HIGH-VOLTAGE GAS-DISCHARGE CURRENT LIMITER-INTERRUPTER USING HIGH-DENSITY GLOW DISCHARGE

I.M. Drozd, A.I. Kuzmichev

National Technical University of Ukraine “Kiev Polytechnic Institute”, Kiev, Ukraine

E-mail: I.Drozd@kpi.ua

The features of operation of a high-voltage gas-discharge switch device with two control electrodes (grids) are considered. The high-density crossed fields low-pressure glow discharge of magnetron type with a cold cathode is used. The device is able to switch electric current at high voltages in three modes: either in the thyratron mode (as a closing switch), or in the tacitron mode (as a closing/opening switch with controllable current interruption), or as a current limiter-interrupter device (as a tacitron with automatic restriction of maximal value of the anode current in the case of shorted load circuit). Such features of device operation are realized due to small gaps between the microperforated control grids and the anode and employing specific pulse operation modes of the control grids.

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INTRODUCTION

Gas filled discharge switch devices are widely used for high voltage pulse generation in pulse radiolocation techniques, for laser pumping and electromagnetic (including X-rays) radiation generation, in an electrophysical apparatus, technological facilities for material treatment, plasma-chemical systems, and powerful ozone generators due to their best relevant features. Extant devices, however, are not capable to resolve all actual problems of power pulse generation, so a development of new switches with enhanced features is required [1].

The most actual is creation of the fast gas discharge switches with full control, *i.e.* closing/opening devices. The opening devices are capable to interrupt electrical current at simultaneous sharp voltage rising up to high values and the most known fast devices of such a kind are the tacitron type thyratrons and crossatrons with a grid control [1, 2]. However, the usual tacitrons contain the hot cathode with well known demerits. The cold cathode may provide short readiness time, long lifetime, high radiation resistance, low cost, *etc*. The crossatrons use a cold cathode but together with tacitrons cannot restrict the maximal current in anode circuits during spontaneous shorting caused by electric breakdown and sparking in the load. Thus, the development of tacitrons with a cold cathode, which are capable to automatically limit the maximal current in the anode circuits, is the vital problem. This work deals with development and investigation of the tacitron type cold cathode device, which can not only interrupt the current but limit the anode current, too. The high-density (up to 1 A/cm^2) low-pressure glow discharge of magnetron type with crossed fields is used as it has lower voltage drop [3]. The two-grid control system is selected since it provides wide possibilities in realization of the desired characteristics of the switch device [4].

1. EXPERIMENTAL APPARATUS

The electrode configurations of experimental switch devices of a tacitron type with a cold cathode and gas discharge in a crossed **E**×**H** fields are shown in Fig. 1. They have cylindrical hollow cathode 1 with an opened upper end, two microperforated control plate electrodes (grids) 3, 4, and plate anode 5. The diameter of grid openings is about 0.5 mm. The cathode is immersed in an axial magnetic field, generated with a permanent magnet. The devices are filled with hydrogen at pressure p = 1…10 Pa. Auxiliary electrodes 2 with positive potential are entered to create a pre-ionization in the cathode chamber and stabilize igniting the devices. These electrodes are made with different shapes and dispositions to select the suitable variant. In Fig.1 (*a,d,e,f*), we have the structures of an inverted magnetron type [3]. In Fig. 1,b,c, we have the structures of a hollow cathode type with a plate anode. The supplemental elements 6 are entered to facilitate igniting the start discharge between cathode 1 and 1st grid.

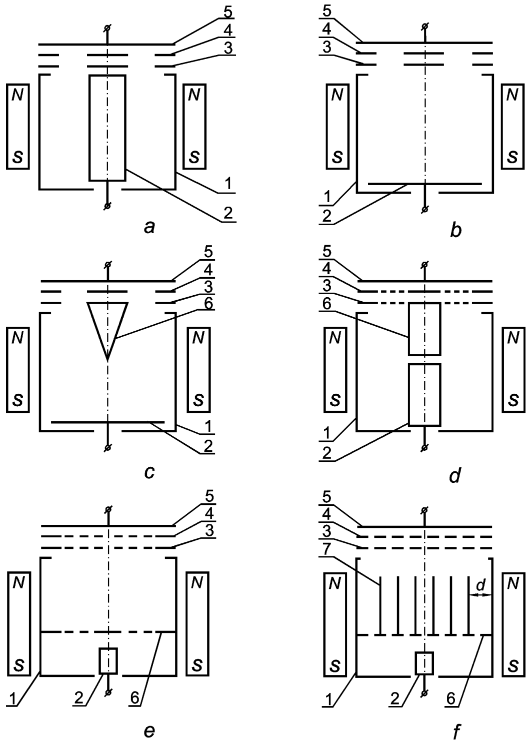

Fig. 1. Schematic structures of experimental electrode system: 1 – cold cathode; 2 – auxiliary pre-ionizating discharge electrode; 3 – 1st grid; 4 – 2nd grid; 5 – anode; 6 – supplemental element of 1st grid or diaphragm; 7 – cathode cylindrical inserts

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Cathode cylindrical inserts 7 are entered to study the hollow-cathode effect in order to decrease the voltage drop ΔU_a during the conduction period of device operation.

The electrode material was molybdenum. The electrode structures were mounted inside a sealed glass envelope of industrial thyratron.

Fig. 2 presents one of the suitable variant of the operational electric scheme for the electrode structures such as in Fig. 1,a,b,c,d.

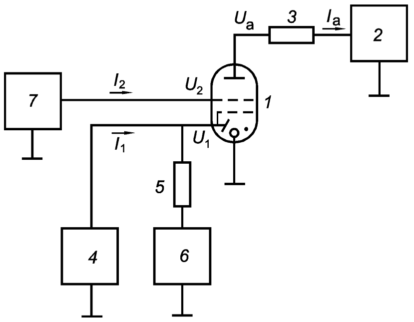

Fig. 2. The operational electric scheme; 1 – switch device; 2 – high voltage supply; 3 – load; 4 – starting pulse generator for the 1st grid; 5 – ballast resistor; 6 – power source for the auxiliary pre-ionization electrodes 2; 7 – control pulse generator for the 2nd grid

High voltage supply 2 provides voltages U_a up to 20 kV and pulse current I_a up to 600 A at pulse duration 1…10 μs. So, the high density glow magnetron discharge (current density~ 1 A/cm^2) may be maintained in the switch device. The DC current of auxiliary pre-ionization discharge commonly is some tens of milliamperes. The pulse mode of this discharge also may be used with current up to tens of amperes.

2. RESULTS AND DISCUSSION

The device operates as the follows. At the beginning, the pre-ionization discharge with the positive electrode 2 is established. Then a positive pulse voltage is applied to the 1st grid to establish a starting discharge generating plasma serving as a plasma emitter of electron for the 2nd grid and then for the anode 5 (see Fig. 1) [5]. When voltage of the 2nd grid U_2 and current of plasma electrons to the anode are higher than some critical values, the device closes the anode circuit. There are three ranges of operation parameters. The first range relates to the thyratron mode (the 1st grid current $I_1 > I_{cr.1}$ at any 2nd grid voltage $0 < U_2 < 3.5$ kV; $I_{cr.1} \sim 160…180$ A). The second range relates to the tacitron mode with possible anode current interruption ($I_{cr.2} < I_1 < I_{cr.1}$, 1.5 kV< U_2 < 2.5 kV, $I_{cr.2} \sim 60$ A, the decrease of U_2 down zero or a negative voltage interrupts the anode current). The third range relates to the current-limiting mode with possible anode current interruption ($I_1 = 5…18$ A, $U_2 = 0.7…1.5$ kV). The mentioned parameters have been measured with the electrode structure depicted in Fig. 1,d at the anode voltage $U_a = 10$ kV.

The operational device characteristics in the tacitron mode depends on different parameters (hydrogen pressure, magnetic field, current and voltage of the grids) including dependence on shape of the starting and control pulses and their delay of the control pulses relatively the starting pulses. Fig. 3 shows the diagrams of grid voltages (U_1, U_2) and anode current (I_a) in the case of trapezoidal shape of pulses. One can see anode current pulse duration ($\tau_a = t_5 - t_2$) practically equals to control pulse duration.

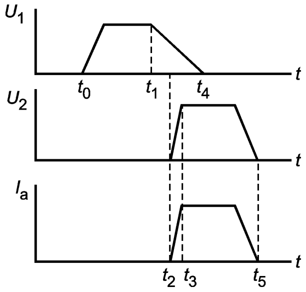

Fig. 3. Operational diagrams for the tacitron mode; U_1 – 1st grid voltage; U_2 – 2nd grid voltage; I_a – anode current

Ratio of anode current I_a to starting discharge current (or to 1st grid current) I_s depends on time parameters of grid pulses. Table 1 illustrates how I_a/I_s ratio depends on the delay ($\tau_d = t_2 - t_1$) of the control pulse relatively the starting pulse back front and the front duration ($\tau_f = t_3 - t_2$) of the control pulse. The parameter $\tau_b = t_4 - t_1$ is the back front duration of the starting pulse.

Table 1

Dependence of I_a/I_s ratio on time parameters

τ_d/τ_b	0.1	0.2	0.3	0.4	0.1	0.2	0.3	0.4
τ_f/τ_b	0.25	0.25	0.25	0.25	0.5	0.5	0.5	0.5
I_a/I_s	0.76	0.43	0.21	0.12	0.49	0.35	0.09	*

*oscillations; $\tau_d = t_2 - t_1$, $\tau_b = t_4 - t_1$, $\tau_f = t_3 - t_2$

As it seen from Table 1, it is appropriate to choose the delay time τ_d less then one third of τ_b value and τ_f less then a half of τ_b to enhance the energy efficiency of the device. When delay is very large, current oscillations arise in the anode circuit.

Fig. 4 illustrates capability of the device to limit (restrict) anode current in the case of shorted load circuit. The case was modeled by shunting the anode load resistor with a thyratron. One can see, the device behaves in this case as an electron tube of beam tetrode type.

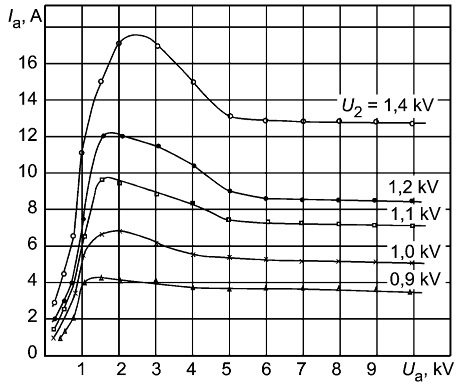

Fig. 4. Anode current I_a dependence on anode voltage U_a with a different control pulse voltage U_2. Load resistance equals zero

Anode current restriction can be explained by the specific combination of two grids with low electrical and electron penetration and the plasma nature of the primary electron source. The 2nd grid with small perforations/openings (less then 1 mm) prevents the anode field penetration to the space below the 2nd grid, but this grid can attracts the electrons from the starting discharge plasma. The plasma electrons diffuse through the openings of the 1st grid toward the 2nd grid and then through the openings of the 2nd grid toward the anode. It can be conclude that the electron current to the 2nd grid is a current of semi-self-sustained (or impeded) glow discharge. At the higher starting discharge currents, the situation is more favorable for filling the gaps between the grids and the anode by plasma, and the effect of current interruption disappears.

Consider the results of study how cylindrical inserts 7 and values of d affect the voltage drop ΔU_a during the conduction period of device operation. In these experiments with electrode structures depicted in Fig.1,e,f, the 1st grid was used as an anode of the hollow-cathode discharge. One can see in Fig. 5: there is the optimal value of d = 4 mm, at which ΔU_a is minimal. Such feature is typical for hollow-cathode discharges. When electrode 5 was used as an anode of the hollow-cathode discharge and the device worked in the thyratron mode, the voltage drop ΔU_a increased by 50…100 V due to additional voltage drop on the gap between the grids and on the gap between the 2nd grids and the anode 5.

The products of p and gaps δ between the grids and between the 2nd second grid and the anode are very small (δ ~ 3 mm) and correspond to values $p\delta$ at the left of the left branch of Paschen curve. Therefore the self-maintained discharge within the gaps is impossible (as in vacuum), and we have the combination of a gas discharge part with a vacuum part inside of the device. However, some gas ion generation by electrons emitted through the 1st grids leads to compensation of electron space charge in the gaps, that ensures the low additional voltage drop on the gaps during the conduction period of device operation.

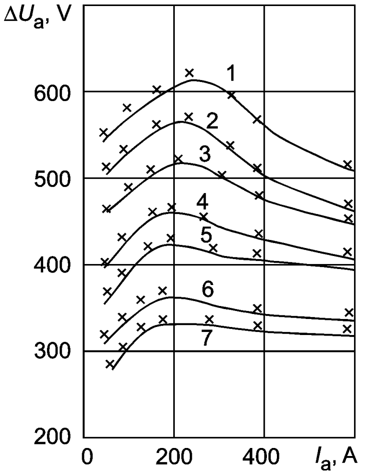

Fig. 5. Voltage drop ΔU_a at different values of d (see Fig. 1,e,f; d, mm; 1 – 43; 2 – 14; 3 – 8; 4 – 6; 5 – 2; 6 – 3; 7 – 4. Cathode diameter is 43 mm; the case of d = 43 mm relates to structure presented in Fig. 1,e

Taking into account the aforementioned and the desire to simplify the design of the device, the electrode structures, shown in Fig. 1,a,d, were selected as the most suitable. Accordingly, the electrodes 2 were connected to the cathodes 1 to form hollow cathodes, and the 1st grids were used both for the pre-ionization, and ignition of the device. The electric scheme, which shown in Fig. 2, may be used for such type of operation of the electrode structure presented in Fig. 1,a,d.

It is worth to note that the structure in Fig. 1,a of inverted magnetron type with cylindrical auxiliary electrode 2 provides the lower voltage drop of the pre-ionization discharge than the structure in Fig. 1,b with the plate auxiliary electrode 2. Also, the structure in Fig. 1,d with cylindrical supplemental element 6 of 1st grid provides the better ignition characteristics than the structure in Fig. 1,c with the conical supplemental element 6.

Table 2 presents main switch parameters for the possible mode of two-grid device operation.

Table 2

The main parameters of the two-grid switch device

Operational mode	Peak pulse anode current, A	Anode voltage recovery time, µs	Recommended pulse generation mode
Thyratron	500	8	Packet-pulse mode with full energy storage discharge
Tacitron	75	0.7	Packet-pulse mode and continuous pulse mode
Current limiter	5…18	0.3	Packet-pulse with shorted circuit current limitation
Peak pulse anode voltage U_a: 10 kV Average anode current $I_{a.av}$: 150 mA Voltage drop in active mode ΔU_a: 300…650 V			

CONCLUSIONS

The research, which was performed, confirmed the possibility to work out a high voltage gas discharge switch device using the high density glow discharge with crossed fields and cold cathode which can operate in thyratron, tacitron and current limiter modes depending on control parameters. The switch device can combine some useful features of vacuum tubes in the anode current saturation mode and a gas discharge device. The investigation of experimental samples of the switch devices was performed to optimize their design, parameters and modes. Some guidelines on development of devices with enhanced time and energetic parameters are formulated.

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ВЫСОКОВОЛЬТНЫЙ ГАЗОРАЗРЯДНЫЙ ОГРАНИЧИТЕЛЬ-ПРЕРЫВАТЕЛЬ ТОКА, ИСПОЛЬЗУЮЩИЙ ВЫСОКОПЛОТНЫЙ ТЛЕЮЩИЙ РАЗРЯД

И.М. Дрозд, А.И. Кузьмичёв

Рассмотрены особенности работы высоковольтного газоразрядного коммутирующего прибора с двумя управляющими электродами (сетками). Используется высокоплотный тлеющий разряд низкого давления в скрещенных полях магнетронного типа с холодным катодом. Прибор способен коммутировать ток при высоких напряжениях в трёх режимах: в тиратронном режиме (как включающий прибор), либо в таситронном режиме (как включающий/выключающий прибор с управляемым прерыванием тока), либо как ограничитель-прерыватель тока (как таситрон с автоматическим ограничением максимальной величины анодного тока в случае короткого замыкания в нагрузке). Такие особенности работы прибора реализуются благодаря малым зазорам между микроструктурированными сетками и анодом и использованию специфических импульсных режимов работы управляющих сеток.

ВИСОКОВОЛЬТНИЙ ГАЗОРОЗРЯДНИЙ ОБМЕЖУВАЧ-ПЕРЕРИВНИК СТРУМУ, ЯКИЙ ВИКОРИСТОВУЄ ТЛІЮЧИЙ РОЗРЯД ВИСОКОЇ ГУСТИНИ

І.М. Дрозд, А.І. Кузьмичев

Розглянуті особливості роботи високовольтного газорозрядного комутуючого пристрою з двома керуючими електродами (сітками). Використовується тліючий розряд високої щільності низького тиску в схрещених полях магнетронного типу з холодним катодом. Прилад може комутувати струм при високих напругах в трьох режимах: в тиратронному режимі (як прилад тільки для вмикання), або в таситронному режимі (як вмикаючий/вимикаючий прилад з керованим перериванням струму), або як обмежувач-переривач струму (як таситрон з автоматичним обмеженням максимальної величини анодного струму у випадку короткого замикання навантаження). Такі особливості роботи приладу реалізуються завдяки малим зазорам між мікроперфорованими сітками та анодом та використанню специфічних імпульсних режимів роботи керуючих сіток.