THE OPTIMIZATION OF RF DEFLECTOR INPUT POWER COUPLER

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Abstract

This paper concerns the investigation of different types of input power cell for S-band RF electron deflector. This device serving for slice emittance diagnostics is a disc-loaded waveguide which operates with TE_{11}-like wave in travelling wave regime with 120 deg phase shift per cell. Since this deflector meets the restriction on its length and has to provide high enough deflecting potential to a particle during its flight time it is significant to increase the transversal field strength in coupling cell or to shorten it so that the deflecting potential remains constant. The total structure consists of 14 regular cells and two couplers. As it is now all cells have the same length equal to D=33.34 mm and the field in couplers is lower than that of regular cells. In this paper different lengths are considered and numerically simulated in order to choose the best one.

INTRODUCTION

A deflecting voltage seen by a particle travelling along the axis of a disc-loaded waveguide driven with dipole TE_{11} (Fig. 1) mode can be calculated using transversal values of on-axis electric and magnetic fields or using longitudinal value of the electric field at some offset from the axis (Panofsky-Wenzel theorem) [1].

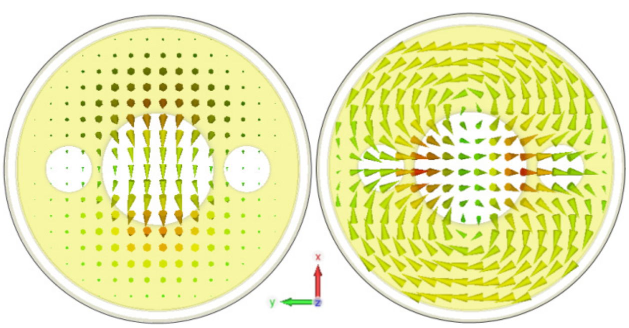

Figure 1: Electric (left) and magnetic (right) fields of TE11 mode.

In the first method, we can use x-component (vertical) of E-field and y-component (horizontal) of H-field distributions along the axis z, since the particle experiences actions from both fields. Electric and magnetic fields are orthogonal to each other. The equivalent transversal deflecting field can be derived from the expression of Lorentz force $F_L=eE_d=e(E_x \pm vB_y)$:

$$\dot{E}_d(z) = \dot{E}_x(z) \pm \mu_0 \beta c \dot{H}_y(z)\,, \qquad (1)$$

where (and further on) the sign '±' refers to the interplay of the particle and the wave propagation directions. According to time dependence of field components as $\exp(i[\omega t+\theta])$, this gives the equation for the transversal potential that is gathered by electron on a path from z=0 to z=L (structure length):

$$V_d(\theta) = \int_0^L \Re\left(\dot{E}_d(z)\right) dz =$$
$$= \int_0^L \left|\dot{E}_d(z)\right| \cos\left(\varphi_{E_d}(z) \pm \frac{2\pi}{\lambda} z + \theta\right) dz\,, \qquad (2)$$

where λ=c/f is the wavelength and θ is the initial phase of the deflecting voltage with respect to particle. Now by varying θ through the range from 0 to 2π one can find the maximal value of the deflecting voltage V_{dmax}.

An approach through Panofsky-Wenzel theorem requires longitudinal component of the electric field only, which is taken at some small enough vertical offset from the structure axis a – $E_z(z, x=a)$. The transverse deflecting field in this case is

$$\dot{E}^{PW}(\theta) = \frac{\lambda}{2\pi} \left.\frac{\partial \dot{E}_z(z)}{\partial x}\right|_{x=0} \approx \frac{\lambda \dot{E}_z(z, x=a)}{2\pi a} \qquad (3)$$

due to the fact that longitudinal on-axis field $E_z(x$=0) is nil for hybrid waves. And the corresponding potential V_{dmax} can be found from the following expression by varying θ from 0 to 2π:

$$V_d(\theta) = \frac{\lambda}{2\pi a} \times$$
$$\times \int_0^L \left|\dot{E}_z(z, x=a)\right| \cos\left(\varphi_{E_z}(z, x=a) \pm \frac{2\pi}{\lambda} z + \theta\right) dz. \quad (4)$$

Both dependencies (2) and (4) are sin-shaped and shifted with 90^0, which is result of Maxwell equations.

TRANSVERSE DEFLECTING STRUCTURE

The structure layout [2] is presented in Fig.2. Cell irises have two additional holes used both for coupling between the cells and for stabilization of the mode polarization plane. The deflector consists of 14 regular cells with length of D=33.34mm (required for a phase shift of 120^0 per cell) and two power couplers, therefore total length is 16D=533.44mm. It operates at frequency of 3 GHz. The input power is 2.5 MW, which provides total deflecting

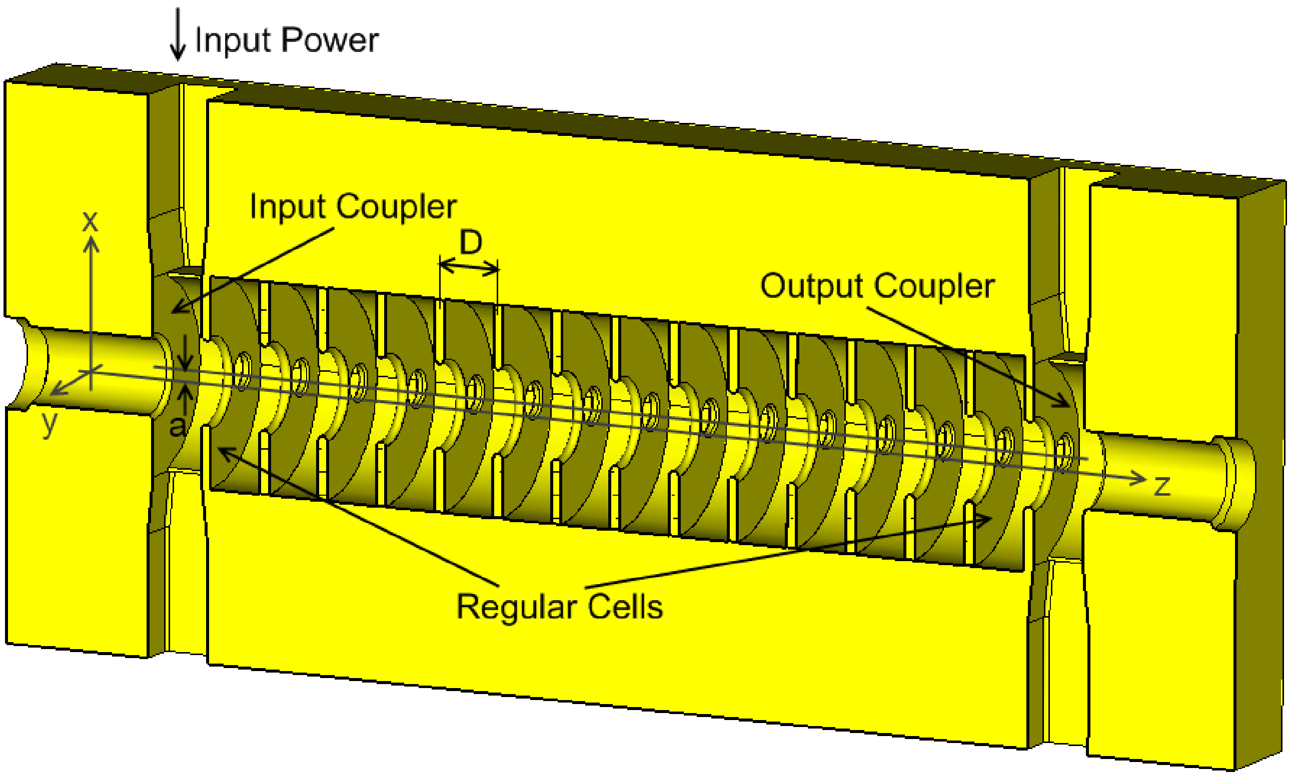

Figure 2: Transverse deflecting structure (longitudinal section).

voltage of 1.8 MV. Both couplers are equal and are tuned to provide matching with feeding rectangular waveguides at the operating frequency, which results in travelling wave regime inside the structure.

COUPLERS COMPARISON

In this section we will describe the investigation of three couplers with different lengths – *D*, 3*D*/4 and *D*/2, (the latter one is shown on Fig. 3) in terms of deflecting efficiency.

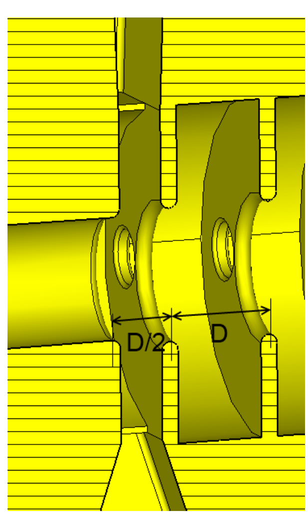

Figure 3: Coupler with length of *D*/2.

In order to calculate the transversal voltage we first tune all couplers by adjusting its radius and the width of coupling window to have good matching at 2997.2 MHz (as shown on Fig.4) and travelling wave with phase shift of $120^0 \pm 1^0$ per cell.

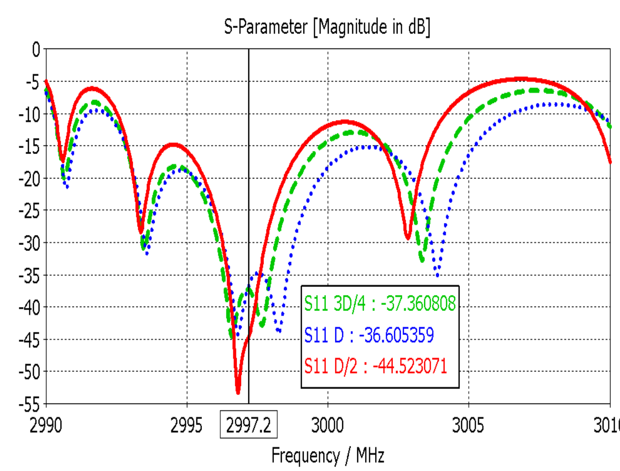

Figure 4: S11 vs. frequency for different coupler lengths: *D* (blue, dotted), 3*D*/4(green, dashed), *D/2* (red, solid).

Second, we extract required field distributions along the specified lines from numerical simulations and then we renormalize these values for input power of 2.5 MW in order to calculate deflecting fields with (1) and (3). The corresponding curves are plotted on Fig.5 and Fig.6 respectively.

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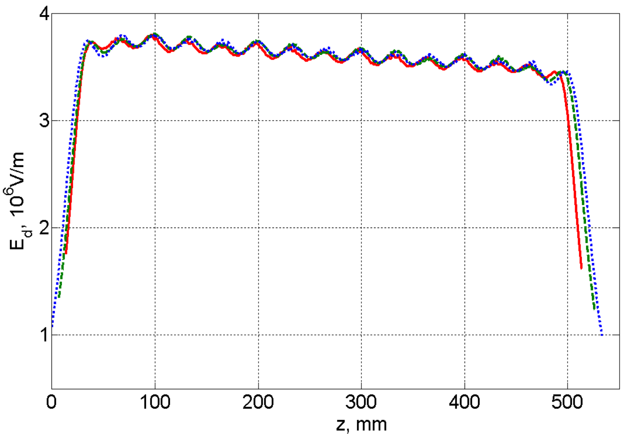

Figure 5: E_d (z) for different coupler lengths: D (blue, dotted), $3D/4$(green, dashed), $D/2$ (red, solid).

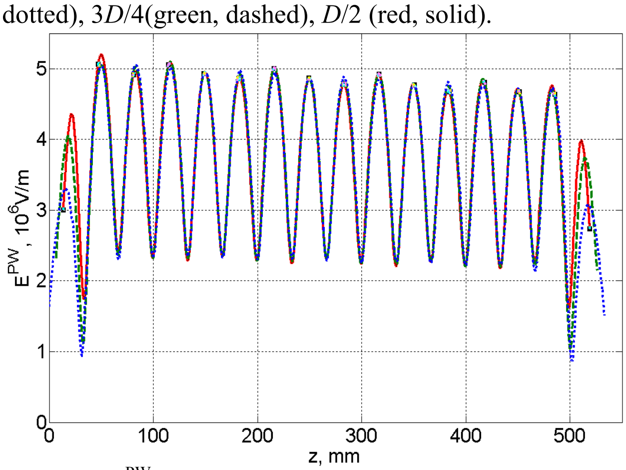

Figure 6: E^{PW} $(z,x=a=4\text{mm})$ for different coupler lengths: D (blue, dotted), $3D/4$(green, dashed), $D/2$ (red, solid).

The plots on Fig.5 and Fig.6 are snapped over the range from D to $15D$ (33.34..500.10 mm) to indicate that the deflecting fields corresponding to the regular cells are equal and do not depend on the coupler geometry. The only difference appears in couplers. The slope along z-axis is due to the RF power dissipation in copper walls.

Third, using (2) and (4) we calculate the deflecting voltages inside two regions: the full structure including all cells and in regular cells only. The field penetration inside the beampipes is not considered. The difference between potentials of these two regions is sum of both couplers potentials. The results of the calculations are listed in Table 1.

Table 1: Deflecting Voltages with Different Couplers

Coupler Length	Method	V_{dmax}, MV		
		Full Structure	Regular Cells	Couplers
D	On-axis	1.8356	1.6858	0.1498
	P-W	1.8138	1.6782	0.1356
3D/4	On-axis	1.8164	1.6864	0.130
	P-W	1.8012	1.6791	0.1221
D/2	On-axis	1.7982	1.6924	0.1058
	P-W	1.7863	1.6832	0.1031

It is shown that the two methods coincide well. The average value of potential contribution from each regular cell is 0.1202 MV. The renormalization of the deflecting potentials to the same coupler length gives the following relation between the coupler efficiencies with respect to a regular cell:

$$D : 3D/4 : D/2$$
$$62.5\% : 72.1\% : 83.2\%$$

CONCLUSIONS

In this work the three types of power coupler for RF deflector were considered. The total deflecting voltage seen by a particle was calculated with direct approach using on-axis fields and with Panofsky-Wenzel theorem. It was shown that twice as shorter coupler provides 1.33 times better deflecting efficiency. This fact can be used when it is preferable to increase the total deflecting potential of the deflector but also to keep its length the same by adding one regular cell.

REFERENCES

[1] W.K.H. Panofsky, W.A. Wenzel, Rev. Sci. Instr. 27, 967, 1956.

[2] L.V. Kravchuk et al., “Layout of the PITZ Transverse Deflecting System for Longitudinal Phase Space and Slice Emittance Measurements”, Proc. of LINAC10, Tsukuba, Japan, 2010.