NEW EXPERIMENTAL RESULTS ON RF ACCELERATOR WITH PARALLEL-COUPLED STRUCTURE AND RF CONTROLLED GUN

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Abstract

New data on the development and experimental investigation of the RF accelerator based on the 9-cavities parallel-coupled accelerating structure that is equipped with a high-frequency grid-controlled electron gun are presented. Accelerating structure, injection system and focusing system are improved. Previously observed second emission resonant discharge - multipactor is suppressed by increasing the field amplitude in the structure first cavity and using the protector. The parameters of the accelerated beam close to the design ones, i.e. electron energy up to 8 MeV, capture to the acceleration mode up to 100%, were received. Capture is provided by the RF electron focusing of the microwave field structure with usage of the magnetic focusing system based on permanent magnets and pulsed "π-injection" of the beam by the microwave grid control in the electron gun.

INTRODUCTION

A new type RF accelerator based on the accelerating structure with parallel connection (PCS) is being developed in ICKC and BINP SB RAS. In the paper [1], the first experimental results on investigation of the RF accelerator based on the PCS - 9-cavities accelerating structure prototype are presented. The results were discouraging. The secondary emission resonance discharge interfered with achieving the designed conditions of beam acceleration. At relatively small field amplitude values, the secondary emission resonance discharge was localized in the first and second cavity of the structure. The discharge stabilized the accelerating field amplitude at a low level, the first cavities didn’t accelerate the beam and the electrons fell into the third cavity with energy shortfall. Although the rest structure cavities were operating in normal mode due to the PCS properties, the capture ratio was low; the estimated value of the beam output energy wasn’t achieved. It was decided to improve the accelerating structure, increase the field amplitude in the first PCS cavities, and suppress the secondary emission resonance discharge. This was achieved by increasing the communication slots between the accelerating and exciting cavities. To eliminate the secondary emission resonance discharge, a method of suppressing was developed, i.e., a protector was found and conditions of its applying to the secondary emission centers on the cavity surface were selected. The protector application is carried out in the working installation without opening and subsequent contact with the external atmosphere.

Developed by us injection system [2] contains the electron gun with grid control and microwave signal control system supplied to the gun. Previously a circuit scheme was used where the microwave signal was branched off from the main microwave tract of the accelerating structure. There were problems of controlling the signal parameters - amplitude, duration, phase. At this stage, it was decided to upgrade the system, use an additional microwave power amplifier that enables fast electronic control of all the parameters of the microwave signal.

For additional beam grouping in the injection system, a grouping cavity was used previously [1,2], it made it possible to reduce the bunch phase length and increase the beam capture in acceleration mode. The field amplitude in such a cavity was relatively small, and it became an additional place of secondary emission resonance discharge occurrence. Calculations showed that in the acceleration mode high capture close to 100% is possible due to "π-injection", microwave and magnetic focusing and without additional grouping. It was decided to simplify the beam forming system, eliminate the grouping cavity from the electron gun tract. This led to simplification of the electro-optical and magnetic focusing system.

RF ACCELERATOR

Accelerator Bench

Figure 1 shows a bench to study properties of the developed RF accelerator based on the PCS. On the bench, there are installed an improved accelerating structure with integrated focusing system, a new injection system, the measurement elements. Microwave power is supplied through the feed waveguide 1 to the accelerating structure 3. To measure the current accelerated, the Faraday cup 2 mounted on the structure output is used. Focusing of the accelerated beam is made by the installed magnetic system 4. The magnetic system consists only of permanent magnets and shunts without additional focusing coils and tuning elements. Due to the radial input and reverse, a longitudinal focusing magnetic field is generated almost exclusively on the axis of the PCS accelerating cavities, in the area of the beam span, so the magnet mass is relatively small, and in this case, the total weight of the magnetic system is less than 2 kg. Usually in the accelerators in the initial acceleration stage, a solenoid which weight is comparable with the weight of the accelerating structure is used for focusing. Probes 5 are used for measuring the form of waving microwave signals from the first and second cavities of the structure. Microwave signal is supplied via high-voltage antenna lead-in 7 [3] to the electron gun 6. One of the antennas is grounded, and the other is under injection voltage. Among the antennas there is a ceramic insulator. The gun is equipped with an isolation

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transformer 8. The DC high voltage from the source located in the remote control is supplied via a coaxial cable 9. To measure the pulsed injection current, an inductive sensor mounted on a wire supplying high voltage to the gun 10. High-vacuum pumping is carried out by pumps 11.

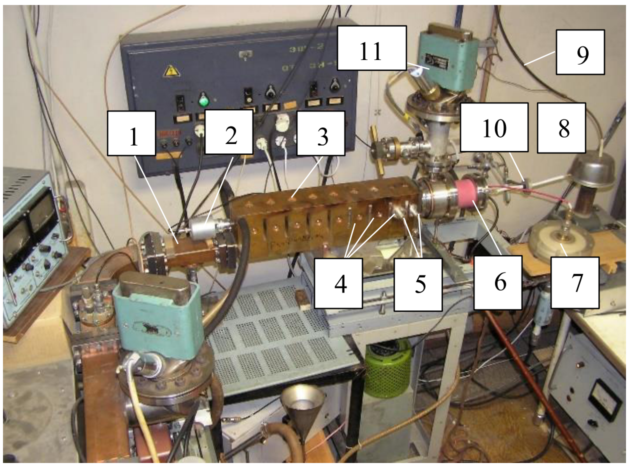

Figure 1: Experimental accelerator stand. The structure length is 0.5 m.

Injection System

Injection system includes a three-electrode electron gun with injection current grid control, an amplifier forming microwave power pulses, timing frequency synthesizer. In our device, a cathode-grid assembly of ГС-34 (GS-34) triode is used, the grid-cathode distance is about 0.1 mm. A cathode-grid unit is installed into a coaxial cavity with a grid-cathode concentrated capacitance. The controlled microwave signal under the injection voltage (about - 50 kV) is supplied via the antenna lead-in to the coaxial cavity. While delivering the controlled microwave signal in the grid-cathode gap, electrons are injected into the grid-anode gap during the half of the microwave period - at a negative cathode voltage relative to the grid. The so-

Figure 2: The gun cathode-grid subunit in the assembled condition. The focusing electrode is removed. The outer diameter is 56 mm.

called "π-mode" beam injection is implemented. The cathodic electrode of the cavity is DC isolated from the grid one and there is a negative DC voltage shift between them, hence, the gun is locked without controlled microwave voltage. This makes it possible to apply a DC-voltage source for the high-voltage power supply of the pulsed electron gun. In this case, a source providing DC high voltage up to -60 kV and current up to 1 mA is used. To generate a pulsed injection current up to 0.5A microwave power up to 0.5 kW in the pulse is required. The exterior assembly of the gun cathode-grid unit is shown in Figure 2.

EXPERIMENTAL RESULTS

The experimental results in beam acceleration were obtained on the stand, Fig. 1. Previously observed second emission resonant discharge [1] is suppressed by applying the protector and increasing the amplitude of the RF electric field in the first and second cavities of the 9-capacity accelerating structure (Fig. 3). It appears that found by us protector and a method to suppress the second emission resonant discharge are universal and applicable in other cases, they require further experimental and theoretical studies and discussions.

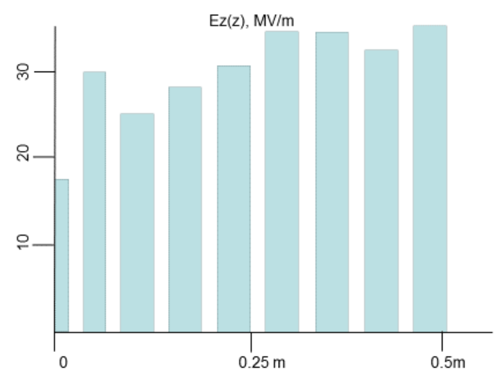

Figure 3: The accelerating field amplitude on the axis of the PCS at 3 MW generator power.

For microwave power of linear electron accelerator, a klystron КИУ-111 (KIU-111) is used [4]. The injection current pulse duration is set in the range of $\tau = 0.1 - 4$ µs, injection current pulsed value - up to 0.3A. We measured: input current - I_{in}, and output current - I_{out}, beam energy, as well as the shape of the waving microwave power incident on the PCS and reflected. The shape detected pulses is shown in Figure 4. Sweep is 0.5 µs/div. The klystron microwave power pulse of about 2.5 MW with duration of 5 µs is shown in line 1. The reflected from the structure signal is shown in line 2. At a minimum of the reflected signal, a tuning to the structure resonant frequency is carried out. Line 3 - input current I_{in} = 200 mA (inductive sensor, 0.9 A/V), line 4 - output current = 200 mA (the Faraday cup at the output of the PCS, 20 mA/V). In this measurement, at a frequency of 2449000 kHz, the electron capture rate in the acceleration mode, $I_{out}/I_{in} \approx 100\%$.

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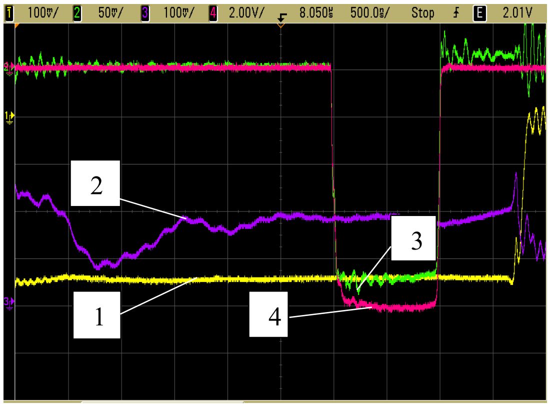

Figure 4: Oscillograms characterizing the beam acceleration mode in the PCS.

The accelerated beam energy is measured by delaying in the metal plates at the beginning of the pulse. Figure 5 shows the dependence of the capture ratio I_{out}/I_{in}, %, and the beam energy, MeV, on the frequency at I_{in} = 100mA. The beam energy is maximal at the frequency 2448950 kHz. The capture ratio is maximal at the frequency of 2449000 kHz due to, presumably, the optimal conditions of the beam microwave focusing by the accelerating electric field. This property of the PCS requires a further experimental and theoretical study. By increasing the current, the capture rate and the particles energy decrease due to the load of the accelerating structure by an electron beam and the decrease in the amplitude of the accelerating field.

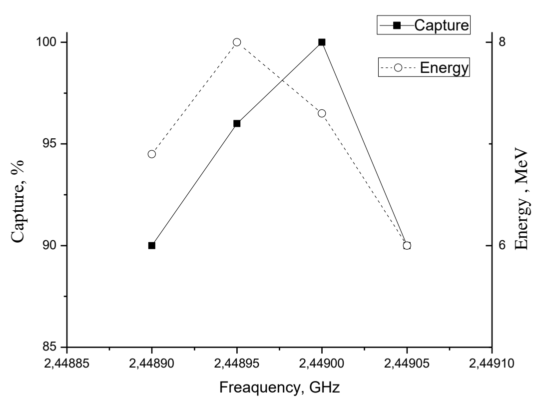

Figure 5: The dependence of the capture ratio in the acceleration and beam energy modes on the frequency.

The investigated PCS is designed to check for key properties and peculiarities of the new type accelerating structure [5,6] and is calculated on the current in the range of 0.1-0.3A in the pulse. By modifying the structure according to the calculations, it is possible to obtain high pulse currents up to 0.5-1A at high capture rate.

CONCLUSION

In the improved microwave accelerator containing the 9-cavity PCS with installed magnetic periodic focusing system based on permanent magnets and in the injection system with RF grid-controlled injection current, the parameters of accelerated electrons beam are received close to the calculated values: at "π-mode" injection, pulse duration is 0.1 - 4 µs, pulse current of the beam - up to 0.3A; beam capture in acceleration mode at currents up to 0.2A in the pulse - 100%; beam energy - up to 8 MeV. At "2p-mode" injection and the pulse duration 4 ns, the capture is about 50%, the pulse current is up to 0.6A, the beam energy is about 8 MeV. The secondary emission resonance discharge in the system is suppressed by increasing the field in the first structure cavities and developing the suppression method including the protector and its method of application to the centers of the cavity secondary emission surface. These experimentally proven properties can be attributed to advantages of the RF accelerators based on the new type PCS [5,6] in comparison with conventional accelerating structures with serial communication.

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