HIGH POWER ELECTRON S-BAND LINAC FOR INDUSTRIAL PURPOSES

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Abstract

The high-power S-band linac KYT-20 with electron energy 20 MeV and average beam power up to 20 kW was designed and fabricated in the NSC KIPT. The linac was put into operation in 2002. The accelerator is devoted to irradiation applications mainly for radioisotope production for medicine. The KYT-20 consists of two accelerating structures with variable geometry and the injector system. The wave phase velocity in the structures is equal to the velocity of the light. Length of the accelerating section is 1.23 m. The linac is equipped with different output systems to extract the beam. The paper contains a detailed description of the main linac systems. The results of KYT-20 testing and the beam parameters measurement are presents.

INTRODUCTION

Development of advanced radiation technologies requires designing of a proper accelerator technique. In the last few years at the NSC KIPT several types of technological linacs with an electron energy of 10-20 MeV and an average beam power up to 20 kW were developed [1]. One of such installations is the powerful S-band electron linac KYT-20 [2]. The main purpose of the KYT-20 is to produce isotopes for medical needs. The accelerator design and accelerated beam parameters make it possible to use it for other tasks, for example, radiation treatment of materials, gamma-activation analysis, carrying out of experiments in the field of radiation physics etc. The linac consists of a small-sized injector and two accelerating sections with a moving wave. For realization of radiation technologies the accelerator is provided with different output units. Below the description of basic accelerator systems and results of their testing are presented.

INJECTOR

The injector system of the linac KYT-20 comprises a low-voltage diode electron gun, a bunching cavity and an accelerating cavity. The diode electron gun with an impregnated cathode of 14 mm in diameter was used as an electron source. The microperveance of the source was 0.58 $A/V^{3/2}$, that ensured, at an anode voltage of 25 kV, a pulse current of 2.3 A. The density of an emission current did not exceed 1.6 A/cm^2.

The self-frequency, quality factor and the shunt resistance of the bunching cavity were 2797.15 MHz, 3000 and 0.39 MOhm, respectively. The accelerating cavity is a cylindrical E_{010} cavity. The quality factor and the shunt resistance were $1.1.10^4$ and 1.1 MOhm, respectively. The coefficient of coupling with the waveguide transmission line was equal to 4.5. The cavity is provided with a device for frequency tuning within ± 3 MHz. At the 1 MW microwave power the maximum field strength along the axis of the cavity without field was 56.5 MV/m. At the accelerating cavity exit an induction monitor of the pulse beam current was installed. The magnetic system of the injector is composed of two axially symmetrical magnetic lenses. The first of them, arranged between the gun and the bunching cavity, can be used for control of the pulse beam current value. The total length of the injector is 20 cm.

Experimental investigations of the injector were carried out on a special test bench. The investigations included measuring the energy spectrum and the emittance, evaluating the phase length of bunches. The methods of evaluating the phase length of bunches was based on a supposition that the phase portrait of particles at the phase-energy plane can be represented in the form of a line. The phase spread of particles at a given energy is substantially less than the phase length of bunch. The line thickness depends, in our case, only on the energy spread that occurs due to the action of the space charge force and electric field force in the bunching cavity. As it follows from the simulation results (see Fig.1) this spread is rather insignificant.

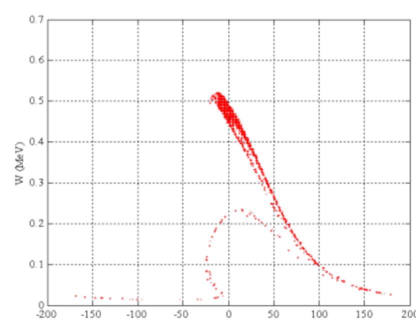

Figure.1: The calculated phase portrait of the beam at the injector output (70% of particles are within the phase and energy intervals being 24° and 18%, respectively)

To evaluate the phase length of bunches we have used a E_{010} cavity at the exit of the magnetic analyzer. It permitted to measure the phases of the centers of gravity for particle bunches that passed through the magnetic analyzer aperture at different magnetic field values, and thus to plot the phase-energy relation of particles. Fig.2

shows the measured phase-energy relation and the energy beam spectrum for one of realizations of injector performances. The data for the plot were taken in the time point corresponding to the middle of the current pulse. In this case the microwave power supply was 1.26 MW, the current at the injector output was 1.25 A. One can see that the results obtained are in a good agreement with the computer simulation data.

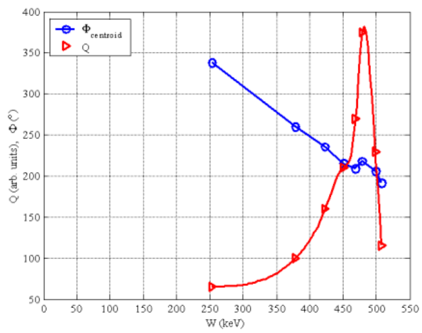

Figure.2: The phase-energy distribution of particles at the injector output and the energy spectrum

As is seen from Fig.2, the beam has a core. The FWHM energy spectrum is 13%, the phase length is near 25%. Nevertheless, the beam contains the particles with sufficiently high energy whose phase differs, at least, by 150°. Since the accelerator is not large and the field strength in the beginning of sections is sufficiently high, the particle from the bunch "tail' can lead to forming the low-energy halo at the linac exit.

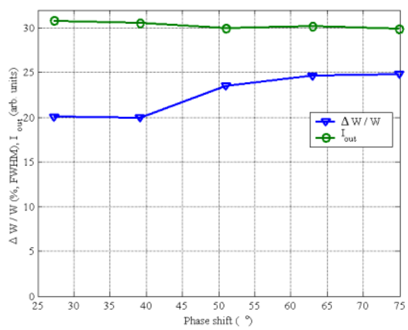

Figure 3: The beam current and the integral energy spectrum width as a function of the phase shift between the bunching and accelerating cavities.

The energy spectrum width at the injector output depends on the phase shift between the bunching and accelerating cavities, while the output current depends slightly on changing this parameter in wide ranges. The value of the integral energy spectrum width was determined with taking into account the particle energy changing during transitional processes in the injector cavities.

The transversal emittance was measured by the three gradients method. The results of measurements of the vertical beam profile width as a function of the quadrupole current with a beam current at the injector output equal to 0.8 A are presented in Fig.4.

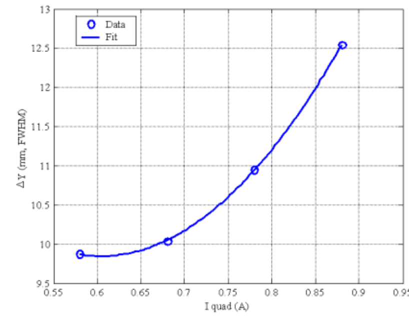

Figure 4: The half-width of the vertical particle density distribution as a function of the quadrupole current.

In this case the normalized emittance was 22 π·mm·mrad. It should be noted, that as the current at the injector output increases up to 1.4 A, then the transversal emittance increases insignificantly and equals to 30 π·mm·mrad. In the course of injector testing, a beam autobunching was observed – electron bunching was observed even in the case when the microwave power was not supplied into the bunching cavity. The effect can be explained by the following manner. A part of electrons being not captured into the acceleration mode fall into the slowing-down phase and are accelerated in the reverse direction. The reverse electron flow consists in a sequence of bunches following with an operating frequency. The flow of "reverse" electrons passes through the bunching cavity and excites in it electromagnetic oscillations. In turn, the beam coming from the gun interacts with the field excited by these electrons that results in grouping the electron bunches. In more details this effect is described in [3].

ACCELERATING SECTIONS

To reach a maximum efficiency the accelerator is provided with two accelerating sections of 1.23 m length having a variable geometry of the accelerating structure. The phase wave velocity in the accelerating structures of the sections is equal to the light velocity. The developed novel mathematical model of coupled cavities and diaphragmatic waveguides, as well as, the proposed methods of tuning [4, 5, 6] allowed us to solve completely the problem of tuning the cells in the nonhomogeneous accelerating structures., The $2\pi/3$ mode sections with a variable geometry were created using these methods. In the first section of the KYT-20 the radius of coupling holes is decreased linearly from the entry to the exit of the section. The second section has a quasi-constant law of changing the radii of coupling holes linearly with decreasing the radii in transition cells. The chosen sequence of arranging the sections with different sizes of accelerating cells decreases a possibility for occurrence of BBU effect. At the input power of 15 MW and the accelerating current 1.0 A each of the accelerating sections provides an energy gain of 12.2 MeV.

OUTPUT UNITS

In connection with that the accelerator can be used for different purposes requiring diverse spatial electron distributions on the target we have developed and tested a set of systems for the beam extraction.

The first of them is a magnetic system designed for the beam scanning with a 3 Hz frequency. Here the beam is extracted via the air-cooled titanium foil. The beam dimensions on the foil are 10x100 mm. When scanning the beam at the pulse repetition rate exceeding the scanning frequency, there is the considerable particle density nonhomogeneity in time and space. For a number of applications such a situation is not acceptable. The use of the secondary system eliminates these disadvantages. The beam is extracted from the accelerator via the double water-cooled foil and incomes into the special quadrupole lens where the beam defocusing in the vertical plane and focusing in the horizontal plane occur. A required electron beam distribution on the target is formed after placing it at the distance exceeding the focal length of the lens. The design of the device makes it possible to perform remotely the quadrupole lens replacement with a special target unit designed for target irradiation according to the program of radionuclide production. The unit comprises a special converter, a system for cooling the converter and remotely operated mechanism for removing of the irradiated target and its further transporting. For carrying out of experiments requiring an insignificant energy spread a magnetic system of "chicane" type was designed. The system consists of four permanent magnets with a field of 0.18 T in the 3.5cm clearance. To release the energy of a necessary range, in the place of maximum system dispersion a collimator was disposed.

RESULTS OF ACCELERATOR TESTS

In the course of accelerator tests we have adjusted all its systems and determined basic beam parameters at the accelerator exit as well as their relations. For measurement of the pulse beam current there are installed three beam current monitors. One of them (at the accelerator exit) is combined with the induction monitor for measuring the position of the beam center of gravity [7]. The system of secondary-emission monitors was used for monitoring of the irradiation field [8]. The particle energy was determined using a magnetic system of the scanning device. The tests showed that the beam parameters satisfy, in main, the specifications on intensity, power and efficiency. Fig.5 presents the electron energy v.s. the pulsed beam current at the RF power supply of 14.5 MW to each of accelerating sections.

At a pulse repetition rate of 200 Hz, a current pulse duration of 3.6 μs and a pulse current of 1.2 A, the mean beam power equals ≈ 18 kW. The electron efficiency is about 87%. From the analysis of beam current passage along the accelerator it follows that more than 75% of particles injected into the first accelerating section arrive to the accelerator exit. This value increases with pulse current decreasing.

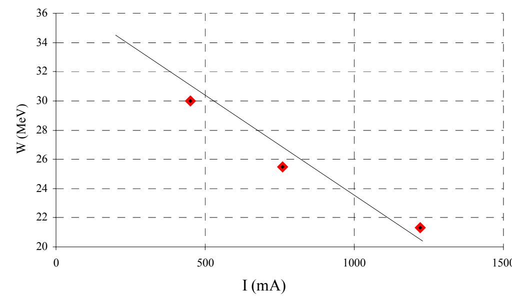

Figure 5: Electron energy versus pulse current. Points - experimental data, curve - calculation.

It has been found that at a pulse current exceeding 800 mA in the electron energy spectrum at the accelerator exit the low-energy halo is observed. Its occurrence is related, probably, with features of the injector operation in the heavy current mode. We plan to conduct a series of investigations aimed to removing this phenomenon.

To date the accelerator has gained the operating time more than 2000 hours for applied and research programs.

ACKNOWLEDGE

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