EXPERIENCE OF OPERATION OF THE ELECTRON LINEAR ACCELERATOR BASED ON PARALLEL COUPLED ACCELERATING STRUCTURE*

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Abstract
Electron linear accelerator based on parallel coupled accelerating structure was developed and produced by Budker institute of nuclear physics SB RAS and Institute of Chemical kinetics and combustion SB RAS. There were short and long parallel coupled accelerating structures with frequency 2450 MHz. For easy disassembly the electrical and vacuum connections for the first structure are performed by indium. The second structure is brazed. Now accelerator is working for researching in the field of accelerating and RF technologies. In the report the features of the accelerator working are demonstrated. The test of the long parallel coupled accelerating structure is discussed. The result of dissembled of the short accelerating structure is shown. The RF antenna lead and solid-state key for beam driving of the electron gun with RF control were developed. The design and characteristics of these devices are presented. Now the short parallel coupled accelerating structure is under modernizing to increase the accelerated beam current.

INTRODUCTION

The compact linear electron accelerator produced by Budker Institute of Nuclear Physics of SB RAS and Institute of Chemical Kinetics [1]. It consists of new type parallel coupled accelerating structure and injector based on electron gun with RF control.

Parallel coupled accelerating structure consists of accelerating cavities which are excited from one common cavity. The feature of this design is absence connections between accelerating cavities by electromagnetic field, individual coupling slot for every accelerating cavity and possibility to use magnetic system based on the permanent magnets. All of these lead to more stable working under RF breakdown, more efficient of the particles capture, make the free RF power distribution and so on [1-2]. There were produced two accelerating structure with 5 and 9 accelerating cavities and operating frequency 2450 MHz. For easy disassembly the electrical and vacuum connections for the first structure are performed by indium wire. The second structure is brazed.

The short parallel coupled accelerating structure is successfully working during 3 years for different researchers in the field of accelerating and RF technologies. The last beam parameters were obtained: beam current up to 100 mA with pulse duration 5 μs and the energy was 2.5 MeV with beam capture of 100% [1]; beam current up to 300 mA with pulse duration 2.5 ns and energy of 4 MeV.

The long parallel coupled accelerating structure was brazed, but during testing with high RF power some problems were appeared and the working beam parameters were not achieved.

Besides accelerating structures the linac has injector which allows us working with three regimes: short beam pulses with duration about 3 ns, long pulses with duration more then 0.5 μs and long pulses with RF control. To make the last regime two new devices were developed and produced. These are RF antenna lead and RF coaxial switch based on pin-diodes correspondingly.

In this report some results of linac operating with new devices and ideas are discussed.

TEST OF THE PARALLEL COUPLED ACCELERATING STRUCTURE WITH NINE CELLS

The long parallel coupled accelerating structure consists of 9 cavities, which are brazed with each other. It is shown on the Fig. 1. To match the unrelativistic injected beam with accelerating field the first and second cavities have variable lengths. The sizes of the individual coupling slots between accelerating cavities and exciting cavity were calculated to make increasing electric field distribution for smoothing accelerating.

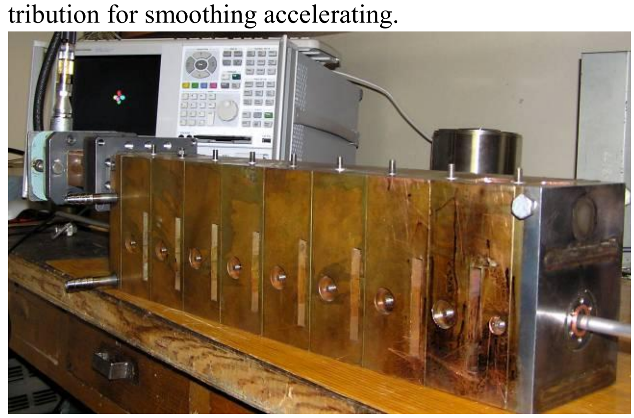

Figure 1: Accelerating structure with 9 accelerating cavities.

After brazing the structure were tuned and measured. According to [4] the coupling factors between exciting and accelerating cavities were obtained and electric field distribution along accelerating cavities was calculated. The histogram of the electric field amplitude with generator power of 2.5 MW is shown on the Fig. 2.

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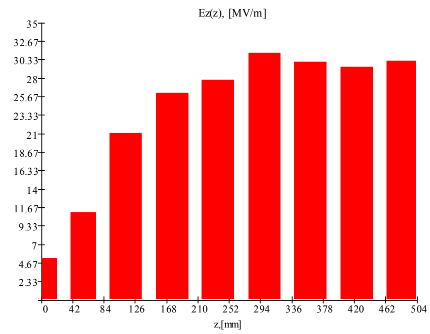

Figure 2: Histogram of the electric field amplitude with generator power of 2.5 MW.

Unfortunately, RF power was found less then it is planed and, due to this, the multipactor effect in the first and second accelerating cavities was shown during accelerating structure operation. In result these cavities were not excited and electric beam in the end of accelerator was unstable and couldn't achieve the required energy. The oscilloscopes of the multipactor effect in the first cavity and envelope of the accelerated beam current are presented on the Fig. 3 and 4 correspondingly. Now the possibilities to suppress the multipactor effect and increase the RF power in the first accelerating cavity are investigated.

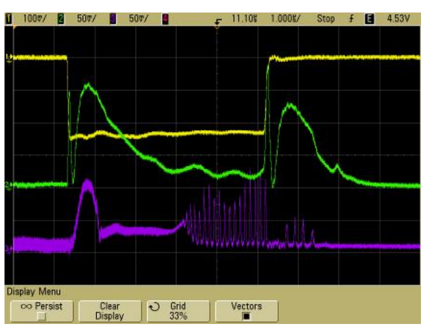

Figure 3: Oscilloscope of the multipactor effect: 1 (yellow) – input klystron's signal, 2 (green) – reflected from the structure signal, 3 (purple) – signal from the first accelerated cavity.

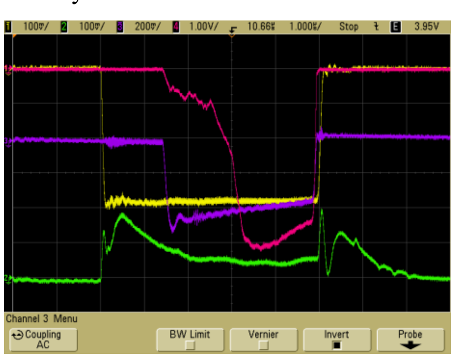

Figure 4: Oscilloscope of the envelope of the accelerated beam current: 1 (yellow) – input klystron's signal, 2 (green) – reflected from the structure signal, 3 (purple) – beam current from the electron gun, 4 (red) – accelerated beam current.

TEST OF THE PARALLEL COUPLED ACCELERATING STRUCTURE WITH FIVE CELLS

Parallel coupled accelerating structure with five cavities is performed with indium packing for easy disassembly and researchers. It is working during 3 years and some results were reported in LINAC12 and RUPAC12 [1-3]. In this year the structure was disassembled to modify the first accelerating cavity and investigate the accelerating cells after long operating time. The photos of the internal surfaces one of the cavities are presented on the Fig. 5. Other accelerating cells are the same this picture.

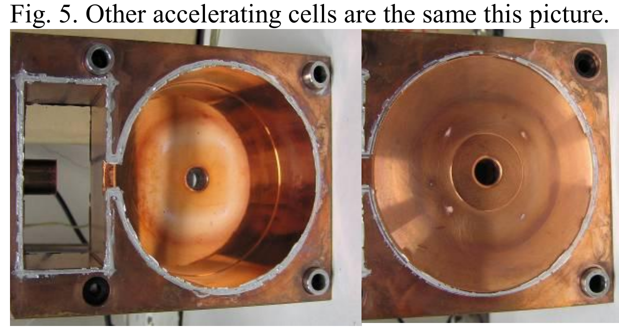

Figure 5: Internal cavity's surfaces.

On the Fig. 5 you can see the place exposed by RF field. The dark circle on the right picture is effect from magnetic field. As we suppose the light contour on the left photo and four points on the right picture are result of the indium ions sputtering under the action of RF field and focusing magnetic system during training process. The magnetic system is performed from the permanent magnets with rectangular contours. The magnetic flow is closed between cavities sides shown in the left and right pictures on the Fig. 5. The places with four points in the right photo are concentration of the magnetic field. The indium ions can be appeared under RF breakdown action from the indium pieces which are pressed inside the cavities. Now this accelerating structure under modernizing and due to this the beam energy were increased from 2.5 MeV to 3.3 MeV with current amplitude of 120 mA. The beam current oscilloscope with such parameters is shown on the Fig. 6.

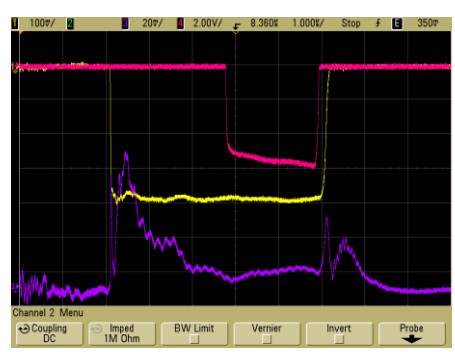

Figure 6: Beam current oscilloscope with amplitude of 120 mA and energy of 3.3 MeV: 1 (yellow) – input klystron's signal, 3 (purple) – reflected from the structure signal, 4 (red) – accelerated beam current.

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RF ANTENNA LEAD AND SOLID STATE RF KEY

Injector is the electron gun with DC voltage of 50 kV and pulse current up to 1 A. It is based on RF triode GS-34. Injector can work with following regimes: short pulses with duration of about nanoseconds, long pulses with duration of microseconds and long pulses with RF control for a beam π-chopper. Under using RF control the beam is modulated by coaxial cavity on bunches with length equaled to half wavelength of RF field. Due to this feature, the beam capture can be achieved up to 100% [1].

The cathode-grid is under potential of -50 kV. So, to feed the coaxial cavity the antenna-type coaxial lead was developed and produced [5]. It is shown on the Fig. 7. The antenna-type lead consists of two symmetrical parts of coaxial half-wave resonator. The resonator is cut along perpendicular to the longitudinal axis plane of symmetry. The solid dielectric disk is located between the halves.

The measured reflection coefficient S_{11} at the operating frequency is 0.098 and the transmission coefficient S_{21} is 0.976. Bandwidth at the attenuation level of -3 dB is more than 1800 MHz (73%).

Figure 7: Antenna type RF lead.

To drive beam under operating regime with RF control using common RF power source for electron gun and accelerating structure the solid state RF key was developed, produced and now under testing. It is presented on the Fig. 8 and consists of toroidal cavity and driven p-i-n diodes. It has following characteristics: operating frequency 2450 MHz, pulsed RF power up to 3, 1 or 0.2 kW and depends on diode types, pulse edge is 200 ns, 50 ns or 30 ns correspondingly. The RF pulse generated by RF key is shown on the Fig. 9.

Figure 8: Solid state RF key.

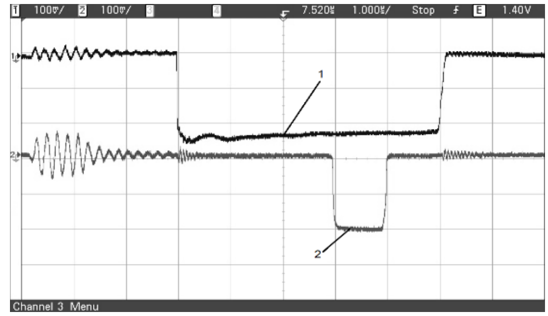

Figure 9: Pulse formed by RF key: 1 – envelope of incident RF signal, 2 – envelope of generated RF signal by RF key.

CONCLUSION

The linear electron accelerator with parallel coupled accelerating structure and injector with RF control consists of new devices and ideas. Many of these should be continued to study and test. One of the features of parallel coupled accelerating structure is possibility to make a free power distribution. But with very low RF power the multipactor effect can be significantly problem. Otherwise developed and produced linear accelerator permits us to have stable work with different accelerating regimes, beam currents and energies including high RF power, beam current and particles capture.

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