ELECTROMAGNETIC FIELDS AND BEAM DYNAMICS SIMULATION FOR THE SUPERSTRUCTURE OF TESLA LINEAR COLLIDER CONSIDERING FIELD ASYMMETRY CAUSED BY HOM AND POWER COUPLERS

M.V. Lalayan, D.V. Kostin, N.P. Sobenin, V.I. Shvedunov[1], A.A. Zavadtzev[2], M. Dohlus[3]
MEPhI (Technical University),
[1] Scientific Research Institute JAF of the Moscow State University,
[2] RTI Russian Academy of Science,
[3] DESY (Germany)

Some features of accelerating section field computation presented by the development of power and HOM couplers for TESLA linear collider are considered. The devices mentioned produce electromagnetic field asymmetry in the beam area, thus causing transverse kick. For this kick and its influence on beam under acceleration parameters estimation the dynamics modelling calculations were done. 3D-simulation code MAFIA was used for field computation. These data were further used in beam dynamics calculations by means of TRMTrace code. Standing wave mode was simulated while considering HOM couplers, and travelling wave in case of power couplers. Transverse kicks and focussing forces are calculated for one HOM coupler design and two coaxial FM couplers.

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1 INTRODUCTION

The superstructure layout according TESLA collider scheme proposal [1] is shown in Fig. 1, where one could see the FM coupler along with HOM couplers position. Estimation of the transverse kick seen by a particle moving through asymmetry field regions was based on field components obtained by MAFIA electromagnetic modelling code. Then the values of field components were exported to RTMTRACE code, and by means of it the dynamics calculations of the beam under acceleration were performed.

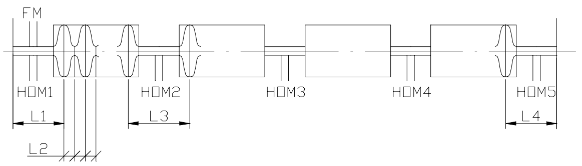
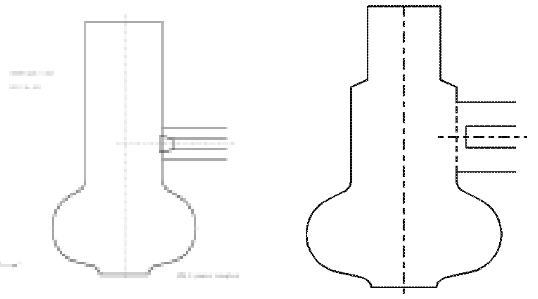


Fig. 1. Superstructure layout with FM and HOM couplers positions.

For correct beam dynamics simulation while moving through accelerating structure one must consider the electromagnetic fields in relatively long part of it. To avoid excessive memory consumption and long computation time the full superstructure model was divided into separate parts with computation followed by fields merging. The following elements were used: cavity end cell with drift tube and input coupler attached, two half-cells and drift tube with HOM coupler, and cavity middle cell. Latter two elements computation was done in SW mode using MAFIA's eigenvalue solver module. In the input coupler region the electromagnetic wave is travelling, and in order to make a correct evaluation one have to apply another approaches.



a) FM3 b) FM5

Fig. 2. End cell with two types of input couplers.

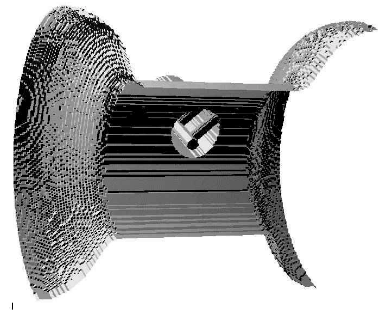


Fig. 3. Two half-cells and HOM coupler.

2 TW FIELDS COMPUTATION

Two different ways were used to solve this task - two standing waves combining method and the one based on time-domain computation.

Models used in each case were the same in order to make the results comparable. Considerable attention was put to obtain model's azimuthal symmetry in order to eliminate pretended field unsymmetry effects. But quadrupole effects could not be completely eliminated because of MAFIA's way of rounded borders approximation with straight lines.

2.1 Two standing waves combining method

Travelling wave in coaxial input coupler could be treated as two standing waves interferention. To get the correct simulated fields vales it is sufficient to apply two types of boundary – magnetic and electric one in coaxial line, provided the reference plane position in line is chosen correctly. For this task one could only deal with eigenvalue problem, solvable by many well-developed codes, for example by E module of MAFIA.

Reference plane coordinate is to be chosen so that the frequencies f_e, f_m, and operating frequency f_o were equal ($f_e = f_m = f_o$), where f_e – frequency corresponding to electrical boundary conditions in reference planes 1 and 2, f_m - the same for magnetic ones.

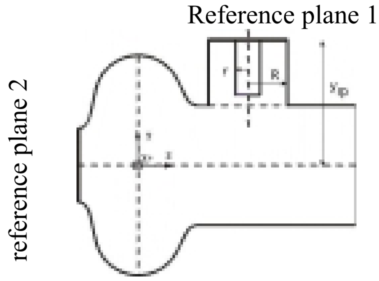


Fig. 4. Input coupler model with reference planes positions showed.

At the second stage travelling wave fields in input coupler are computed. This computation uses two fields components: $E_{x,y,z}^{(e)}$, $B_{x,y,z}^{(e)}$ for electrical boundary conditions in reference planes, and $E_{x,y,z}^{(m)}$, $B_{x,y,z}^{(m)}$ for magnetic ones, obtained by two MAFIA runs. The following normalising procedure is essential: the $E_{z\ \text{мах}}^{(e)}$ и $E_{z\ \text{мах}}^{(m)}$ components maxima along coaxial line inner conductor surface (at z = r) are to be equal. After this the field amplitude and phase of travelling wave in coaxial waveguide calculation became possible.

$$E_{x,y,z} = \sqrt{\left(E_{x,y,z}^{(e)}\right)^2 + \left(E_{x,y,z}^{(m)}\right)^2} \qquad \varphi_{E\ x,y,z} = \operatorname{arctg}\left(\frac{E_{x,y,z}^{(m)}}{E_{x,y,z}^{(e)}}\right)$$

$$B_{x,y,z} = \sqrt{\left(B_{x,y,z}^{(e)}\right)^2 + \left(E_{x,y,z}^{(m)}\right)^2} \qquad \varphi_{B\ x,y,z} = \operatorname{arctg}\left(\frac{B_{x,y,z}^{(m)}}{B_{x,y,z}^{(e)}}\right)$$

In order to make an $E_{x,y,z}$ and $B_{x,y,z}$ amplitudes correspond to some power P transmitted along the waveguide the second normalisation is to be done. In the reference plane 1 vicinity one should calculate the following factor

$$\alpha_2 = \frac{Ez(x=0, y, z=r)\cdot r}{\sqrt{120 \cdot P \ / \ \ln\frac{R}{r}}}$$

and then divide all $E_{x,y,z}$ and $B_{x,y,z}$ amplitudes by it.

2.2 Method using MAFIA T3 module for TW fields calculation

Model used for calculations consisted of one cell with magnetic boundary placed at the iris, drift tube and the coaxial coupler, all having the geometry like corresponding TESLA ones. Drift tube was long enough to the field considerably decayed along it.

Because of very small coupling the only way to solve this problem using MAFIA is to reverse the power flux. The field excitation was realised by two currents. They are high-frequency Gaussian pulse modulated sine with determined pulse width of 300 MHz. At the first stage the frequency of this signal has been chosen equal to 1300.0 MHz, which is close to yet unknown resonance frequency.

Excitation currents pass the cell parallel to the beam axis with each having 45 degrees off the symmetry plane with the displacement equal to the drift tube radius (see Fig. 6). Two beams were used during the calculation because in the task description for MAFIA it is not allowed to have magnetic boundary and beam on the same plane. Otherwise we could have used only one beam passing the model along cavity axis.

As it was already mentioned, at the first stage of computation the excitation pulses frequency was chosen just close to resonance, and signal propagating along the coaxial line was of interest. This signal was obtained by placed in coaxial line virtual monitor – special MAFIA means for calculation data storing during the time integration loop.

Having pulse length determined one could get excitation pulse length (t_{puls}), and take into account for the later treatment only part of output signal, in the region from about $1.2 \cdot t_{puls}$ to 3 t_{puls}. Applying harmonical analysis to this signal we could determine the exact resonance frequency of excited oscillations, those apparently became free after excitation pulse ended. This was done by determining a complex function

$$C(t, f_{est}) = \left(A(t) + i \cdot A\left(t - \frac{1}{4 * f_{est}} \right) \right) * e^{-i*2\pi*fest*t},$$

where A(t) is the output signal, f_{est} is the estimation for the resonant frequency.

Proper choose of this estimation gives us a constant argument of C(t, f_{est}). During the second MAFIA run fields in the entire volume were monitored after the excitation pulses pass. Signal decreasing has substantially low rate, so one could put the amplitude to be constant in some short time period. Using special MAFIA means having resonant frequency known online vector Fourier transformation was performed, thus providing us travelling wave fields.

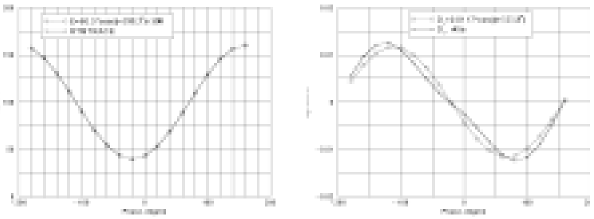
3 BEAM DYNAMICS CALCULATION

While beam dynamics calculating transverse kick could be treated as following [4]:

$$\Delta\vec{p}_t = D_x \vec{x}_0 + D_y \vec{y}_0 + F(x\vec{x}_0 + y\vec{y}_0) +$$
$$+ Q(x\vec{x}_0 - y\vec{y}_0) + S(y\vec{x}_0 + x\vec{y}_0)$$

where $\Delta\vec{p}_t$ - transverse kick, $\vec{x}_0, \vec{y}_0$ - unit vectors for horizontal and vertical plane, x, y - initial particles displacements, D_x, D_y - dipole kick components, F, Q, S - azimuthal, quadruple and skew quadrupole focussing strengths, all but F are energy-independent. Thus the simulation results obtained for some energy could be applied to the cases having other beam energy. All the simulation were done assuming the particles are electrons with charge sign taking into account. Beam energy on particles phase with respect to field dependence allows us to derive a transverse kick to maximal acceleration phase relation. For the estimation HOM and FM couplers shares in transverse kick independent simulations were done for the superstructure having five identical HOM couplers and the one with input coupler of different constructions.

Fig. 5 illustrates simulation done by the RTMTrace code for the energy of particles leaving superstructure (a) dependence on their initial phase along with dipole momentum (b) computed for the input coupler construction #5 and both dependencies approximation by cosine function.



a. b.

Fig. 5.

In Table 1 the simulation results for HOM couplers and two variants of input coupler are presented.

Table 1. Transverse kick dipole components and quadruple focussing strengths for different couplers.

Coupler type	D_{y0}, KeV/s	φ_{Dy0}	Q_0, KeV/s/m	φ_{Q0}
HOM, SW	6.7±0.1	393^0	212±7	218^0
FM #3, SW	1.4±0.1	125^0	40±7	293^0
FM #3, TW	2.3±0.1	129^0	69±7	291^0
FM#5a TW	11.7±0.1	93^0	337±7	266^0

In order to make these results easily comparable they were normalised for the same energy gain by the superstructure equal to 60 MeV having initial particle energy of 100 MeV. Besides in each case the reference plane for particles phase definition was placed with its offset of the first cell centre corresponded to maximum acceleration at $\varphi = 180^o$.

For input coupler #3 the simulation results for TW and SW calculations are presented. These cases have close transverse kick phase values, but 1.6 to 1.7 times differ in its amplitude. Taking into account an asymmetrical field component high sensitivity to the reference plane position in the input coupler simulations using SW mode we assume these results of less accuracy and exclude them from further analysis.

Transverse kick caused by the input coupler was estimated also by travelling wave field integrals using MAFIA code means. Transverse kick absolute value calculated using the integral for field normalisation according to Table 1 data is 2.37 KeV for coupler #3 which is pretty close to D_{y0} values. It is worth to be mentioned that only a dipole kick component could be estimated using integrals along the beam axis calculation.

For asymmetric component role studying the transverse kicks and focussing strengths corresponding to a particle phase of maximal acceleration are of significant interest. These data are presented in Table 2.

Table 2. Transverse kick dipole components and quadruple focussing strengths for different couplers

Coupler type	D_{x0}, KeV/s	D_{y0}, KeV/s	Q_0, KeV/s/m	S_0, KeV/s/m
HOM, SW	-1.1±0.1	-5.6±0.1	167±7	14±7
FM, #3, TW	–	1.4±0.1	-25±7	–
FM, #5a, TW	–	0.6±0.1	23±7	–

4 CONCLUSIONS

Input coupler #5 has the largest transverse kick amplitude and quadrupole focusing strength, but at the phase corresponding to maximal acceleration these parameters values for HOM couplers are greater than for input ones. For example trajectory tilt angle at the end of superstructure caused by HOM couplers for the beam injected along it axis will be about 50 μrad and focal distance about $6 \cdot 10^5$m. Transverse kick caused by couplers to the particles bunch under acceleration couple be partially compensated with beam correctors. Most dangerous with respect to emittance dilution is the kick dependence on the particles position in the bunch. Transverse kick dependence on particle phase in the bunch could be evaluated: $dD_y/d\varphi = -D_{y0}\sin(\varphi+\varphi_{Dyo})$. This value for three couplers mentioned in Tables 1 and 2 is 3.6, 1.8, 11.7 KeV/s/rad, respectively. Assuming the bunch having the length of 1 mm at the superstructure entrance (phase length of 0.027 rad) one could estimate transverse kick in bunch occupied region, $d\sigma_{Dy} = 0.097$, 0.049 and 0.320. To make normalised mean-squared respective emittance growth we could use the following expression [5]: $d\varepsilon_{n,y}/\varepsilon_{n,y} = d\sigma_{Dy}/\sigma_{py}$. Impulse mean-squared scattering for the bunch to be injected in TESLA collider is $\sigma_{py} \cong 1.5$ KeV [5]. So, the relative transverse emittance growth after the superstructure passing by a bunch in maximal acceleration phase is 6, 3, 21% and of this reason the input coupler construction #5 is less suitable.

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