DESIGN AND EXPLOITATION POWERFUL THYRATRON SWITH IN MODULATORS ACCELERATORS NSC KIPT

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Modulators performed according to linear circuit with PFN depletion via pulse transformer are used in NSC KIPT active electron accelerators. Switch and its components determine the reliability of a plant. Hydrogen thyratrons providing the current switching up to 2.3 kA at anode voltage up to 40 kV are used as a switch in modulators of technological accelerators. The results of study of operational reliability of switches in active accelerators are reported in this article.

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INTRODUCTION

Hydrogen thyratrons (three-electrode or four-electrode) intended for generation of high voltage short pulses at high currents in load are used as a switch in many plants. Hydrogen thyratron made of ceramic and metal as a rule has a heated cathode and control grid. Typical pulse parameters are: duration – nano or microseconds, voltage (5…50 kV), current (50 A…15 kA), pulse frequency 0.2…100 kHz.

Pulses are generated by fast connection of the load to energy storage (capacitor, pulse forming network), which is fully discharged during the pulse. The connection is carried out by the thyratron when relatively low-powered voltage pulse enters the control electrode. Modulators on hydrogen thyratrons have a number of advantages. They are simple constructed and have a high efficiency.

The switch is an important part of the plant. A number of requirements regarding peak operating voltage, peak switching current, average current etc. are imposed to it. So the selection of a switch and its components largely determines the reliability of the plant [1, 2]. The selected thyratron must have characteristics complied with technical requirements to the technological accelerator. Compliance with switch operation conditions is required for their service life extension. New thyratrons and thyratrons used in the accelerators previously were studied.

EXPERIMENTAL PLANT

Modulators operated in NSC KIPT active accelerators are performed according to linear circuit with PFN depletion through a pulse transformer. Ceramic-metal thyratrons TGI1-2500/50, CX1525A of company E2V, ceramic thyratrons L-4174, thyratrons TGI1-1000/25 and glass thyratrons TGI1-2500/35 are used as switches. The main parameters of thyratrons used in technological accelerators are presented in Table. We can see that thyratrons TGI1-2500/50 and CX1525A are preferable to be used in modulators of powerful accelerators; they allow switching the current up to 2.5 kA at the anode voltage of 40 kV.

The only thyratron TGI1-2500/50 is water-cooled, the others – air-cooled. TGI1-2500/50 is reliable in operation, its connection diagram is quite simple. The thyratron has one grid. Pulse voltage of 1000…1200 V with a rise time of 5…10 kV/μs is applied to this grid from the trigger unit manufactured in NSC KIPT.

Subject to compliance with the technical requirements for the operation the most of the thyratrons significantly exceed the guaranteed operation time. However, the service life of most thyratrons has expired.

Thyratrons CX1525A were used in modulators of accelerators. Their trigger parameters, cathode filament voltage of 6…6.6 V, voltage of hydrogen generator heating of 6…6.6 V, filament current of 37 A are similar to TGI1-2500/50 parameters. The distinctive features of this thyratron are the necessity for control over two grids and deuterium filling. Trigger unit MA2709 of company E2V, as well as single-channel trigger units manufactured in NSC KIPT are used for activation of double grid thyratron CX1525A.

Technical requirements for thyratron

Parameter name, Unit of measurement	CX1525a		TGI1-2500/50		L-4174		TGI1-1000/25	
	Rating	Actual	Rating	Actual	Rating	Actual	Rating	Actual
Pulse anode voltage, kV	50	45	10…50	45	33	33	5…25	–
Pulse anode current, kA	5	2	2.5	2	2	2	1	–
Average anode current, A	5	3	4	3	4	3	1	–
Frequency, Hz	2500	300	400	300	500	300	700	–
Cooling	Air 5 cube/min		Water 3l/ min		Air 5 cube/min		Air 1 cube/min	

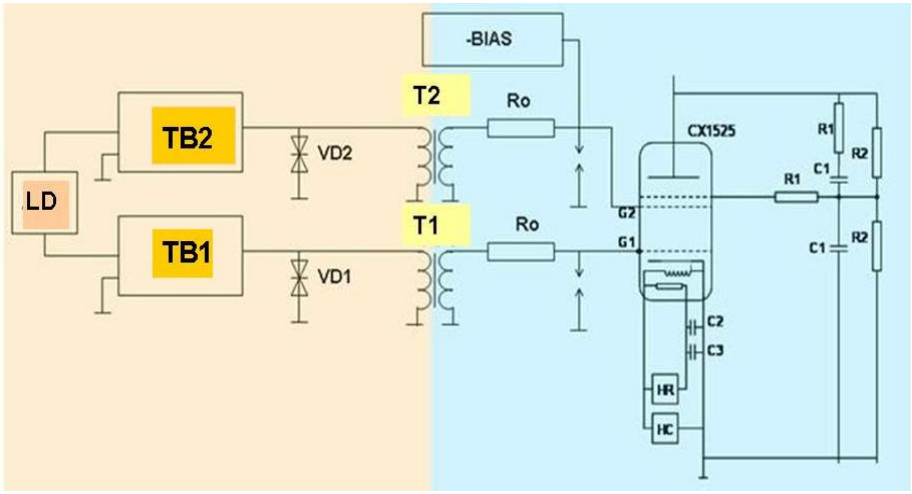

Fig. 1. Diagram of thyratron grids connection to trigger units

Diagram of double-grid thyratron connection to trigger units and protection is presented in Fig. 1. The current in the cathode circuit can generate a potential difference of hundreds volts or more. To protect trigger units their output circuits are galvanically isolated from the thyratron cathode using the transformers T1, T2. Suppressors VD1, VD2 enable to limit the amplitude of voltages supplied to the circuit elements of trigger units are also used for protection. Aerial fuse charge eliminators, which render possible to avoid the probability of disruptive discharge over the thyratron surface, and limit resistors Ro enable to set grid current values according to the technical specifications, are used to protect the thyratron.

Gradient divider having resistive and capacitive parts (for fast rise time) is used for switch reliably operation. The gradient divider ensures distributing the anode potential over the thyratron surface, it make possible to avoid disruptive discharge over the thyratron surface. Signals from trigger unit MA2709A on thyratron grids at cooled thyratron are presented in Fig. 2. Trigger unit applies signals with amplitude of 500 V to the first (bottom) grid and 1000 V with negative shift -100 V to the upper grid. Pulse delay on the second grid relative to the first grid is 0.5 μs.

Fig. 2. Pulses on thyratron grids from trigger unit MA2709A

Oscillograms of pulses on thyratron grids at switched-on filament are presented in Fig. 3. We can see change of pulses after thyratron heating. The pulse spike with duration of ~ 300 ns and amplitude of ~ 1000 V occurs on the first grid. Thus, the rate of voltage pulse rise increases, it is -10 kV/μs. The amplitude of the pulse on the second grid decreases in the positive area, therefore the second grid operates for a negative shift It allows reducing the deionization time after discharge through the switch, what is required for operation at high frequencies.

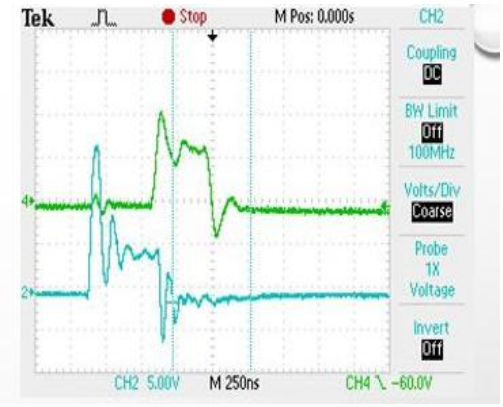

Fig. 3. Pulses on thyratron grids when filament is switched on

The trigger unit enable to apply voltage pulses of 500…2000 V with duration of 0.5…2 μs to two thyratron grids is required to activate the thyratron. Fig. 4 shows oscillograms of pulses on thyratron grids at the modulator startup using two single-channel units, manufactured by NSC KIPT, with thyratron filament on and off.

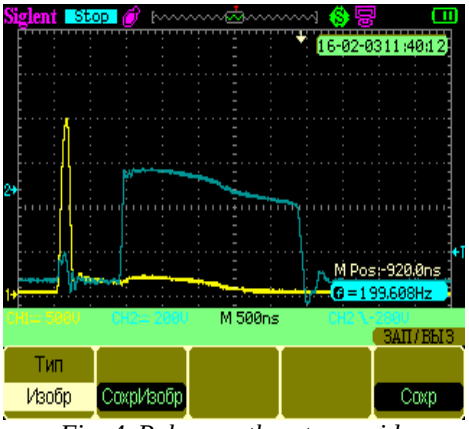

Fig. 4. Pulses on thyratron grids from two single-channel trigger units

The output signal amplitude on both units was 1200...1500 V. One of the units was constructed using thyristors, the second – transistors IGBT. The edges on the second unit were steeper, so this unit was used in the circuit of the second thyratron grid, where the requirements to the rate of pulse rise are higher. As shown in Fig. 4, the pulse on grids distorts when thyratron is heating. Lockouts control signal was transmitted directly from the trigger unit.

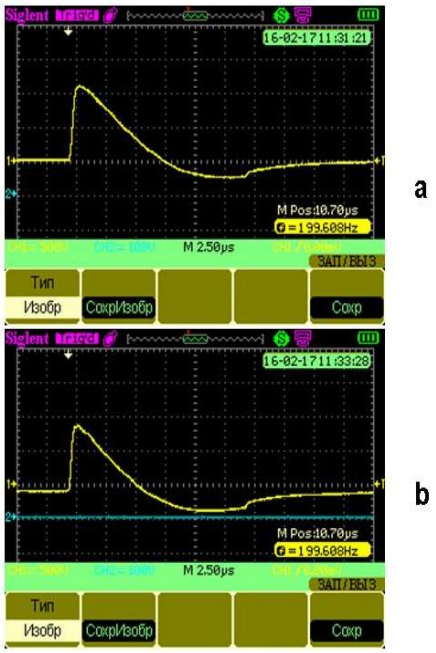

Fig. 5. Voltage pulses on the first thyratron grid when the thyratron filament is off before (a) and after (b) the isolating transformer

Pulses from the trigger unit on the channel of the first grid before the isolating pulse transformer and after are presented in Fig. 5. We can see that isolating transformers distort slightly the transmitted pulse. The pulse edge on the transformer primary winding was 5 kV/µs, then 4.8 kV/µs, besides the pulse amplitude decreased from 1000 to 850 V, this is due to connection of the limit resistor of 27 Ω to the grid circuit.

Voltage pulses on the first thyratron grid at switched-on filament are presented in Fig. 6. As shown in the Figure, the shape of the pulse on the grid distorts, when the thyratron is heated, at that the transformer slightly changes the pulse shape.

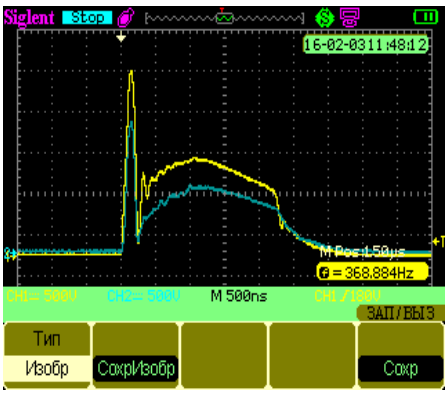

Fig. 6. Pulses on the first thyratron grid at switched-on filament on the primary and secondary windings of the isolation transformer

The amplitude of the grid current is very important for the thyratron steady operation. The current pulse on the first thyratron grid is presented in Fig. 7. The pulse amplitude is 14 A, it meets the requirements to the thyratron technical specifications. The required value of the pulse amplitude is achieved by selection of the limit resistor R0 in the thyratron grid circuit.

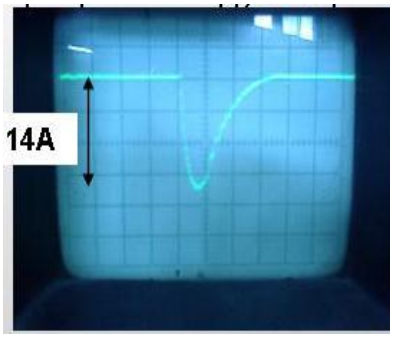

Fig. 7. The oscillogram of the current pulse of the first grid of the thyratron CX1525A

As can be seen from above the thyratron CX1525A can be used in the modulator circuit of powerful technological accelerators ("EPOS", KUT-1, LUE-10). The oscillogram of voltage pulse at the modulator output of the accelerator "EPOS", is presented in Fig. 8.

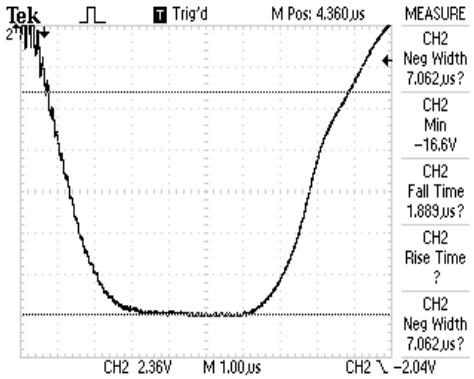

Fig. 8. The voltage pulse at the output of the accelerator "EPOS"

Thyratron L-4174 can be used in some modulators of accelerators. As seen in the Table 1, its basic characteristics are similar to characteristics of other thyratrons, however the peak anode voltage of 33 kV is less then others.

This thyratrons can be used in one of the sections of the accelerator "EPOS", where the requirements to the output pulse are slightly lower.

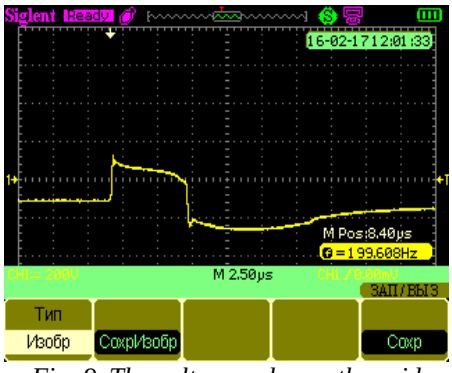

Fig. 9. The voltage pulse on the grid of the thyratron L4174

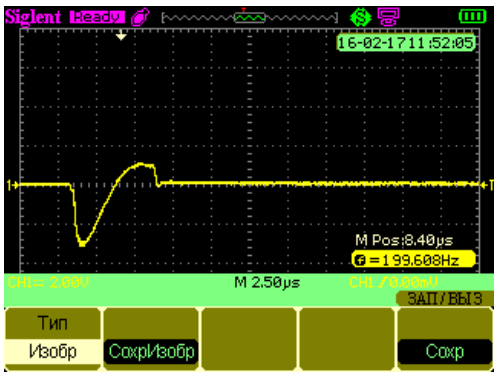

Fig. 10. Current pulse on the grid of the thyratron L4174 in the modulator of the accelerator "EPOS"

The voltage pulse on the grid of thyratron L4174 is presented in Fig. 9. According to the requirements to the pulse, the negative shift of ~100 V was applied to its grid; the amplitude of the positive pulse on the grid is ~ 150 V.

The current pulse of the grid is presented in Fig. 10. Its amplitude was 6A; it was achieved by connection the limit resistor of 50 Ω to the grid circuit.

Thyratrons TGI1-1000/25 and glass thyratrons TGI1-2500/35 can be used in accelerator modulators, but they must be connected in series, it significantly complicates the design and failure diagnostics, as well as increases the element base.

CONCLUSIONS

In the course of executed work:

Triggering of switches was carried out in the operation mode of technological accelerators.

It is demonstrated, that with the required signals presence on the thyratron grids, the modulator is triggered in a stable manner, at that, the filament voltages of the thyratron and the hydrogen generator do not exceed the rated values. The switch life increases in this case.

Switchboards on the basis of the thyratron CX1525A were used in accelerators KUT-1, "EPOS", LUE-10. By now the thyratrons in modulators of technological accelerators have operated 2-4 thousands hours.

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РАЗРАБОТКА И РЕЗУЛЬТАТЫ ЭКСПЛУАТАЦИИ ТИРАТРОННЫХ КОММУТАТОРОВ ДЛЯ МОДУЛЯТОРОВ УСКОРИТЕЛЕЙ ННЦ ХФТИ

В.И. Белоглазов, И.А. Чайка, И.А. Чертищев, Д.А. Каплий, А.И. Косой, В.П. Ромасько, В.Ю. Титов, Ю.Д. Тур, В.А. Цымбал, И.Н. Зайцев, Е.И. Зайцев

В действующих в ННЦ ХФТИ ускорителях электронов работают модуляторы, выполненные по линейной схеме с полным разрядом формирующей линии через импульсный трансформатор. Коммутатор и его комплектующие определяют надежность работы установки. В качестве коммутатора в модуляторах технологических ускорителей используются водородные тиратроны, обеспечивающие коммутацию тока до 2,3 кА при анодном напряжении до 40 кВ. Приведены результаты исследования эксплуатационной надежности коммутаторов в режиме действующих ускорителей.

РОЗРОБКА І РЕЗУЛЬТАТИ ЕКСПЛУАТАЦІЇ ТИРАТРОННИХ КОМУТАТОРІВ ДЛЯ МОДУЛЯТОРІВ ПРИСКОРЮВАЧІВ ННЦ ХФТІ

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У діючих прискорювачах електронів у ННЦ ХФТІ працюють модулятори, що виконані за лінійною схемою з повним розрядом формуючої лінії через імпульсний трансформатор. Комутатор і його комплектуючі визначають надійність роботи установки. Як комутатори у модуляторах технологічних прискорювачів використовуються водневі тиратрони, що забезпечують комутацію струму до 2,3 кА при анодній напрузі до 40 кВ. Приведені результати дослідження експлуатаційної надійності комутаторів у діючих режимах.