap through the boreholes in the upper plane of electrode \( C \). This leads to initiation of the discharge in the main gap [5].

It should be stressed that besides the current of the auxiliary glow discharge between the electrodes \( A_1 \) and \( C_1 \) there exists a small so-called parasitic current to the electrode \( C \). For the circuit under consideration this current is monotonically increases from 0.1 mA to 1.5 mA with the increase of the discharge current from 10 mA to 30 mA. Due to the auxiliary discharge current the cathode \( C_1 \) turns out under the positive potential of about several tens of volts with respect to the grounded cathode \( C \). In such conditions the electrons from the negative glow plasma, that is located in the cathode cavity \( C_1 \), are not able to enter in the gap between electrodes \( C_1 \) and \( C \) through the aperture in the electrode \( C_1 \).
However the gap $C_1-C$ is an accelerating gap for the ions. Thereby, a part of ions that moves towards the inner surface of the cathode $C_1$, are accelerating in the cathode voltage drop, enters in the gap $C_1-C$ through the aperture in the electrode $C_1$ and passes to the electrode $C$. Due to the $\gamma$ processes a current of electron emission from the surface of the cathode $C$ arises. These electrons moves to the electrode $C_1$ and contribute to the parasitic current.

After application of the trigger pulse, potential of the electrode $C_1$ becomes negative with respect to the electrode $C$. As a result, parasitic current is rearranged and intensified. Ions in the gap $C_1-C$ are accelerated towards the electrode $C_1$, electrons towards the electrode $C$. This leads to the ignition of the trigger discharge between the electrodes $C_1$ and $C$ and to the breakdown in the main gap of the thyratron.

Figure 2 shows the waveform of the voltage at the thyratron anode $V_A$, discharge current in the main gap $i_a$ and the trigger pulse $V_T$ illustrating the breakdown process of the main gap of the thyratron. In initial conditions a high voltage $V_0=40$ kV is applied to the anode $A$, and an auxiliary glow discharge with the current $i=10$ mA is sustained in the trigger unit. At instant $t_0=0$ a trigger pulse is applied to the resistor $R_T$ and potential of the electrode $C_1$ increases. During 100 ns voltage $V_T$ reaches 4.3 kV and then decreases. At instant $t_1=370$ ns a sharp partial drop in voltage is observed at the waveform $V_T$. Obviously, this drop is associated with the discharging of the intrinsic capacitance of the gap between the electrodes $C$ and $C_1$ through the discharge at the stage of its ignition. As a result, after 26 ns, at instant $t_m$ the process of the breakdown development in the main gap starts.

The delay time to breakdown in the main gap is the time interval between the instant $t_1$ and the beginning of a sharp decreasing in the anode voltage $V_A$ (instant $t_m$ at the voltage waveform). It is seen, that the delay time to breakdown is extremely small, $(t_m-t_1)=26$ ns. It should be noted that the main contribution in total time $t_m$ is provided by the delay time in the trigger system (time interval $t_1$). The total jitter $\Delta t_m$ in the time $t_m$ is also determined by the jitter in the time $t_1$ and does not exceed 6 ns.

The delay time $t_m$ and the jitter can be reduced by an increase of auxiliary discharge current. For example, if we increase current $i$ to 20 mA, the delay time decreases to $t_m=226$ ns and jitter to $\Delta t_m=2$ ns. It is notable that the time interval $(t_m-t_1)$ for the case of increased current $i$ is not changed and equal to 26 ns. Reduction of the delay time is provided by a decrease in delay time $t_1$. 

![Figure 1](image1.png)

**Figure 1.** Schematic of the TPI1-10k/50 thyratron with a new trigger unit and the electric circuit for triggering. $R_1=26$ kΩ, $R_B=60$ Ω, $R_T=4.4$ kΩ, $V_0=(10-40)$ kV, $C_0=10$ nF, $L_0=1.3$ µH, $R_0=10$ Ω.

![Figure 2](image2.png)

**Figure 2.** Waveforms of the voltage at the thyratron anode $V_A$, discharge current in the main gap $i_a$ and the trigger pulse $V_T$ for the trigger circuit in figure 1. (25 pulses are superimposed). $V_{hi}=5.25$ V, $i=10$ mA, $V_d=280$ V, $V_0=40$ kV.
Figure 3 shows a schematic of the thyatron and another trigger circuit. In this case a positive voltage \( V_1 \) for auxiliary discharge ignition and sustaining is applied to the electrode \( C_1 \) and a negative trigger pulse \( V_T \) is applied between electrode \( A_1 \) and grounded cathode \( C \).

![Schematic of the TPI1-10k/50 thyatron and the electric circuit for triggering.](image)

**Figure 3.** Schematic of the TPI1-10k/50 thyatron and the electric circuit for triggering.

- \( R_1 = 26 \, \text{k}\Omega \)
- \( R_0 = 60 \, \Omega \)
- \( R_T = 4.4 \, \text{k}\Omega \)
- \( V_0 = (10–40) \, \text{kV} \)
- \( C_0 = 10 \, \text{nF} \)
- \( L_0 = 1.3 \, \mu\text{H} \)
- \( R_0 = 10 \, \Omega \)

For this circuit electrode \( A_1 \) is the hollow cathode of the auxiliary discharge, electrode \( C_1 \) is the hollow anode and electrode \( C \) is the grounded cathode. As far as in the auxiliary discharge circuit there is a resistor \( R_T \), the potential of electrode \( C_1 \) is higher than the discharge burning voltage \( V_d \). For example, for discharge current \( i=10 \, \text{mA} \) voltage \( V_d=385 \, \text{V} \), and the potential of electrode \( C_1 \) is 430 \, \text{V} \). It means that the electrons from discharge plasma are not able to enter in the gap between electrodes \( C_1 \) and \( C \). Thereby parasitic current is mainly provided by the ions from plasma in the cavity \( C_1 \) that passes through an aperture and accelerates in the gap between electrode \( C_1 \) and \( C \).

After application of a trigger pulse an auxiliary discharge current increases as far as the trigger discharge current start flowing from electrode \( A_1 \) to electrode \( C_1 \). Since this pulsed current is restricted by a resistor \( R_1 \), the potential of electrode \( C_1 \) becomes negative with respect to a grounded electrode \( C \). Then an electron current from discharge plasma starts flowing to electrode \( C \). Due to this electron flow the trigger discharge between the electrodes \( A_1 \) and \( C \) is ignited that leads to breakdown in the main gap.

The waveforms for the circuit under consideration are shown in figure 4. It is seen that for the case of \( i=30 \, \text{mA} \) the delay time to breakdown and jitter are rather small, \( t_m \pm \Delta t_m = 110 \pm 2 \, \text{ns} \). If we reduce the current \( i \) to 10 \, \text{mA} \) the delay time and jitter are increased to \( t_m \pm \Delta t_m = 300 \pm 4.5 \, \text{ns} \).

![Waveforms of the voltage at the thyatron anode \( V_A \), discharge current in the main gap \( i_a \) and the trigger pulse \( V_T \) for the trigger circuit in figure 3. (25 pulses are superimposed). \( V_A=5.25 \, \text{V} \), \( i=30 \, \text{mA} \), \( V_d=345 \, \text{V} \), \( V_0=38 \, \text{kV} \).](image)

**Figure 4.** Waveforms of the voltage at the thyatron anode \( V_A \), discharge current in the main gap \( i_a \) and the trigger pulse \( V_T \) for the trigger circuit in figure 3. (25 pulses are superimposed). \( V_A=5.25 \, \text{V} \), \( i=30 \, \text{mA} \), \( V_d=345 \, \text{V} \), \( V_0=38 \, \text{kV} \).
Circuit operates as follows. Before the application of the trigger pulse, the electrode $A_1$ is the anode and the ions move towards the cathode $C$ from the cavity $C_1$. When the trigger pulse is applied, the potential of the anode $A_1$ becomes negative and discharge in the trigger unit is rearranged. Discharge current of about 0.5 A starts flowing between cathode $A_1$ and anode $C_1$. Moreover, due to this pulsed current the potential of electrode $C_1$ becomes negative. As a result, an electron current from plasma in cavity $C_1$ starts flowing to the gap $C_1$–$C$, trigger discharge between the electrodes $A_1$ and $C$ arises and the breakdown in the main gap occurs.

![Circuit diagram](Image)

**Figure 5.** Schematic of the TPI1-10k/50 thyatron and the electric circuit for triggering. $R_1=26$ kΩ, $R_T=4.4$ kΩ, $C_0=10$ nF, $L_0=1.3$ μH, $R_0=10$ Ω, $C_T=3.3$ nF.

**Figure 6.** Waveforms of the voltage at the thyatron anode $V_A$, discharge current in the main gap $i_a$ and the trigger pulse $V_T$ for the trigger circuit in figure 5. $V_H=5.25$ V, $i=10$ mA, $V_d=280$ V, $V_0=38$ kV.

A sample of the waveforms for the case of the trigger circuit in figure 5 is presented in figure 6. Even for the auxiliary discharge current $i=10$ mA the delay time to breakdown and jitter are 87 ns and 2.5 ns respectively. An increase in the auxiliary discharge current $i$ to 20 mA leads to decrease in the delay time to breakdown $t_m$ to 82 ns. However, with the further increase of the current $i$ up to 30 mA the delay time to breakdown is not changed and equal to $t_m=82$ ns.

### 3. Conclusion

The sealed-off cold-cathode thyatron TPI1-10k/50 type with the new trigger unit based on auxiliary glow discharge is developed. Three types of trigger circuits have been tested. The minimal delay time to breakdown $t_m=82$ ns and the jitter $\Delta t_m=2.5$ ns are reached for the circuit in which the voltage for powering the auxiliary discharge and the trigger pulse are applied to the electrode $A_1$. Just for this circuit the delay time to breakdown practically does not depend on the auxiliary discharge current.

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