INVESTIGATION OF BIPERIODIC ACCELERATING STRUCTURE FOR THE FREE ELECTRON LASER BUNCHER.

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Some features of calculation and experimental study of a biperiodical structure consisting of $1\frac{1}{2}$ accelerating cells and a coupling cell are considered. The structure is intended to be used as a radio frequency photocathode source.

I. INTRODUCTION

One of the unique features of high-gradient rf electron injectors is that the beam can be accelerated to relativistic energies in two cells. Cells geometry is chosen so that the electric field radial component is minimised in the beamline vicinity, so the unwanted increasing of the emittance is limited [1]. At the same time the geometry should also ensure optimal values of shunt impedance and accelerating field providing the electric field at the structure surface is below the breakdown level. Our studies have resulted in the determination of a structure which met requirements mentioned above and was suitable for acceleration of 100 A electron beam with the values of micropulse length 30 ps and macropulse length 10 µs. The beam energy of 3 MeV was obtained in the structure having $1\frac{1}{2}$ accelerating cells and being fed from a klystron with 3.5 MW power value and frequency 1.3 GHz. In this paper we discuss the results of calculation, tuning and experimental study of a prototype of the structure under consideration operating at the frequency 2800 MHz.

II. BASIC PRINCIPLES OF THE ACCELERATING STRUCTURE CALCULATION

The equivalent scheme of the resonant section consisting of an accelerating half-cell, a coupling cell and accelerating full cell is shown in Fig.1. It is valid for the case when the overcell coupling and resistive losses can be neglected.

It is assumed that the own frequencies of the cells are equalized $\omega_{01} = \frac{1}{\sqrt{2L_1C_1}} = \omega_{02} = \frac{1}{\sqrt{2L_2C_2}} = \omega_0$. Denoting as i_1, i_2 and i_3 the loop currents and assuming that the coupling between the accelerating half-cell and full cell is negligible, one can write:

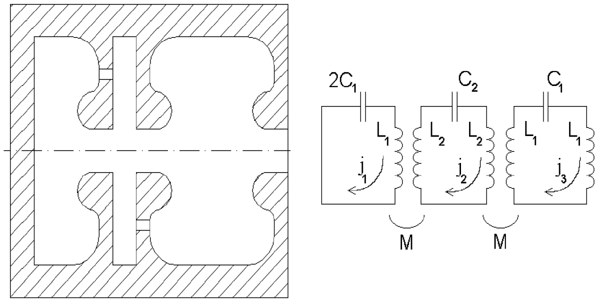

Figure 1. Resonance model and its equivalent scheme

$$\begin{cases} \left(1-\frac{\omega_0^2}{\omega^2}\right)\dot{X}_1 + \frac{k}{\sqrt{2}}\dot{X}_2 = 0 \\ \frac{k}{\sqrt{2}}\dot{X}_1 + \left(1-\frac{\omega_0^2}{\omega^2}\right)\dot{X}_2 + \frac{k}{2}\dot{X}_3 = 0 \\ \frac{k}{2}\dot{X}_2 + \left(1-\frac{\omega_0^2}{\omega^2}\right)\dot{X}_3 = 0 \end{cases} \tag{1}$$

where $\dot{X}_1 = \sqrt{L_1}\dot{i}_1$, $\dot{X}_2 = \sqrt{L_2}\dot{i}_2$, $\dot{X}_3 = \sqrt{L_1}\dot{i}_3$ and the coupling coefficient $k = M\big/\sqrt{L_1L_2}$

By equalising the determinant of the system (1) to zero one can get

$$\left(1-\frac{\omega_0^2}{\omega^2}\right)^3 - \frac{k}{2}\left(1-\frac{\omega_0^2}{\omega^2}\right) - \frac{k}{4}\left(1-\frac{\omega_0^2}{\omega^2}\right) = 0 \tag{2}$$

The solutions of Eq. (2) are

$$\omega_1 = \omega_0 \tag{3}$$

$$\omega_{2,3} = \frac{\omega_0}{\sqrt{1 \pm \frac{\sqrt{3}}{2}k}} \tag{4}$$

According to the expression given in [1]

$$\omega = \frac{\omega_0}{\sqrt{1-k\cos\theta}} \tag{5}$$

the structure under consideration would be exited at $\pi\!/\!2$, $\pi\!/\!6$ and $5\pi\!/\!6$ modes.

For the determination of the optimal shape of the accelerating cell in respect to the parameters $\left|E_r\!/\!E_z\right|$, shunt impedance $r_{sh.eff}$ and k the computer program PRUD-0 [2] was used which was developed for the calculation of axially symmetrical modes of oscillations. This program was also used for the determination of coupling cell dimensions.

For the determination the coupling cell dimensions which provide the chosen coupling coefficient one can use the following expression [3]

$$k=-\frac{Z}{Z_0}N\,\frac{l_s^3}{6}H_c(r_s)H_a(r_s), \tag{6}$$

where Z is the coupling slot wave impedance, its value being normalised with respect to the free space impedance Z_0

$$\frac{Z}{Z_0}=\left\{\frac{t_c}{\Delta}+\frac{2}{\pi}\left[1+\ln\left(\frac{\pi t_c}{2\Delta}+1\right)\right]\right\}^{-1} \tag{7}$$

Here t_c is the slot depth, Δ is the slot width, r_s is the slot axial position radius and N is the number of coupling slots.

Note, that $H_c(r_s)$ and $H_c(r_s)$ were obtained from calculations according to the program PRUD-0.

In case when the coupling slot edges are rounded with the radius $\Delta/2$ the effective length would be

$$\tilde{l}_s=l_s\left[1+015\sin\left(\frac{\pi\Delta}{2l_s}\right)\right] \tag{8}$$

The calculation of a coupler which connects the rectungular waveguide having cross-section dimensions $A\times B$ mm^2 with accelerating cell of a biperiodic structure is carried out on the basis of the formula [3]

$$\frac{Z_{in}}{Z_c}=\frac{Q_0}{v_{01}}\frac{\left(\frac{A}{\lambda}\right)^3\left(\frac{B}{\lambda}\right)}{\left(\frac{L}{\lambda_0}\right)\left(\frac{\lambda_w}{\lambda}\right)}\tan^4\left[\frac{\pi(h-t)}{2A}\right], \tag{9}$$

where Q_0 is the accelerating cell unloaded Q factor, h and t are the width and depth of the inductive coupling window, L is the net length of all accelerating cells , λ_W is the wave length in the rectangular guide (assuming that the accelerating cell has cylindrical geometry), $\frac{Z_{in}}{Z_c}$ is equal to ρ for the case of overcoupling and $\frac{Z_{in}}{Z_c}$ is equal to 1/ρ for the case of undercoupling , ρ is the voltage standing wave ratio coefficient.

III. CALCULATION AND EXPERIMENTAL STUDY OF THE ACCELERATING STRUCTURE PROTOTYPE.

The S-band accelerating structure consisting of one and a half accelerating cell and one coupling cell was calculated and tuned. The frequency f=2800 MHz was chosen as operational one. The shape of the accelerating cell with optimal dimensions corresponding to f=2800 MHz is shown in Fig.2. Its basic dimensions are given in Table 1.

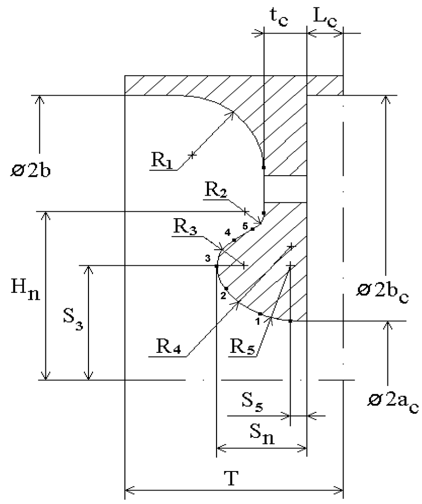

Figure 2. The basic dimensions of the structure.

Table 1. Basic dimensions of the structure Fig.2 (mm).

T	$L_C/2$	b	a	t_C
26.768	1.500	42.836	5.900	2.500

S_n	H_n	R_1	R_2	H_3
7.472	13.525	21.800	2.784	13.672

R_3	R_4	S_5	R_5	b_C
3.978	10.342	1.899	3.978	41.010

With the purpose of minimization the field quadrupole component exited by not strongly relativistic beam four slots are cut in each wall of the coupling cell, slots in the adjacent walls being rotated by 45° for diminishing the coupling between accelerating cells. For the coupling coefficients calculation the expressions (6), (7) and (8) were used. The following dimensions are given: r_S =22 mm, D= 4 mm, t=2.5 mm, l_S =12.4mm. The normalized magnetic field values are

$$H_a=11095m^{-\frac{3}{2}};\ H_c=252m^{-\frac{3}{2}}.$$

Taking into account the data given above one can obtain from (7) the coefficient of coupling between the accelerating half cell and coupling cell (if N=4) k_C=1.56 %. The coupling between the accelerating full cell and coupling cell is characterized by k_C=1.1 %.

To evaluate the dimensions of the coupling slot between the rectangular feeding waveguide and the accelerating cell it is helpful to use formula (9) with the assumption that at the operational frequency the coupling with the resonator is critical, i.e. $\frac{z_{in}}{z_0}=1$, and the slot height "b" is equal to the rectangular guide dimension "B". With Q=10000, t=1 mm, f=2800 MHz and A×B=72×34mm^2, the slot width was obtained to be h=13.3 mm.

The tuning routine is as follows. At first the prototype is assembled as shown in Fig.3. The coupling cell is detuned by a metal ring. Then by changing the accelerating cell diameter the resonant frequency is made equal to 2800 MHz.

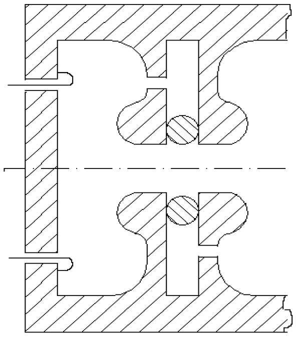

Figure 3. Resonance model for the half accelerating cell frequency tuning .

The environmental temperature and humidity should be accounted for. After that the resonant prototype consisting of two accelerating half cells and one coupling cell is assembled. By cutting the cylindrical surface of the coupling cell the symmetrical dispersion curve with respect to the operational frequency is obtained. The tuning criterion is the realization of the following equation

$$|\omega_2 - \omega_{01}| \approx |\omega_3 - \omega_{01}| \qquad (10)$$

where

$$\omega_{2,3}^2 = \frac{\omega_{01}^2 + \omega_{02}^2}{2(1-k^2)} \pm \frac{1}{2(1-k^2)}\sqrt{(\omega_{01}^2 - \omega_{02}^2) + 4k^2\omega_{01}^2\omega_{02}^2} \qquad (11)$$

and the frequency ω_{01} should be equal to the operational one.

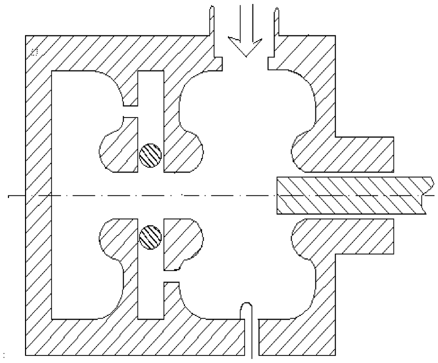

Figure 4. Resonance model for the coupler tuning .

The next stage of the tuning procedure includes the tuning of the whole structure with the RF power feeding element (Fig.4). At the variation of feeding window width we have to retune the accelerating cell (the coupling cell is detuned) to the operational frequency and to measure the reflection coefficient from the RF power feeding element. To avoid the frequent cuttings of the accelerating cell peripheral surface the operational frequency is being maintained by a plunger inserted trough the cut off hole in the drift tube. In this manner the critical coupling regime was obtained. The final tuning to the operational frequency is realized by changing the accelerating cell diameter, the plunger being withdrawn.

The basic experimental technique for the measurement of electric field in accelerating resonators is the reactive probe technique. For its realisation an automation measuring complex [3] is used. The electric field in the vicinity of the beamline was measured inside the half of accelerating cell. The dielectric perturbing probe was used in the measurements. It had the shape of a cylinder with diameter 0.9 mm and length 3.5 mm. The probe material was characterised by $\varepsilon=25$, and the formfactor was equal to $k^{(E)}=3.2\times10^{-20}$ m^2c/Ohm.

The electric field versus z distributions at different r are shown in Fig.5. In this figure the result obtained with PRUD-0 are also presented. The ordinate is normalised, i.e. $\xi = \frac{E}{\sqrt{PQ}}$.

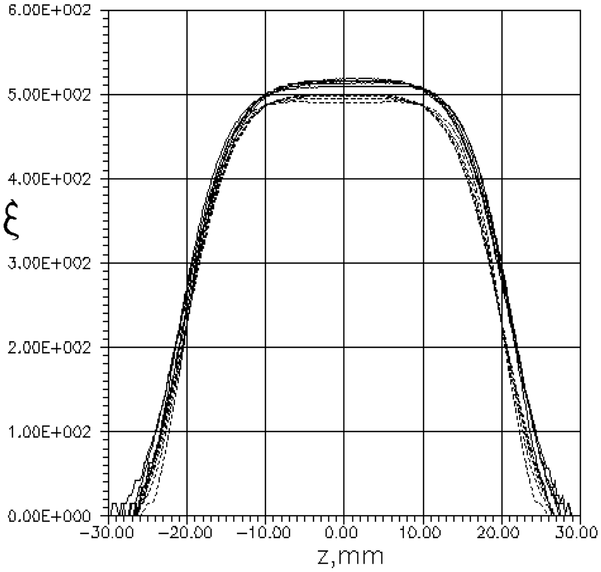

Figure 5. $\xi = \frac{E}{\sqrt{PQ}}$ vs Z-coordinate at the different values of r: 0, 1, 2, 3, 4 mm.

___ experimental data;_ _ _ PRUD-0 calculations.

IV. CONCLUSION

Analytical formula and experimental techniques offered in this paper have enabled us to carry out simple and rather precise tuning of the system under consideration including the structure itself which consisted of $1\frac{1}{2}$ accelerating cells and one coupling cell and the feeding waveguide. The electric field distribution measurements conducted in S band accelerating half-cell show good agreement with the calculation data.

V. REFERENCES.

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[3] N.P.Sobenin, B.V.Zverev, “Electrodynamic Characteristics of The Accelerating Cavities”, Moscow, Energoatomizdat, 1993, 220 pages.