MAIN SYSTEMS DEVELOPMENT OF K-BAND LINAC

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INTRODUCTION

Nowadays the majority of radiation technologies for both industrial and medical purposes is based on the use of electron beams with energies E=1÷10 MeV and average power P>0.5 kW. The beam acceleration up to such energies with operating performances, accepted to applied application, mainly is realized in resonance accelerators, in which the energy from an external microwave source is transformed to the energy of electrons. A microwave oscillations of L- and S-bands were widely used till now, though the number of development on the use of X-band was conducted in the 80-ies as well [1-3]. However, numerous science-research jobs and experimental-constructive jobs, carried out now in many science centers in order to develop future linear colliders, have again attracted attention of the developers of the applied accelerating equipment to the X-band oscillations [4, 5]. As until recently this range was poorly used in accelerating equipment, the number of the most acceptable RF-sources (P=1-2 MW) for use in applied accelerators of X-band is limited (1.5 MW a magnetron PM-1100X and some devices in development [5]). However, there are a number of sources with a smaller output pulse power, which were already used in accelerators, [1] or were developed for other applications.

The main purpose of our work is the creation of the small-sized linear electron accelerator on the energy up to 5 MeV on the base of such low-power X- and K-bands sources. In this paper the results on development of main systems for such an accelerator are represented: two versions of an injector system and accelerating section. The operating frequency of the accelerator is 12500 MHz.

TRADITIONAL INJECTOR SYSTEM

In this section the traditional type of injector system's version is considered. The injector consists of an electron source [6], buncher and accelerating resonance RF system. It was supposed that the initial electron energy makes 25 keV and the power of a microwave feed source is 100 kW. The injector system of an S-band accelerator KUT [7] containing one bunching and one accelerating resonator was accepted as a prototype. On the base of simulations and analysis we have carried out the cylindrical resonator was selected as a buncher. At the input power of 107 W and the beam current of 50 mA the bunch phase length 40° is ensured on a distance 1.8 cm from the center of a resonator.

On the smaller working wave lengths at the limited microwave feed power and low injection energy for maintenance of effective capture of particles in the process of acceleration it is necessary to use an accelerating system consisting of several resonators. By the experience of developing the resonance structure for injector systems [8], the lengths of the first and second accelerating resonators and the field strength in them were selected to provide the intense phase particle movement that is necessary for an effective bunching. The main increase of energy is carried out in consequent resonators. In the result of multiple calculations of particle dynamics and distribution of an accelerating field we selected a variant of an accelerating part of three resonators with π - mode (see Fig. 1). The Q-factor of such a system is 6200. The average field in resonators appropriating to the input power 100 kW is 25.4 MV/m.

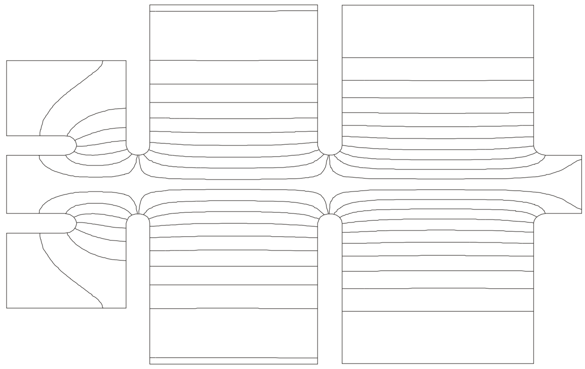

Fig. 1 Injector accelerating system.

3

The simulation of electron dynamics was done with using the PARMELA code [9]. At the input power 100 kW the maximum electron energy is 480 keV. For this the energy spectrum width is $\Delta W/W$=30 %, and the phase one is $\Delta\varphi$=23°. The beam normalized emittance increasing because of its interaction with the field of a buncher and accelerating system does not exceed $\varepsilon_{rms} = 3.3{\cdot}\pi{\cdot}$mm·mrad, and the maximum value of capture coefficient is 96 %.

According to simulations the input power variation within ±10-20 % relating to the initial one does not render essential influence on the normalized beam emittance. Its relative variation is only 10 %. The input power increasing within the limits of 10-15 % leads to the improvement of the spectral beam characteristic obtained. So, at the value of an input power 120 KW it is possible to receive the beam energy spectrum width $\Delta W/W$=15 %, and the phase one $\Delta\varphi$=23°. At this point, accordingly, the total energy gained by the beam will increase. In this case, it will be 530 keV that corresponds to a beam phase velocity $\beta_{ф}$ = 0.87 c.

RF-GUN

In this section the possibility of the RF-gun with the thermionic cathode [10] using as an accelerator injector system is considered.

The resonance system was calculated in two stages. The RF-gun resonator geometry was optimized at the first stage. The purpose of optimization was the obtaining such an axial electrical field distribution at which the beam characteristics would satisfy the declared requests. On the other hand, the geometry of resonators would satisfy the technological possibilities of their manufacturing. At the second stage for the selected gun geometry the large amount of calculations was conducted for various maximum values of the accelerating field intensity in a gun E_{max}, for various ratios of maximum intensity of accelerating fields in resonators. At the same time, it is necessary to take into account some features when calculating the RF-guns with a thermoionic cathode. The most important of them is the effect of cathode back bombardment [10].

The electron beam on the RF-gun exit should be with a low emittance, the electron energy approximately of 0.5 MeV, and the energy and phase spectrum width not exceeding 40 % and 60°, respectively. For maintenance of the required energy the resonator system should consist of several resonators. Length of the first resonator and the field strength ensure the delivery of an innumerable electron quantity emitted from the cathode to the second resonator input. The second resonator ensures the grouping of particles. The main energy gain should take place in consequent resonators. Such a RF-gun construction allows to provide the beam grouping sufficient for injection in the accelerating section.

As a result of purposeful searches the axial electrical field distribution which satisfies the stated above principles was found for the resonance system consisting of three accelerating resonators. The RF-gun resonance system geometry and the field distribution are represented in Fig.2.

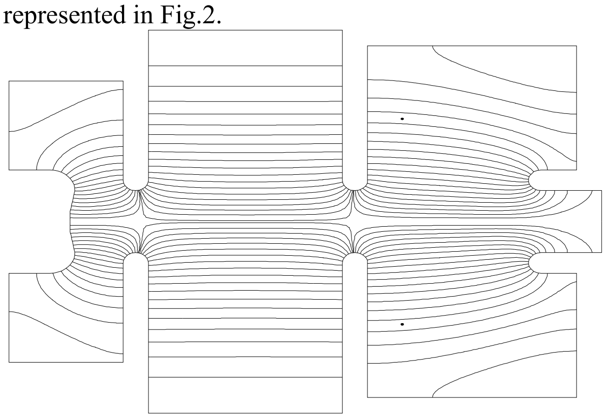

Fig. 2. The RF-gun resonance system geometry.

The Q-factor of the resonance system is 5300, shunt impedance 139 MOh/m. The calculated beam characteristics on the gun exit are represented in table 1.

Table 1

P (kW)	100	120	150	200	250	300
ε_x (mm mrad)	2.64	3.05	2.85	2.83	3.09	3.19
Breadth of an energy spectrum ($\Delta W/W$) , %	45	50	32	36	36	39
$\Delta\varphi$, deg.	50	56	51	47	44	41
Maximum energy (keV)	408	442	489	554	610	660
Average energy (keV)	330	364	408	461	506	541
Capture coefficient (%)	60	62.8	66	70.7	73.6	76

DEVELOPMENT OF THE 12.5 GHz ACCELERATING SECTION

The preliminary characteristics and dimensions of cells of the 12.5 GHz accelerating section with a $2\pi/3$-oscillation mode are calculated by the data given in [11]. Hereafter for a determination of more accurate sizes, special codes developed for these purposes were used [12, 13]. Some sizes: diaphragm thickness t=1 mm, orifice in the diaphragm 2a=6 mm, rounding radii of orifices in the diaphragm 0.5 mm were selected on the technological reasons. The 12.5 GHz structure period on a $2\pi/3$- oscillation mode is D = 7.994 mm. The cell diameter 2b was calculated with using the SUPERFISH code: at f=12500.0 MHz, b=9.5163 mm. Using the codes developed on the base of the method partial areas [12] the main electrodynamic parameters of disk-loaded waveguide were obtained:

- shunt impedance R=117 Ohm/m
- group velocity b=0.021
- damping factor a=0.9 m^{-1}.

The calculation results were used for manufacturing the experimental accelerating cells. The main problem at this point was improvement of the process, methods of tuning and microwave measurements. The measurements of cells have shown that the frequencies of single resonators are close to the preset values. The measurements of a resonance model from five whole- and two semi-rings were conducted. In such resonance model the frequencies appropriate to seven types of oscillations were defined. With using the SUPERFISH code the dispersion curve of such a resonance model was calculated.

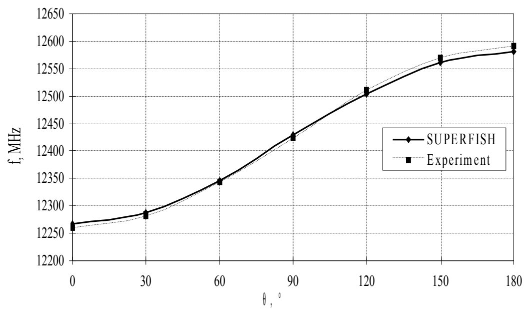

Fig. 3

Fig. 3 represents a dispersion curve designed by the SUPERFISH code (solid) and dispersion curve experimentally measured for the present resonance breadboard model (dash).

The experimentally measured Q-factor is about 1500 that approximately four times less than the calculated one. Such divergence is explained by a poor quality of contacts.

At the following stage the trial soldering of a model consisting of two rings and two semi-rings was carried out. The measurements have shown that the soldering leads to displacement of mode frequencies at 35 MHz. The Q-factor of a soldered model was increased and was on a working mode 2500. The influence of soldering on the frequency was simulated with the SUPERFISH code by introduction of rounding radius in a place appropriate to the meniscus of the solder. It was established that the displacement at 35 MHz corresponds to the rounding radius of 0.6 mm.

For precise frequency tuning of cells the four tuning orifices are made in rings which enable to increase the frequency up to 40 MHz. As a result of measurements the possibility of a resonance model tuning is established to within several tens kilohertz.

The data obtained were used for manufacturing an experimental sample of homogeneous accelerating section consisting of 21 cells. During manufacturing the section the tuning of cells was performed in a special resonance model [14].

We carried out the simulation of particle dynamics in different variants of 12.5 GHz accelerating sections with the use of the PARMELA code [9]. It was determined that for sections with β_ϕ=1 at a microwave feed power of 0.5-1.0 MW the energy of electron injection should exceed 1 MeV. The simulation results are represented in Table 2. Parameters of the electron beam at the input are the following: W_{inj}=1.0 MeV, $\Delta\varphi$ =30^0, $(\Delta W/W)_{rms}$=3.7 %, I=50 mA, L=56.8 cm - length of accelerating section.

Table 2

P_{inj}(MW)	W_{avr}(MeV)	$(\Delta W/W)_{rms}$	$\Delta\varphi$ °	$E_{rms\ x}$, mm·mrad
0.5	5.10	1,81 %	15	1.26
1.0	7.03	0.93 %	20	1.24

Taking into account that the particle energy at the injector system exit being in question is 0.3÷0.5 MeV we have considered a variant of accelerating section with a variable phase velocity. It consists of different phase velocity parts: 0.8c, 0.85c, 0.9c, 0.92c, 1c. The simulation was carried out with the following beam parameters at the section input: W_{inj}=0.34 MeV, $\Delta\varphi$ =30^0, $(\Delta W/W)_{rms}$=7.4 %, I=50 mA. The length of the section is L=65 cm. At the input power 0.5 MW the following results are obtained: W_{max}=4.47 MeV, $(\Delta W/W)_{rms}$= 4.15%, $\Delta\varphi$ = 22^0, $\varepsilon_{rms\ x}$ =1.13 mm·mrad.

CONCLUSIONS

The systems of the K-band accelerator we have developed allow to obtain the high-quality beams at a rather small (up to 0.5 MW) RF-feed power. Both considered schemes of injectors under cosideration can be used. At the same time, it is necessary to note that for the high quality of the electron source the use of a traditional scheme is preferable. The technological methods of manufacturing and technique of tuning of an accelerating structure are developed. All this allows to begin the creation of the operative experimental K-band accelerator.

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