Biperiodic U-structures for Particle Accelerators

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Abstract

Problems of using of biperiodic U-structures in industry and medicine electron LINACs in order to decrease breakdown possibility, to increase acceleration rate and to increase beam current are considered.

1. INTRODUCTION

Compact linear electron accelerators are used now in various industry and medicine fields, for example, radiation control of industrial goods, industrial tomography, semiconductor wares manufacture, radiation analysis, therapy and sterilization. In spite of application of LINACs in various fields of industry and medicine the LINACs elaborators aspire to unification and optimization of parameters and manufactoring technology of accelerating systems. The main requirements presented to accelerating system of LINAC are: high efficiency, high operation reliability, low dimensions, simple manufacturing technology, low manufacturing cost.

2. U-STRUCTURES TYPES

The term "U-structure" is introduced in this paper in accordance with axis crossection form of accelerating cell analogously to Ω-structure.

2.1. Vaguine Structure

The known U-structure is double biperiodic side coupled structure, consisting of two substructures, suggested by V.Vaguine [1]. The accelerating cells of length $\beta_e\lambda/4$, where β_e - relative electron velocity and λ - wave length, belong in turn to first and second substructures. The structure is feeded trough two waveguides with 90° phase shift from 3 dB waveguide hybrid junction. U-structures parameters in comparing with on-axis biperiodic Ω-structure are presented for operating frequency f =2.45 GHz in Table 1, where ZT^2 - shunt impedance, k - overstrength coefficient, D - structure diameter, k_c - coupling coefficient, L - accelerating system length.

$$\Delta f_0 = \frac{\pi k_c f}{4(2/a - 1)}, a = \frac{\beta_e \lambda}{L} \quad (1)$$

Table 1
The accelerating structures parameters

Structure type	ZT^2, MOhm/m	k	D, mm	$\Delta f_{\pi/2}$
On-axis coupled Ω-struc.	76	4.4	95	Δf_0
Vaguine structure	75	1.6	250	Δf_0
RING-2 structure	75	1.6	120	$2\Delta f_0 \frac{1 - a/2}{1 + a/4}$
On-axis coupled U-struc.	68	1.7	95	Δf_0

2.2. RING-2 Structure

The RING-2 structure is shown on Fig.1 and consists of the ring chain of the odd number of coupled accelerating cells of length $\beta_e\lambda/4$ and prismatic resonator coupled with first and last accelerating cells. The feeding of structure is analogous to the Vaguine structure one. The microwave power induces the $\pi/2$-mode through waveguide 1 moreover accelerating fields are equal to the nominal value in odd cells and to 0 in the rest of cells. The microwave power induces the $\pi/2$-mode too through waveguide 2, but the fields are equal to 0 in odd cells and to the nominal value in the rest of cells.

Vaguine and Ring-2 structures have equal values of ZT^2 and k. But the RING-2 structure is more simple for manufacturing and cheap, its diameter is 2 times lesser.

2.3. On-axis Coupled U-structure

On-axis coupled U-stricture is shown on Fig.2. The traditional on-axis coupled Ω-structure has the accelerating gap length, according to maximum ZT^2.

On-axis coupled U-structure has 10% lesser ZT^2 and 2.6 times lesser k.

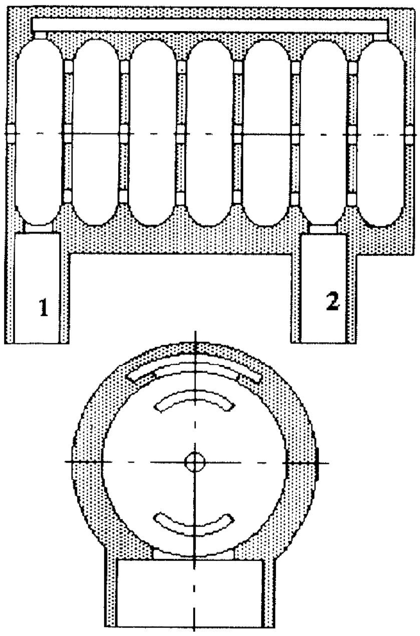

Figure 1. RING-2 structure.

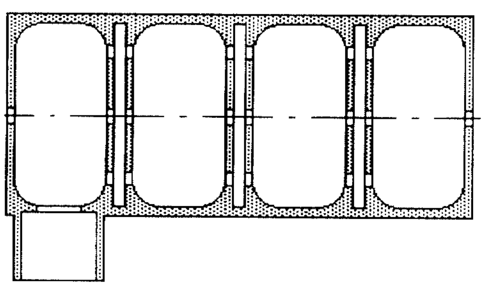

Figure 2. On-axis coupled U-structure.

2.4. Dispersion Dependencies

The analysis of equivalent circuits of these three structures allows to get the expression for Θ_i-modes frequencies:

$$f_i = \frac{f_{\pi/2}}{\sqrt{1 + k_c \cos \Theta_i}} \tag{2}$$

where $f_{\pi/2}$ - $\pi/2$-mode frequency, i=0, 1, 2, ...

Vaguine, RING-2 and on-axis coupled structures have following internal modes respectively:

$$\Theta_i = \frac{\pi i}{N-2}, \quad \Theta_i = \frac{2\pi i}{N+1}, \quad \Theta_i = \frac{\pi i}{2(N-1)} \tag{3}$$

where N - the number of accelerating cells. Calculated frequency differences $\Delta f_{\pi/2}$ of $\pi/2$ and nearest modes are presented in Table 1, which for RING-2 structure is approximately 2 times greater then for Vaguine or traditional biperiodic structure at equal accelerating system length.

3. Ω- AND U-STRUCTURES POSSIBILITIES

3.1. Traditional Ω-structure

The choice of main parameters of the accelerating system may be illustrated by example of 8 MeV compact electron LINAC for medicine units sterilization. Known formulas adduced below allow to determine these parameters [2]:

- maximum accelerated electron energy

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

where P - input microwave power, I - pulse accelerated electron beam;

- coupling coefficient of feeding waveguide with accelerating system

$$\beta = \left(i/2 + \sqrt{(i/2)^2 + 1}\right)^2, i = I\sqrt{ZT^2/P} \tag{5}$$

- maximum electric field on the accelerating system surface $E_s = k\overline{E_z}$

Beam dynamic calculations and beam energy spectrum measurements show that the average beam energy is equal approximately to 75% of maximum energy.

Let us assume, that I = 0.25 A, f = 2.45 GHz, ZT^2=70 MOhm/m, k=4.4 and consider the version of traditional on-axis coupled Ω-structure accelerating system with following electron beam parameters: W=12 MeV, I=0.25 A. The dependence of $W(L)$, calculated by (4) (curve 1 on Fig.3), is sharp at low L and gently sloping at high L. Beginning with some value L, the increasing of L does not result in the essential increasing of W. Let us choice P and L so that the needed value W is equal for example to 85% of maximum energy of curve 1 of Fig.3. P =5 MW and L=1.04 m in this case. Experimental investigations and feedback generation standing wave LINAC operation experience show that the stable operation is guaranteed if β is not more then 2.5-3.0 and maximum electric field E_{SO} on the accelerating system surface at I=0 is not more then 800-900 kV/cm [2]. The calculated parameters of accelerating system are presented in Table 2 (version 1).

3.2. Breakdown free operation

The using of the U-structure in above accelerating system results in decreasing of maximum electric field in accelerating system to E_S =190 kV/cm and E_{SO} =270 kV/cm (version No.2 in Table 2). This provides more reliability operation of the accelerator. Let us note that the using of the U-structure with greater or lesser ZT^2 (Table 1) results in 2.8% difference of **W**.

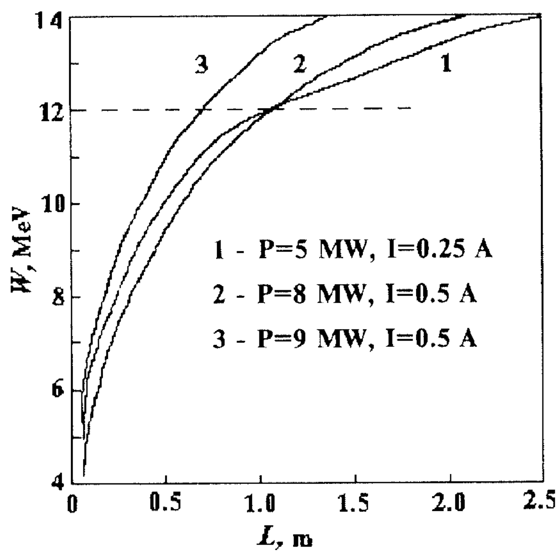

Figure 3. Dependences ***W(L)***.

Table 2.
The parameters of accelerating systems versions

Version No.	1	2	3	4	5	6
Type	Ω	U	U	U	Ω	U
L,m	1.04	1.04	0.43	1.04	1.04	0.67
P,MW	5	5	8	24	8	9
W,MeV	12	12	12	34	12	12
I,A	0.25	0.25	0.25	0.25	0.5	0.5
β	2.5	2.5	1.6	1.5	4.0	2.9
E_S,kV/cm	510	190	460	510	510	290
E_{SO},kV/cm	730	270	560	630	820	430

3.3. High acceleration rate

Let suppose that the accelerating system length at constant beam parameters must be decreased. The using of U-structure allows to decrease length to 0.43 m at greater power P =8 MW and lesser E_S (version No.3 in Table 2). The maximum acceleration rate is needed, for example, for therapy accelerator without bending magnet.

The increasing of power to 24 MW in the U-structure of primary length L =1.04 m results in the increasing of energy to 34 MeV at constant E_S (version No.4 in Table 2).

3.4. High beam current

Let suppose that it is needed to increase the beam current to 0.5 A at fixed energy. It may be made by two ways. Firstly, the input power P may be increased at the accelerating system length L=1.04. The needed energy W=12 MeV is reached at power P=8 MW. The curve 2 of Fig.3 corresponds to dependence $W(L)$ at P= 8 MW and I=0.5 A. The accelerating system parameters for this case are presented in Table 2 (version No.5). The coupling coefficient β has undesirable value. Secondary, we may increase the power some more, for example, to 9 MW. The dependence $W(L)$ for this case is shown on Fig.3 (curve 3). The needed energy W=12 MeV is reached at the lesser accelerating system length L=0.67 m. The using of U-structure in this case allows to guarantee the permissible value of β and breakdown free operation of accelerating system. The parameters of this version are presented in Table 2 (version No.6).

4. CONCLUSION

The carried investigation shows that it is effective to use the biperiodic U-structures in industry and medicine electron LINACs. It allows to decrease 2.6-2.7 times maximum electric field in accelerating system and thus to decrease the breakdown possibility, or to increase 2.6-2.7 times maximum acceleration rate, or to increase the beam current.

5. REFERENCES

[1] V.A.Vaguine, "Electron Linear Accelerator Structure and Design for Radiation Therapy Machines", IEEE Trans. on Nucl. Sci., Vol.NS-28, No.24, pp.1884-1888, 1981.

[2] 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.