THE VEPP-5 INJECTION COMPLEX MODULATOR REVISION AND OPERATIONAL EXPERIENCE

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For the VEPP-5 injection complex klystrons (5045, SLAC Lab., USA) power supply the four modulators producing a pulse voltage of 23.5 kV, a current of 6.3 kA, a pulse-top-duration of 3.7 μs are used. The modulator scheme designed over ten years ago has proved its reliability and let us to find out and study the weak spots of the modulators. The output voltage stability and pulse-to-pulse time jitter improvements are made. The results of the thyratrons TGI1-2500/50 and TGI1-5000/50A long-term exploitation in the VEPP-5 injection complex modulators are presented. The test results of the thyratron TGI1-2500/50 operating in the mode of more then twice pulse current overload at the nominal mode of modulator operation are also presented.

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1. INTRODUCTION

The simplified schematic diagram of the pulse modulator used for the klystron 5045 power supply is presented in fig.1. The features of the early and later modulator modifications were considered in papers [1,2,3]. The last revisions allowing one to improve the modulator pulse parameters are described here.

2. THE USE OF A POSSIBILITY OF THE THYRATRONS TGI1-2500/50 OPERATING IN THE MODE OF MORE THEN TWICE PULSE CURRENT OVERLOAD

Now the thyratrons TGI1-5000/50A are used as switches at the three of four VEPP-5 injection complex modulators. In the case of a nominal mode of operation the thyratrons provide the commutation of a pulse current with an amplitude up to 6.3 kA at an applied voltage up to 47 kV and a repetition rate up to 50 Hz. It should be noted that the basic mode of thyratron TGI1-5000/50A operation, according to the thyratron manufacturer's certificate, is the high-frequency inverter switch mode designed at a repetition rate up to 2.75 kHz, a voltage up to 25 kV and a current amplitude up to 450 A. The manufacturer does not test these thyratrons in the pulse mode of operation. From another side, the thyratrons produced in 1991 are used at the modulators. These circumstances explain the problems connected with the thyratron TGI1-5000/50A operation at the complex VEPP-5 modulators. The lifetimes of these thyratrons taken from one consignment can much differ. It is the main problem. In some cases the term of the thyratron reliable operation in the modulator mode of operation even below the nominal one did not exceed the month. For example the term of reliable operation of the two thyratrons TGI1-2500/50 at the one complex VEPP-5 modulator is more than 10 years.

The problem of fast failure of thyratrons TGI1-5000/50A and their low quantity force us to examine the possibility of the shift to the thyratron TGI1-2500/50 exploitation. According to manufacturer's certificate the thyratrons TGI1-2500/50 are designed for the commutation of pulse currents up to 2.5 kA, so at the complex VEPP-5 modulators they have been connected together in parallel. The parallel connection of the thyratrons results in the following problems: the thyratrons turning-on synchronization has to be provided and the complicated mounting has to be done. At the same time it is known [4], that the thyratrons TGI1-2500/50 used in the pulse mode of operation can maintain more than a three-

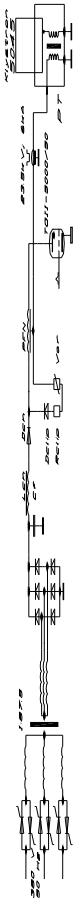

Fig.1. Schematic diagram of the pulse modulator used for klystron 5045 power supply

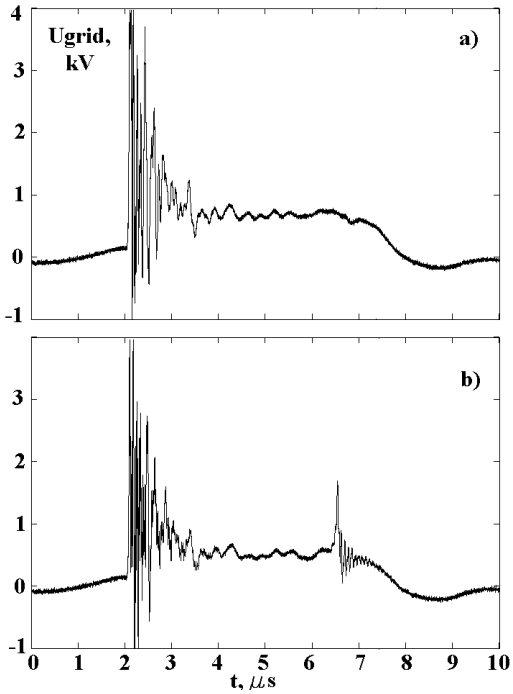

Fig.2. Waveforms of the voltage across the grid-cathode section of the thyratron TGI1-2500/50 without (a) and with (b) the voltage spiking

time current overload under the stipulation that the thyratron mean current does not exceed the certification limit. The mean modulator PFN (pulse former network) discharge current does not exceed 1.7 A while the certification limit of the thyratron TGI1-2500/50 mean anode current is 4 A.

In order to investigate the possibility of the single thyratron TGI1-2500/50 operation as a complex VEPP-5 modulator switch the tests of thyratrons in different modes of modulator operation including the nominal mode have been made. The total test time of one thyratron at the present moment has achieved 2500 hours. During the tests the basic parameters of the thyratron such as turning-on delay time, HG (hydrogen generator) operating voltage (the procedure of HG voltage operating point search was described in [3]) have not changed substantially.

At the nominal voltage 6.3 V across the HG outlets during the current flowing through the thyratron sometimes the voltage spiking across the grid-cathode section has been seen (fig.2). Probably it is caused by the short-time fault of the thyratron conductance. The conductance conditions can be improved by the HG voltage increasing. At a voltage of 7 V across the HG outlets the voltage spiking across the grid-cathode section has disappeared.

In the future the single thyratron TGI1-2500/50 is supposed to be used as a complex VEPP-5 modulator switch.

3. THE THYRATRONS TURNING-ON STABILITY IMPROVEMENT

For the injection complex operation at a full power the coordinated operation of the four modulators is required. It toughens the requirements to the output voltage pulse-to-pulse time jitter of the modulator

The measurements of the thyratron turning-on parameters carried out at the three modulators during the few working days and nights have demonstrated that the thyratron turning-on time jitter has achieved 100 ns.

The working model of the thyratron driving provides a 500 V voltage pulse across the grid-cathode section rising in 600 ns. Having used such the driving parameters the jitter of the order of few nanoseconds is hard to achieve. The thyratron turning-on delay time is 1 μs while such a driving is used.

For the jitter decreasing the scheme providing the voltage 1.4 kV across the grid-cathode section with the rise time 30 ns (fig.3,a) was used. By the use of such a scheme the jitter decreases to 20 ns and the thyratron turning-on delay time reduces to 250 ns.

The use of the pre-triggering scheme allowed the jitter to decrease even greater. In this case the grid-cathode section was supplied by the 100 V voltage 1 ms duration pulse, after that the 1.4 kV voltage 30 ns rise time pulse simultaneously with the start pulse was applied to the grid-cathode section. The use of the pre-triggering scheme for the thyratron TGI1-2500/50 driving allowed one to decrease the jitter to 3 ns and to reduce twice the thyratron turning-on delay time in comparison with the previous driving model (fig.3). However one should to note that the use of pre-triggering resulted sometimes in a spontaneous turning-on of some thyratrons TGI1-2500/50 at the anode voltage close to a nominal value. It is expected that long-term exploitation of thyratrons in the above mentioned operation mode will confirm the expediency of the pre-triggering use

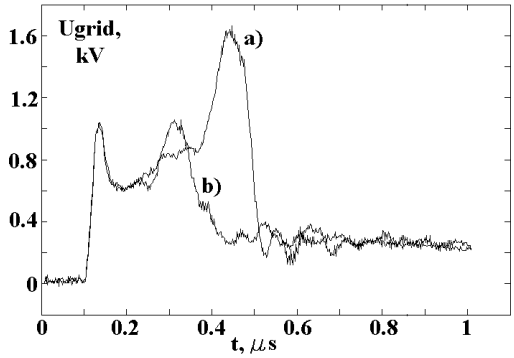

Fig.3. Waveforms of the voltage across the grid-cathode section of the thyratron TGI1-2500/50 without (a) and with (b) the use of the pre-triggering

4. THE VOLTAGE STABILITY IMPROVEMENT

During the injection complex operation at the electron beam load the big pulse-to-pulse instability of the beam energy was discovered. The measurements of the modulators parameters showed that the stability of the PFN charging voltage did not keep within ±0.1%. It does not meet the requirements applied to the stabilization system that represents the charging inductor secondary winding shorted for the purpose of stabilization [2]. This effect was caused by the large triggering delay time of the PFN voltage analog conversion scheme. It resulted in the triggering delay time of the stabilization system and, consequently, in the unsatisfactory modula-

tors output voltage stability. The decreasing of the measuring scheme triggering allowed one to keep the PFN voltage stability within ±0.1%.

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МОДУЛЯТОРЫ ИНЖЕКЦИОННОГО КОМПЛЕКСА ВЭПП-5. ДОРАБОТКА И ОПЫТ ЭКСПЛУАТАЦИИ

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Для питания клистронов 5045 (производство SLAC) инжекционного комплекса ВЭПП-5 используются модуляторы, формирующие импульсы напряжением 23,5 кВ, током 6,3 кА, длительностью 3,7 мкс в количестве 4 штук. Конструкция модуляторов, разработанная около 10 лет назад, доказала свою надежность и, вместе с тем, позволила изучить и выявить слабые места модуляторов. Проведена работа по повышению стабильности напряжения на клистроне, уменьшению временного разброса от импульса к импульсу. Приводятся результаты длительной эксплуатации тиратронов ТГИ1-2500/50 и ТГИ1-5000/50 в модуляторах для питания клистронов 5045. Изложены результаты ресурсных испытаний тиратрона ТГИ1-2500/50 при более чем двойной перегрузке по амплитуде тока в номинальном режиме работы модулятора.

МОДУЛЯТОРИ ІНЖЕКЦІЙНОГО КОМПЛЕКСУ ВЕПП-5. ДОРОБКА І ДОСВІД ЕКСПЛУАТАЦІЇ

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Для живлення клістронів 5045 (виробництво SLAC) інжекційного комплексу ВЕПП-5 використовуються модулятори, що формують імпульси напругою 23,5 кВ, струмом 6,3 кА, тривалістю 3,7 мкс у кількості 4 штук. Конструкція модуляторів, розроблена близько 10 років тому, довела свою надійність і, разом з тим, дозволила вивчити і виявити слабкі місця модуляторів. Проведена робота з підвищення стабільності напруги на клістроні, зменшенню часового розкиду від імпульсу до імпульсу. Приводяться результати тривалої експлуатації тиратронів ТГІ1-2500/50 і ТГІ1-5000/50 у модуляторах для живлення клістронів 5045. Викладено результати ресурсних іспитів тиратрона ТГІ1-2500/50 при більш ніж подвійному перевантаженню по амплітуді струму в номінальному режимі роботи модулятора.