POWER COUPLER FIELD ASYMMETRY INFLUENCE ON PARTICLE BEAMS DYNAMICS IN ACCELERATORS WITH SUPERCONDUCTING CAVITIES

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Abstract

An investigation of input coupler asymmetry influence on electron beam's dynamics in energy recovery linacs (ERL) with superconducting cavities was carried out. There were considered several types of input power couplers – coaxial and waveguide, asymmetric and symmetric. Based on numerical modeling distribution of electromagnetic fields in accelerating cavity with input coupler was found, the transverse deflecting impulse was calculated. RTMTRACE software was adapted for beam's dynamics modeling.

INTRODUCTION

Usage of asymmetric geometry of RF-power input coupler to an accelerator leads to transverse components of EM-field on the beam axis, which are responsible for a transverse impulse deflecting particles from the axis and making the beam emittance grow. To estimate the influence of the current effect on beam's dynamics a notion of the beam's kick is introduced. Numerically it's characterized by a ratio of Lorenz force integral normalized by charge and integral of longitudinal accelerating component of EM-field. Integration is made along the trajectory of the beam's center flight. One must also take into account time flight factor.

$$kick = \frac{V_t}{V_{acc}} = \frac{\int (E_y + eH_x) dx}{\int E_z dz} \qquad (1)$$

Calculation of beam emittance change due to field asymmetry in the region of beam's flight can be performed by usage of analytical formula, which is given in [1]. More precise results can be obtained by modeling of beam's dynamics, i.e. by solving motion equations for all beam particles in the field distribution obtained. RTMTRACE software was used for that. It was written for electron beam's dynamics calculation in microtron [2]. Further developments made it possible to use RTMTRACE for calculation of other accelerating structures. One has to provide EM-field calculated in an external software and written in a file in a specialized format for dynamics modeling. Also, to calculate structures given below initial program text was edited and compiled to produce an executable file.

COAXIAL INPUT COUPLER

Calculations were performed for structures with coaxial and waveguide input couplers given in Figure 1.

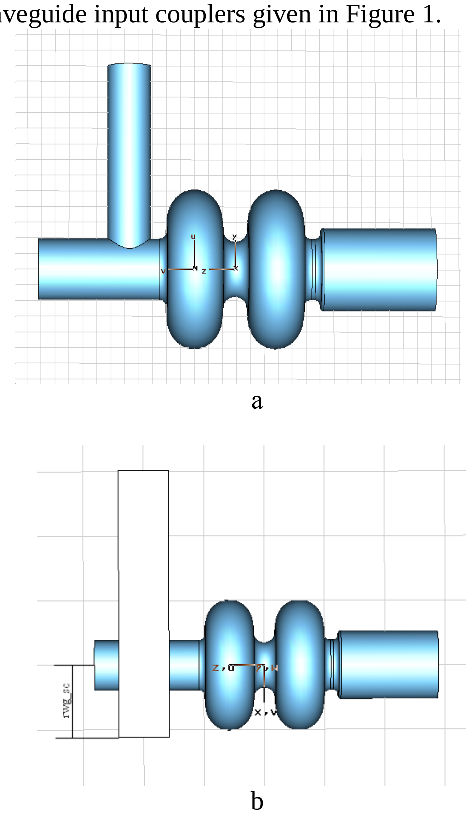
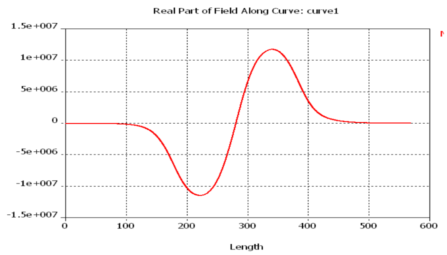


Figure 1: Coaxial and waveguide input couplers.

Calculation for a structure with a single coaxial input coupler (Figure 1, a) was performed to compare results with those given in [1]. During field calculation mesh optimization was performed manually in order to increase the number of mesh elements in the region of the beam's flight. Finally mesh with 160000 elements was used for field calculation, 10000 of which corresponded to the volume of beam flight. Figure 2 gives components of EM-fields in asymmetric coaxial input coupler calculated with a boundary condition of a perfect electric wall. Similar calculations were performed for a perfect magnetic wall.



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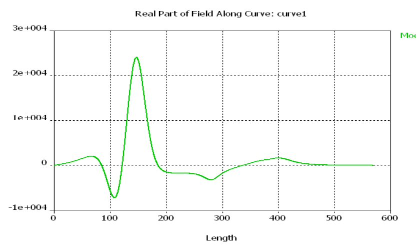

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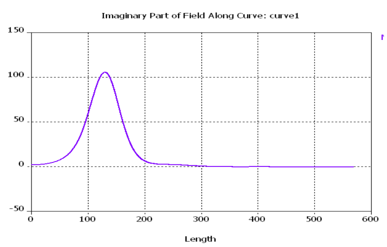

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Figure 2: Longitudinal (a), transverse (в) components of electric field and transverse component of мarmagnetic field (c) on structure axis with electric wall boundary condition usage.

Table 1 gives peak electric and magnetic field components' values, obtained by calculation with two boundary conditions (E-wall and H-wall). In order to determine kick in two-cell buncher of ERL by using these data normalization was made to receive effective accelerating voltage in the cavity at the value of 1 MV. The kick calculation method gave kick= 0.0014 – 0.0018i. The following parameters of ERL injector were used: operating frequency – 1.3 GHz, initial beam energy 4 MeV, accelerating gap voltage 1 MV, beam current 0.1 A, charge 77 pCl, transverse beam radius $\sigma_{x,y}$=2mm, beam length $\sigma_я$=0.6mm, and initial emittance ε_0=1mm*mrad. Beam emittance growth calculated by the analytical formula [1] due to received kick value was 12% for one of the five accelerating cavities. The difference from the result of 20% given in [1] can be explained by mesh effects, and by different software used to compute fields.

Table 1: EM-field components' peak values on beam axis

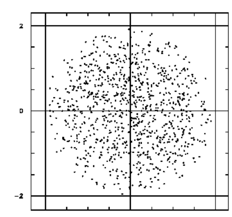
Component	**Peak value**	
	E-wall	**H-wall**
E_z [V/m]	$1.1\cdot10^7$	$1.1\cdot10^7$
E_y [V/м]	$2.6\cdot10^4$	$5.6\cdot10^4$
$c\cdot B_x$ [V/m]	$4.0\cdot10^4$	$4.0\cdot10^4$

Beam dynamics modeling by RTMTRACE in cavity with the single coaxial input coupler was performed for two various electrons bunches. Results are given in Table 2.

Table 2: Electron beam dynamics modeling by RTMTRACE

Bunch	**q [pCl]**	**ε_0 [mm·m rad]**	**σ_z [mm]**	**$\sigma_{x,y}$ [mm]**	**emit-tance growth , %**
1	77	1	0.6	2	5
2	8	0.1	0.6	0.6	12

Beam characteristics are given before and after passing the accelerator in Figure 3 (RTMTRACE). Here are some other output parameters of beam dynamics modeling: energetic spread – 6.23%, maximum deviation of a particle – 2.25 mm from axis, bunch length – 1,05°



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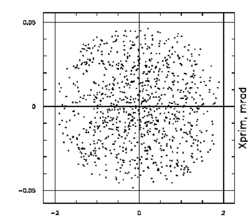

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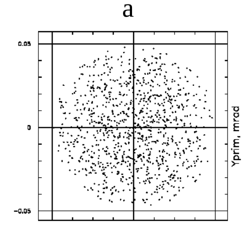

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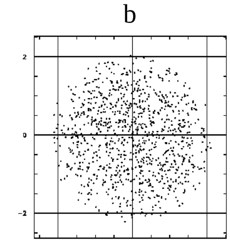

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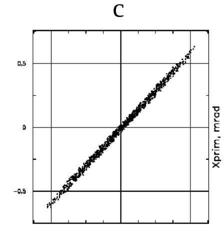

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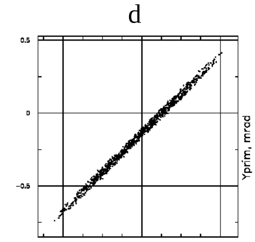

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Figure 3: Beam parameters before (a – cross-section, b – phase plane x-xp, c– phase plane y-yp) and after passing the accelerator (d– cross-section, e – phase plane x-xp, f – phase plane y-yp).

A structure with symmetric coaxial input coupler was also used to determine beam dynamics by means of RTMTRACE. Two cases given in Table 2 were considered. For both of them emittance growth did not exceed 4%.

WAVEGUIDE INPUT COUPLER

Waveguide input coupler, shown in Figure 1, b, will be a good alternative to coaxial coupler if its asymmetry of geometric doesn't lead to considerable transverse components' values of EM-field in the region of beam flight. Analysis of the structure by means of MWS showed that the distribution of fields on axis is strongly affected by the length of waveguide's end, which is shown by size *rwg_sc* in Figure 1, b. Table 3 gives values for peak fields on structure axis for two values of *rwg_sc* – 111 mm and 145 mm.

Table 3: Peak field values on structure axis with various lengths of rectangular waveguide's end

Boundary	**Peak value, rwg_sc 110 mm**		
	E_z [V/m]	**E_y [V/m] (min./max)**	**cB_x [V/m]**
E-wall	$1.15{\cdot}10^7$	$(3.6/4.1){\cdot}10^3$	$1.6{\cdot}10^4$
H-wall	$1.15{\cdot}10^7$	$(3.1/3.8){\cdot}10^5$	$1.4{\cdot}10^6$
	Peak value, rwg_sc 145 mm		
E- wall	$1.15{\cdot}10^7$	$(1.4/1.6)10^3$	$6.4{\cdot}10^3$
H- wall	$1.15{\cdot}10^7$	$(7.0/8.0){\cdot}10^3$	$3.1{\cdot}10^4$

In both cases the estimation of beam emittance growth was made for the bunch (see Table 2) center being in phase with the accelerating wave. Current values were obtained for kick and emittance growth: for rwg_sc = 110 mm кick = 0.0638 – 0,0241i and emittance growth is 154%; for rwg_sc = 145 mm kick = 0.0009 – 0.0006i and emittance growth is 3.8%.

For rwg_sc = 145 mm the transverse components are considerably lower. Obviously, smaller waveguide's end length leads to a local field perturbation.

CONCLUSIONS

The results obtained are evaluative; the calculations did not take into account transverse dependence of electromagnetic fields. However, the following conclusions can be made:

the asymmetric structure with coaxial input coupler cannot provide low beam emittance growth;

the asymmetric structure with waveguide rectangular input coupler with some size optimization can provide quite low emittance growth (3,8%).

REFERENCES

[1] V. Shemelin, S. Belomestnykh and H. Padamsee, "Low-lick Twin-coaxial and Waveguide-coaxial Couplers for ERL", Cornell Lepp Report SRF 021028-08 (November 28, 2002).

[2] V.I.Shvedunov at all., RTMTRACE, VINITI, N 183-B89, 1989