DESIGN PARAMETERS OF BIPERIODIC ACCELERATING STRUCTURE FOR MEDICAL LINAC WITH WIDELY VARIABLE ENERGY

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Abstract

Results on the simulation of the beam dynamics in an accelerating structure with the particle energy varied from 6 to 21 MeV are presented. The structure operating in the standing wave mode consists of two weakly-coupled substructures and resonates at closed frequencies f_1 and f_2. In-phased electromagnetic field oscillations take place in the substructures at the frequency f_1, whereas anti-phased oscillations occur at the frequency f_2. Main features of the accelerating structure are electronic control of the beam energy and possibility to form narrow energy spectrum at both frequencies.

OPERATION PRINCIPLE OF THE STRUCTURE

Different methods are used to vary the energy of electrons in standing wave accelerators [1]-[3]. In the paper, we consider a biperiodic accelerating structure with inner (axial) coupling cells to be used in a medical accelerator. The method of energy variation was suggested in [4]. The accelerating structure consists of two substructures *A* and *B* with an odd (N_A and N_B) number of resonator cells tuned to the same frequency f_0. In each separate substructure, $\pi/2$-oscillations are excited at the frequency f_0. By joining substructures *A* and *B* through a small hole in a diaphragm, a structure, consisting of an even ($N_A + N_B$) number of cells, is formed to resonate at frequencies close to f_0:

$$f_1 = f_0(1 - k_{AB}/(N_A + N_B)),\quad f_2 = f_0(1 + k_{AB}/(N_A + N_B)) \qquad (1)$$

where k_{AB} is the coupling coefficient of substructures. At the frequency f_1, in-phased $\pi/2$- oscillations occur in substructures *A* and *B*, and these oscillations are anti-phased at the frequency f_2. As a consequence, either acceleration of electrons in the substructure *A* and deceleration in the substructure *B* or acceleration in both of these substructures is possible. Switching from one mode to another is realized by change in frequency f_G of the generator, which drives the structure; this produces maximal variation of the beam energy. For “fine tuning" of the beam energy, the power of the RF generator is additionally varied.

FEATURES OF THE STRUCTURE DESIGN AND OPERATING MODE

Similar to the prototype [4], the considered structure consists of sixty six cells, N_A=39 and N_B=27. First ten (cylindrical) cells form a cascade buncher. The remaining elements are standard Ω-shaped accelerating and cylindrical coupling cells, which are uniform in size with exception for two (or four) cells located at the joint of substructures [5]. The axial length of these cells has strong influence on the beam dynamics, therefore their dimensions like the buncher cell dimensions are specially designed. The RF power is supplied to the substructure *A* through the wave converter cell.

In contrast to the prototype-structure [4], the resonance frequency of separate cells, f_0, has been changed from 2856 to 2998 MHz. The dependence of the input VSWR of the structure with the beam off on the generator frequency is shown in Fig. 1. Frequencies f_1 = 2997.693 MHz and f_2 = 2998.307 MHz correspond to operating modes of the structure. Fig. 2 shows an axial distribution of the amplitude of the electric field excited at the frequency f_1 in the cold structure. Practically the same field distribution was obtained in computations performed at the frequency f_2.

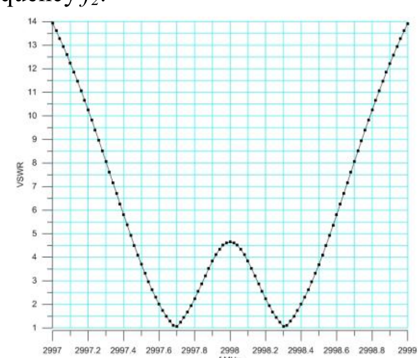

Figure 1: The dependence of the input VSWR of the structure with the beam off on the generator frequency.

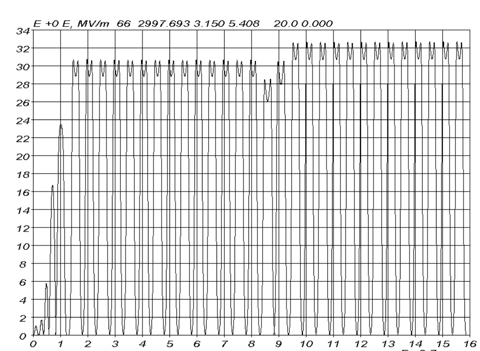

Figure 2: An axial distribution of the amplitude of the electric field excited at the frequency f_1 in the cold structure

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DESIGN PARAMETERS

The results of the numerical simulation of the beam dynamics are given in Fig. 3 and Table 1. Table 1 presents: the generator frequency f_G; pulse RF power P_{inp} supplied to the structure, MW; voltage standing wave ratio (VSWR) in the entrance waveguide; pulse current I_{inp} of the beam injected to the structure, mA; average particles' energy W at the structure output, MeV; beam transmission efficiency, $\eta_1 = I_{out} / I_{inp}$; fraction η_2 of accelerated particles with energies in the $W \pm 5\%$ interval and radius $R_{90\%}$ of the output beam cross-section containing 90% of current, mm.

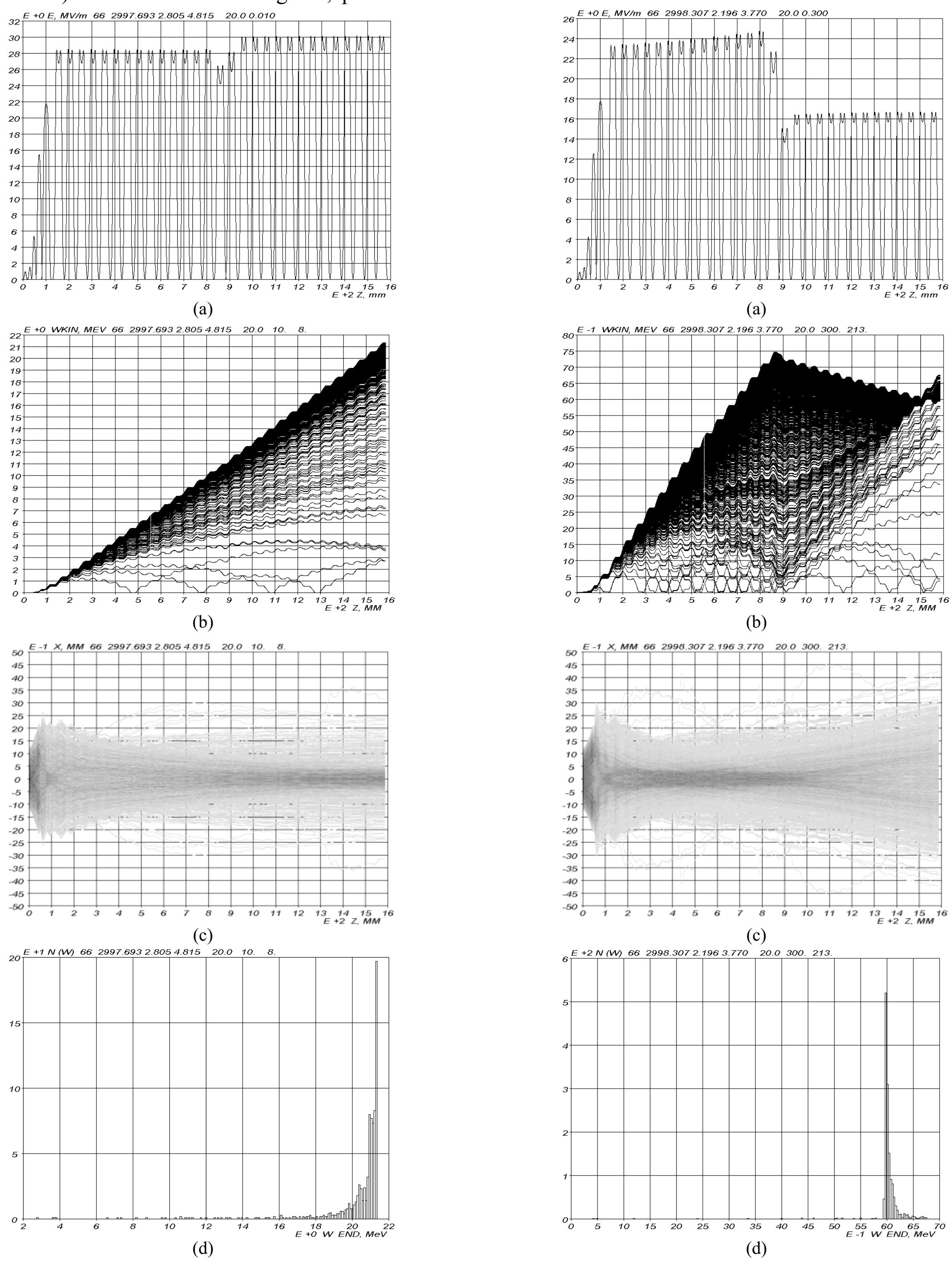

Figure 3: Computational results of the beam dynamics in the structure: to the left – the mode with I_{inp} = 10 mA and W= 21 MeV; to the right – the mode with I_{inp}= 300 mA and W = 6 MeV; (a)- distribution of the electric field amplitude on the structure axis, (b)-kinetic energy of electrons in the accelerating structure, (c)- particle trajectories, (d)- particle energy spectrum at the structure output.

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Table 1: The results of the numerical simulation of the beam dynamics

W	f_G	P_{inp}	VSWR	I_{inp}	η_1	η_2	$R_{90\%}$
21	f_1	4.9	1.039	10	0.81	0.87	1.1
18	f_1	4.7	1.191	50	0.77	0.79	1.0
18	f_1	4.1	1.041	10	0.77	0.70	1.2
15	f_1	3.4	1.042	10	0.73	0.68	1.4
12	f_1	2.9	1.042	10	0.69	0.64	1.5
9	f_1	2.6	1.042	10	0.64	0.47	1.6
6	f_2	3.7	1.073	300	0.70	0.96	2.0
6	f_2	4.9	1.009	30	0.80	0.63	2.0

All the computations have been performed for a particle injection energy of 20 keV. The presented set of output beam energies and currents corresponds to typical operating modes of the medical accelerator [6]. Data on the current transmission and output beam transverse size have been obtained assuming optimal conditions for the beam injection [7]. Transverse size of the accelerated beam is confined by the RF field of the structure; there are no external focusing elements.

To attain an energy of 6 MeV, the particle deceleration mode is used; the accelerating structure is fed at the frequency f_2 with an RF power of 3.7÷4.9 MW depending on the beam current. An increase in the beam current results in a reduced power consumption [8] and a narrower particle energy spectrum. To attain energies in a range of 9÷21 MeV and higher, the normal operating mode of the structure is used. In this case the accelerating structure is fed by pulses at the frequency f_1 with an RF power of 2.6÷4.9 MW. The average energy of particles increases with a higher RF power level, the energy spectrum narrows and the beam transverse size decreases. The widest spectrum was observed with 6, 9 and 12 MeV low-current beams. In the worst case, less than a half of the total number of accelerated particles occurs in an energy range of 9±0.45 MeV. However, it is not a problem as in medical accelerators the non-working part of the spectrum is always eliminated with a magnetic separator installed behind the accelerating structure.

CONCLUSION

The simple and reliable method of the beam energy variation used in the described structure eliminates all the problems typical for the structures equipped with mechanical means for energy variation. Change in energy proceeds by electronic circuits and takes only several milliseconds. Therefore, this method can be used in the accelerators with two energies, which operate in customs inspection systems (so-called dual-energy structures). A definite advantage of the presented structure is a balance between the energy spectrum width and the transverse size of the accelerated beam, which can hardly be attained with a large number of operating modes.

REFERENCES

[1] Patents SU1429919, SU1586502, US4286192, US5821694, US6366021, US6407505, US7491958 et al.

[2] B.Yu. Bogdanovich, A.A.Zavadtsev, D.A. Zavadtsev, V.I.Kaminskiy et al., "Electron Linac Project Based on Biperiodic Accelerating Structure with a Deep Energy Variation in the Pulsed Mode," Proc. of the Xth Int. Conf. on Applied Charged Particle Accelerators in Medicine and Industry (ICAA'01), St.Petersburg, (2001), pp.109-112.

[3] S. Hanna. "Review of Energy Variation Approaches in Medical Accelerators," EPAC08, Genoa, TUPP117, pp.1797-1799 (2008).

[4] Yu.N. Gavrish, O.L. Maslennikov, A.V. Ryabtsov, V.V. Terentyev, "New Method for Deep Electron Energy Variation in Standing Wave Linear Accelerators," Proc. of the XIth Int. Conf. on Applied Charged Particle Accelerators in Medicine and Industry (ICAA'05), St.Petersburg, (2001), pp. 311-314.

[5] Substructures *A* and *B* are joined through a diaphragm separating whole Ω- shaped cells.

[6] Modes with 18 and 6 MeV beam energies and injection currents of 50 and 300 mA, respectively, are used for photon irradiation. The rest modes given in Table 1 are applied for irradiation with electrons.

[7] Non-normalized beam emittance is not more than π 20÷25 mm× mrad and injection from the beam waist of 1.2÷1.4 mm radius for all modes excluding the 6 MeV photon mode. When injection currents are 200÷300 mA, a convergent beam with the 1.8÷2.0 mm radius and the beam envelope slope of 30 mrad is required. Injection conditions are changed to weaken the effect of the beam space charge.

[8] The reason is that a part of the RF field induced by the decelerating beam enters the substructure *A* from the substructure *B* synchronously with the generator-produced field and partially compensates for a field reduction caused by the beam loading.

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