Standing Wave Electron LINAC Accelerating Structure for Technology Purposes

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Abstract

The elaboration of the accelerating system of applied linear accelerator, including calculations of longitudinal and transverse beam dynamics, calculations of electrodynamic characteristics, manufacturing, tuning, measuring of electrodynamic characteristics, manufacturing and testing of beam centering system, is carried out.

1. INTRODUCTION

The described accelerating system is intended as a basis for serial LINACs of technological purposes, for example, for medical units sterilization, radiation treatment of semiconductors wares, radiation analysis, radiography, tomography.

The following initial data are used for the accelerating system elaboration: energy 5 MeV, pulse beam current 0.2 A, injection voltage 40 kV, injection current 1 A, microwave frequency 2.8 GHz, microwave power 2 MW, pulse length 4 μs, pulse recurrent frequency 300 Hz, injected beam crossover diameter 1 mm, external focusing magnetic field is not used.

2. ACCELERATING SYSTEM LENGTH

The on-axis coupled biperiodic structure (see Fig.1) is used for this accelerating system elaboration, as this structure has lesser diameter, is more simple for manufacturing and tuning as compared with side coupled biperiodic structures, for example. The calculated shunt impedance of this structure is ZT^2=81 MOhm/m.

The accelerating system length L may be chosen, using known expression [1]:

$$W = \frac{1}{1+\beta}\left(\sqrt{4\beta PZT^2 L} - IZT^2 L\right) \qquad (1)$$

where W - maximum accelerated electron energy, P - input microwave power, I - pulse beam current, β - coupling coefficient of feeding waveguide with accelerating system,

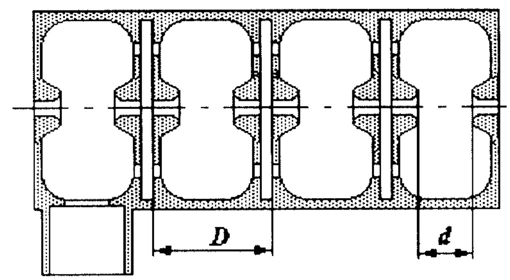

Figure 1. Biperiodic on-axis coupled structure.

$$\beta = \left(\frac{i}{2} + \sqrt{\left(\frac{i}{2}\right)^2 + 1}\right)^2, \quad i = I\sqrt{\frac{ZT^2}{P}} \qquad (2)$$

condition (2) guarantees the matching of feeding waveguide and accelerating system, if beam current is equal to I.

The analysis of (1) allows to choice the length L=0.57 m, that is the number of accelerating cells N=11. β=2.47 in this case.

3. BEAM DYNAMICS

The calculation of longitudinal and transverse beam dynamics is carried out in order to choice the form and geometric sizes of accelerating system and values of electromagnetic fields in it. The finished version parameters are: aperture diameter - 5 mm, accelerating field - 170 kV/cm, D = 45 mm and d = 29.6 mm for cells No.1 and 2, D = 53 mm and d = 37.6 mm for the rest cells. The additional consideration of the accelerating gap length choice is presented in Section 4.

The beam dynamics calculation results are: maximum electron energy 5.9 MeV, average electron energy 4.1 MeV, energy spectrum width 4 %, beam current 0.2 A, beam diameter 1 mm.

The energy spectrum is shown on Fig.2.

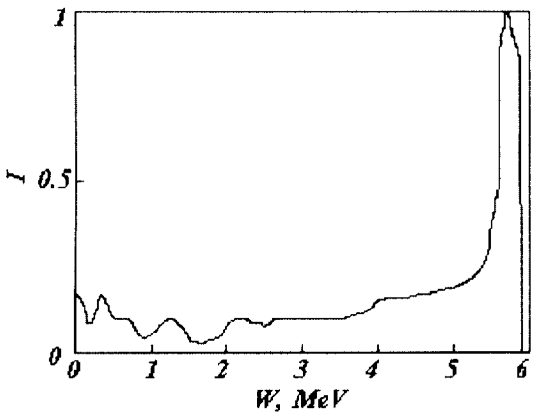

Figure 2. Calculated energy spectrum.

4. ELECTRODYNAMIC CHARACTERISTICS

The choice of geometrical sizes determines main electrodynamics characteristics (EDC) of the accelerating structure: shunt impedance ZT^2, Q-factor Q_0, overstrength coefficient k, coupling coefficient k_c.

The biperiodic structure with d/D = 0.6, corresponding to maximum ZT^2, is used as a rule. However the overstrength coefficient, determined as

$$k = \frac{E_s}{\overline{E}_z T} \quad (3)$$

is very high. Here E_s - maximum surface electric field, $\overline{E}_z$ - average axis electric field, T - transit time coefficient. Here and below absolute values of electric fields are given for beam loading regime. EDC calculation results for d/D = 0.6 and for chosen version with d/D = 0.7 are presented in Table 1.

Table 1.
EDC calculation results

d/D	0.6	0.7
ZT^2,MOhm/m	81	75
k	4.4	3.4
E_s, kV/cm	460	350
W, MeV	6.1	5.9

The choice of the coupling coefficient k_c is determined by two factors. With increasing k_c ZT^2 decreases and the frequency difference $\Delta f_{\pi/2}$ of π/2- and nearest 5π/12- or 7π/12-modes (for N=11) increases. The minimum permissible value of $\Delta f_{\pi/2}$=10 MHz for microwave feeding from typical magnetron with accelerating system in feedback circuit. This leads to following limitation k_c > 0.046 for N = 11. We may make zero coupling coefficient on 5π/12- and 7π/12-modes frequencies, feeding the accelerating system through the middle (No.6) accelerating cell. We must guarantee the following condition $\left| f_{\pi/2} - f_{4\pi/12} \right| \leq 10$ MHz in this case, that is k_c>0.023. The chosen coupling coefficient k_c = 0.03 is provides by two slots in each common wall between accelerating and coupling cells.

The coupling slots length may be calculated using known method [2].

The coupling slots in accelerating system are chosen identical, and the coupling coefficients values are k_c=0.036 for accelerating cells No. 1 and 2, k_c = 0.033 for No. 6 and k_c = 0.032 for the rest sells.

The electric circuits model has been used for the calculation of internal frequencies and field distribution in the accelerating system cells.

The sizes of coupling hole between the waveguide and accelerating cell No.6 have been determined by means of known method [2] and are equal to 23x34 mm (tuned width of hole h = 23 mm) for β = 2.47 and waveguide crossection 72x34 mm.

The calculated EDC are summed up in Table 2.

Table 2
Accelerated system parameters

Parameter	Calculation	Experiment
ZT^2, MOhm/m	77	70
Q_0	18200	$1.6 \cdot 10^4$
k_c	0.0316	0.03
k	3.4	-
E_s, kV/cm	350	340
E_z, kV/cm in cell No.6 in the rest cells	 160 170	 150 160
β	2.47	2.2
h, mm	23	23

5. TUNING AND EDC MEASUREMENTS

The tuning of the accelerating system consists of two operations:

- test of initial frequencies of cells and tuning to 2800±1 MHz;
- tuning of hole for coupling of waveguide with the accelerating system to needed β and simultaneous tuning of accelerating cell No.6 with coupling hole.

The measured dispersion curve is shown on Fig.3. The nearest excited through waveguide 4π/12- and 8π/12-modes frequencies are disposed at 11 MHz from π/2-mode frequency. The non typical form of dispersion curve near 0- and π-modes is explained by difference of coupling coefficients of cells No.1, 2 and 6 from coupling coefficients of the rest cells. The calculation of coupling coefficient of accelerating system according to middle part of measuring dispersion curve is equal to k_c = 0.03. The measured coupling coefficient $\beta = 2.2$.

The measured EDC are presented in Table 2.

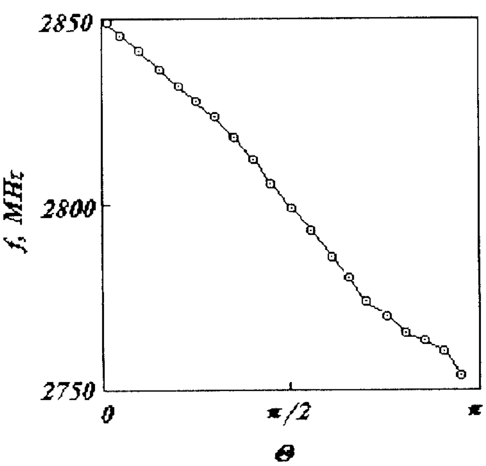

Figure 3. Measured dispersion curve.

6. BEAM CENTERING SYSTEM

The deviation of beam from accelerating system axis takes place in some accelerators because electron injector and accelerating system may be not centered or there is external magnetic field on the accelerating system axis. The special magnetic system has been developed for centering of electron beam. This system consists of two pairs of windings, which create the radial magnetic field of any azimuth direction on the accelerating system axis. This system scheme is shown on Fig.4.

The centering system of 10 cm length has been made. Tests of this system on the operating 4 MeV electron LINAC with 0.35 cm accelerating system allow to get values $\frac{dr}{dI_w}$ = 1.5 mm/A, where r - radial deviation of beam, I_w - current in windings of centering system. The measured value $\frac{dr}{dI_w}$ coincides with the calculated beam trajectory in the magnetic field of windings.

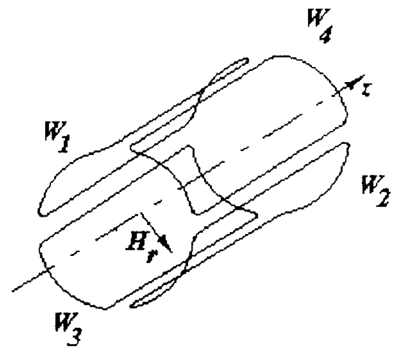

Figure 4. Centering system scheme.
z - beam axis, W_1, W_2, W_3 , W_4 - windings, H_r -radial magnetic field.

7. CONCLUSION

The biperiodic accelerating system with beam centering system for serial industry and medicine electron LINACs has been developed. The beam dynamics and electrodynamic characteristics of chosen version of accelerating system, allowing to get 5 MeV 0.2 A accelerated electron beam at 2.0 MW input power and low surface electric field 350 kV/cm, have been calculated. The accelerating system has been manufactured, tuned and experimental investigated. The calculated and measured parameters coincides satisfactory.

8. REFERENCES

[1] A.A.Zavadtsev, B.V.Zverev and N.P.Sobenin, "Standing Wave Accelerating Structures", Journal of Technical Physics, Vol.54, No.1, pp.82-87, 1984.

[2] B.V.Zverev and N.P.Sobenin, Electrodynamic Characteristics of Accelerating Resonators, Moscow: Energoatomizdat, 1993, pp.64-83.