ANALYSIS OF INPUT COUPLER ASYMMETRY INFLUENCE ON BEAM DYNAMICS IN ACCELERATORS WITH SUPERCONDUCTING CAVITIES

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Abstract

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

INTRODUCTION

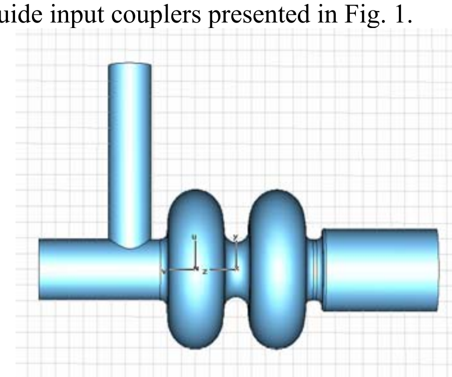
Choice of asymmetric geometry for RF-power input coupler for accelerator leads to transverse components of EM-field on the beam axis, which are responsible for a transverse impulse deflecting particles from the axis and making the beam emittance grow. To estimate the influence of the current effect on beam dynamics a notion of the beam kick is introduced. Numerically it is 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 center. One must also take into account transit-time 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 beam region can be performed by analytical formula, which is given in [1]. More precise results can be obtained by modeling of beam dynamics, i.e. by solving motion equations for all beam particles in the field distribution obtained. RTMTRACE software was used for that task. It was originally designed for electron beam dynamics simulation in microtron [2]. Further developments made it possible to use RTMTRACE for calculation of other accelerating structures. One has to provide EM-field calculated using external software and exported to file in a special format for dynamics modeling. Also, to calculate structures considered below initial program was modified and compiled to produce an executable file.

COAXIAL INPUT COUPLER

Calculations were made for structures with coaxial and waveguide input couplers presented in Fig. 1.



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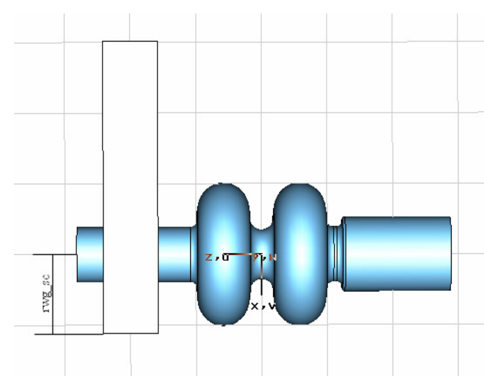

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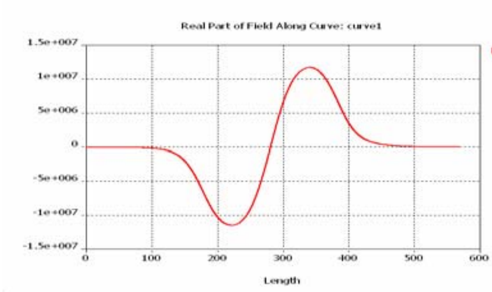
Figure 1: Coaxial and waveguide input couplers.

Calculation for a structure with a single coaxial input coupler (Fig.1, a) was performed to compare results with those given in [1]. During field calculation manual mesh optimization was performed in order to increase the number of mesh nodes in the beam region. Finally mesh with 160000 elements was used for field calculation, 10000 nodes corresponded to the beam region. Fig.2 presents the components of EM-fields in asymmetric coaxial input coupler calculated for perfect electric wall set as boundary condition. Similar calculations were made for a perfect magnetic wall.



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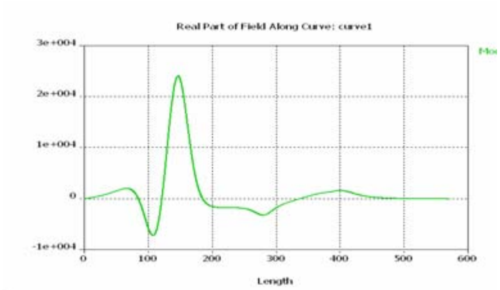

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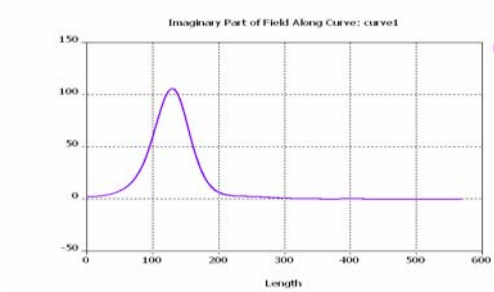

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Figure 2: Longitudinal (a), transverse (b) components of electric field and transverse component of мarmagnetic field (c) on structure axis for electric wall boundary condition.

Table 1 gives values of 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 get effective accelerating voltage in the cavity equal to 1 MV. The kick calculation method gave kick = 0.0014 – 0.0018i. The following parameters of ERL injector were used: operating frequency is 1.3 GHz, initial beam energy 4 MeV, accelerating voltage 1 MV, beam current 0.1 A, charge 77 pC, transverse beam radius $\sigma_{x,y}$=2 mm, beam length $\sigma_я$=0.6 mm, and initial emittance ε_0=1 mm*mrad. Beam emittance growth calculated by the analytical formula [1] for kick value obtained 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.

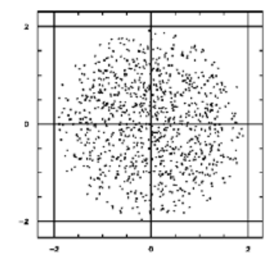
Beam dynamics modeling by RTMTRACE in cavity with the single coaxial input coupler was done for two various electron bunches. Results are given in Table 2.

Table 1: EM-Field Components Peak Values on Beam Axis

Component	Peak value	
	E-wall	H-wall
E_z [V/m]	$1.1{\cdot}10^7$	$1.1{\cdot}10^7$
E_y [V/м]	$2.6{\cdot}10^4$	$5.6{\cdot}10^4$
$c{\cdot}B_x$ [V/m]	$4.0{\cdot}10^4$	$4.0{\cdot}10^4$

Table 2: Electron Beam Dynamics Modeling Results

Bunch	q [pC]	ε_0 [mm·mrad]	σ_z [mm]	$\sigma_{x,y}$ [mm]	emittance growth, %
1	77	1	0.6	2	5
2	8	0.1	0.6	0.6	12



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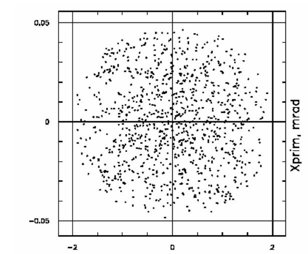

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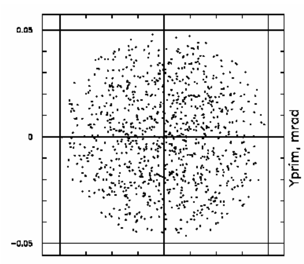

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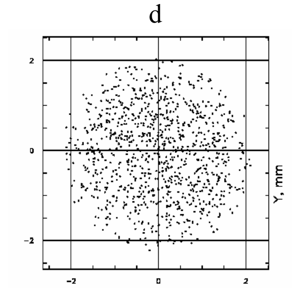

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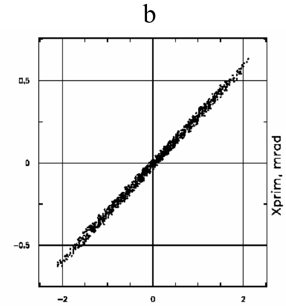

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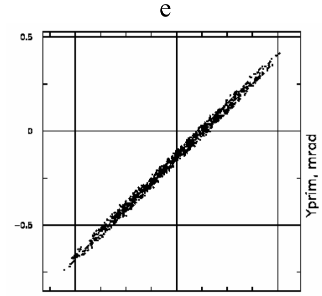

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Figure 3: Beam parameters before (a – cross-section, b – phase plane x-xp, c– phase plane y-yp) and after passing the accelerator (d– cross-section, e – phase plane x-xp, f – phase plane y-yp).

Beam characteristics obtained using RTMTRACE before and after passing the accelerator are presented on Fig.3. Here are some other output parameters of beam dynamics modeling: energy spread – 6.23%, maximum particle deflection – 2.25 mm from axis, bunch length – 1.05º.

Structure with symmetric coaxial input coupler was also used to determine beam dynamics with RTMTRACE. Two cases given in Table 2 were considered. For either case the emittance growth did not exceed 4%.

WAVEGUIDE INPUT COUPLER

Waveguide input coupler, shown in Fig. 1, b is proposed as a good alternative to coaxial coupler if geometric asymmetry does not lead to considerable transverse components values of EM-field in the beam region. Analysis of the structure using MWS showed that on-axis field distribution is strongly affected by the length of short-circuited waveguide, which is noted as *rwg_sc* in Fig. 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

Boundary	Parameter		
	E_z [V/m]	E_y [V/m] (min./max)	cB_x [V/m]
	Peak value, for rwg_sc = 110 mm		
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, for 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. The following 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 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 al., RTMTRACE, VINITI, N 183-B89, 1989