# ION BEAM DYNAMICS

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# MODERNIZATION OF THE HELIUM ION ACCELERATOR MICROWAVE POWER SUPPLY SYSTEM

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The high-voltage rectifier modernization, which is part of helium accelerator (PSS-4) high-frequency system, is described. The rectifier supplies the pulse modulator with direct current energy. The valves of the modulator used are mercury thyratrons. Modernization involves replacing thyratrons with semiconductor diodes. In the article, a comparative analysis of the parameters of thyratrons and diodes, which are supposed to be replaced by thyratrons, is carried out, and the expediency of such a replacement is substantiated.

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## INTRODUCTION

A linear helium ion accelerator with A/q=4 and energy up to 4 MeV has been developed, manufactured and put into operation at the Institute of Plasma Electronics and New Methods of Acceleration (IPENMA) NSC KIPT [1]. The accelerator is destination for operation as part of the MILAC (linear accelerator of multiply charged ions) as a pre-stripping section (PSS-4). As a result of nuclear reactions occurring in the materials of nuclear power facilities (NPFs), residual fission products are formed. The development of works on the creation and study of structural materials for nuclear reactors has led to the development and use of linear ion accelerators for these purposes.

Among the residual fission products, helium should be especially singled out, the accumulation of which has a destructive effect on the general physical and mechanical characteristics of materials. Its accumulation has a destructive effect on the general physical and mechanical characteristics of materials, namely radiation swelling, embrittlement, sputtering, creep, erosion (blistering and flaking), etc. [2 - 6]. To date, there is a lack of experimental data on the formation of helium during irradiation in NPF sand its effect on the properties of materials. Experiments to study the effect of helium, carried out directly at NPFs, are time-consuming and rather complicated. Therefore, the possibility to simulate damage of materials by using linear accelerators and bombarding samples with helium ions is currently being studied [7]. For this purpose a materials science complex was created in the laboratory of IPENMU, the main component of which is the PSS-4 – linear helium ion accelerator.

A detailed description of calculations, structure designs and parameters of the accelerator is given in our previous publications. The main given parameters and distinctive features of PSS-4 make it possible to use it as a source of a helium ion beam to simulate the effect of the radiation background of a NPFs on the materials of the divert or and the first wall of the reactor. The importance of these physical studies requires both the expansion and improvement for the quality of studies, and further development of the technical components of the accelerator. This is achieved, first of all, by increasing the reliability of units based on replacement with using modern elements and technologies.

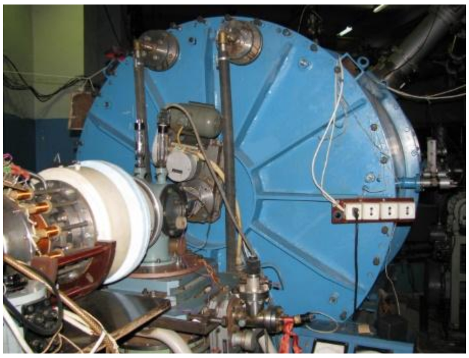

*Fig. 1. PSS-4, helium ion accelerator*

## PSS-4 SHORT DESCRIPTION

Currently, the main studies are carried out using the PSS-4 section (Fig. 1), designed to accelerate helium ions with A/q ≤ 4 from 30 keV/n to 1 MeV/n. The PSS-4 is based on an irregular in terdigital accelerating structure operating on the acceleration method, developed at KIPT – variable-phase focusing with a step change in the synchronous phase along the focusing period. The advantages of this structure in the examined ion energy range are its small size, high acceleration rate, and high electrodynamic characteristics, which ensure stable operation and economical power supply. In current physics studies, PSS-4 contains a helium ion injector, a beam tracking and control line, an ion accelerator, a focusing triplet, and a chamber for samples irradiation.

In experiments to study the properties of structural materials operating in the radiation fields of NPFs, there are increased requirements for the equipment used. First of all, this is the high stability of the parameters of the facility during irradiation, which determines the high quality of the accelerated helium ion beam during the experiment. In this case, special requirements are imposed on the microwave power supply system of the accelerator, since even slight changes in the amplitude and frequency of the accelerating field cause large changes in the experimental conditions for irradiating samples.

The power supply system of a linear helium ion accelerator contains a pulse modulator, a microwave generator, and a high-voltage rectifier, the modernization of which is the subject of this work. The microwave system has the following characteristics.

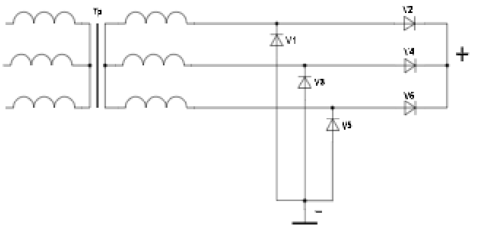


*Fig. 2. Two-stroke rectification circuit*

The maximum pulse output power of the generator is 500 kW and, depending on the type of accelerated particles, can be controlled by changing the anode voltages of the six-stage microwave generator. The pulse modulator produces high-voltage pulses with a duration t = 1 ms, and with a repetition rate f = 1…10 Hz to power the lamps of the microwave generator. The maximum pulse power consumed by the generator from the modulator is 1 MW. The high-voltage rectifier is designed to power the pulse modulator with direct current electrical energy. The average power consumed by the modulator from the high voltage rectifier (HVR) is 11 kW. The HVR is assembled according to a two-stroke scheme and is powered by a three-phase transformer, the windings of which are connected by a “star” (Fig. 2). Mercury thyratrons TR1-40/15, which opens at a certain voltage at the anode, are used as valves V1…V6 in the HVR circuit. The circuit with switching of each thyratron is shown in Fig. 3, where T1 is a transformer for powering the heating of the indirectly heated cathode.

Basic parameters of thyratron TR1-40/15: heating voltage – 4.75…5.25 V, heating current – 58…68 A, anode voltage (direct and reverse) 15 kV. The highest amplitude value of the anode current is 120 A, the average current value is 40 A. The operating temperature range of the thyratron is 15…35°. The maximum service life is about 3000 h. When turned on, it takes at least 30 min. to warm up the cathode. Along with the obvious advantage in the form of a high allowable anode voltage, this type of thyratrons also has significant disadvantages. This is the need for a step-down transformer to power the filament circuits with a power of about 400 W, the secondary winding of which must withstand high voltage.

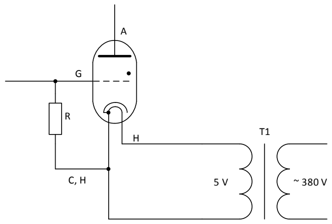


*Fig. 3. Scheme of thyratron connection*

The filament voltage must be maintained with an accuracy of at least 5%, which in turn requires the presence of a mains voltage stabilizer with a power of at least 2.5 kW. Thyratrons of this type allow operation in a narrow temperature range, which leads to the use of an air conditioning system. The presence of toxic mercury vapors and the glass version of the device require special precautions when servicing HVR and replacing thyratrons. Currently, TR1-40/15 thyratrons are not produced by the industry, so the replacement of used devices is practically impossible.

## CHANGES DESCRIPTION

The purpose of the modernization of HVR is: to increase the reliability and durability of work, to reduce the overall energy consumption, to abandon the systems for stabilizing the network and air conditioning. Additionally, the environmental requirements associated with the disposal of thyratrons will be reduced.

In modern electronic equipment, previously widely used, electronic and ion valves are replaced by semiconductor ones. An analysis of the properties of semiconductor valves of various types showed that silicon diodes have the highest allowable reverse voltage and the highest rectified current. Taking into account the requirements for the reliability of the operation of HVR, for the development of a new power supply circuit for the microwave system of the accelerator, diodes of the D122-32 type were selected. The main parameters of this diode are: the maximum allowable forward current at a temperature of 150°C is 32 A; impulse reverse voltage – no more than 1200 V; direct current for single pulses at 25°C is 500 A; ambient temperature is from -50° to the maximum allowable temperature of n-p transition 190°C. A big advantage of electrical circuits based on semiconductor devices is the absence of incandescent transformers, which significantly affects the power consumption and dimensions of the devices. An important role in this is played by the lack of network stabilization and air conditioning systems. Disposal of devices that have worked out their term is also not a problem, since they do not contain toxic substances.

A significant disadvantage of diodes is their low allowable reverse voltage, which depending on the class, is limited to an amplitude of 1600 V. The solution to this problem is to create a circuit of series-connected diodes. Each diode in such a circuit must be shunted with resistors to equalize reverse voltages and capacitors to suppress transient surges. But the reverse current changes for different instances of diodes of the same type. In addition, it increases with increasing temperature. Therefore, the resistance of the diodes in the reverse direction is different and decreases with increasing temperature. If special measures are not taken, this causes an uneven distribution of reverse voltages on the diodes of the series chain and can cause a breakdown of one of the diodes, and after it the rest. The resistance of the shunt resistor must be at least 10 times less than the minimum reverse resistance of the diodes.

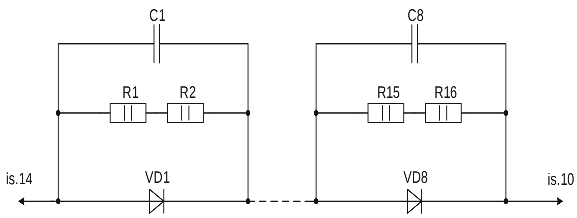


*Fig. 4. Scheme for diodes switching*

On Fig. 4 there is the proposed scheme for switching on diodes as HVR valves in the microwave power supply system of the accelerator. Eight series-connected diodes D122-32, replacing one mercury valve, will be sufficient for reliable operation in the HVR circuit. Diodes are mounted on radiators. Cooling is natural.

## CONCLUSIONS

In order to improve the parameters of individual units of the PSS-4 accelerator, an analysis was made of the state of the high-voltage rectifier (VVR), which is the power source of microwave system. A decision was made to replace obsolete mercury thyratrons with chains of silicon diodes. Despite the simplicity of this solution, in order to maintain the stability of the power supply and the overall reliability of VVR, it is necessary to select diodes for the identity of their parameters. The adoption of this solution makes it possible to further reduce the energy, consumed by the accelerator, as well as to simplify its design by eliminating the stabilization and cooling systems.

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## МОДЕРНІЗАЦІЯ СИСТЕМИ ЖИВЛЕННЯ МІКРОХВИЛЬОВОГО ПРИСКОРЮВАЧА ІОНІВ ГЕЛІЮ

***М.І. Гапоненко, В.А. Сошенко, Б.В. Зайцев, В.Г. Журавльов***

Описано модернізацію високовольтного випрямляча, що входить до складу високочастотної системи прискорювача гелію (ПОС-4). Випрямляч живить імпульсний модулятор енергією постійного струму. Вентилями модулятора використовуються ртутні тиратрони. Модернізація передбачає заміну тиратронів на напівпровідникові діоди. Проведено порівняльний аналіз параметрів тиратронів і діодів, що передбачає заміну тиратронів, та обґрунтовано доцільність такої заміни.