ELECTROMAGNETIC DESIGN OF NEW RF POWER COUPLERS FOR THE S-DALINAC

M. Kunze#, W.F.O. Müller, T. Weiland, TEMF, TU Darmstadt, Darmstadt, Germany
M. Brunken, H.-D. Gräf, A. Richter, IKP, TU Darmstadt, Darmstadt, Germany

Abstract

The electromagnetic design of new rf waveguide-coax input power couplers for the S-DALINAC is presented. Special consideration is spent on the minimization of the transverse electromagnetic field on the beam axis which would cause an emittance growth of the electron beam. It is shown that an external Q of about $Q_{ext} = 5\cdot10^6$ which is necessary to accelerate beam currents from 150 to 250 μA can easily be reached.

INTRODUCTION

The superconducting Darmstadt electron linear accelerator (S-DALINAC) is a recirculating machine operating at 3 GHz [1]. Since its first operation in 1987 the S-DALINAC has continuously be improved. Presently, the third generation of components of this accelerator is under development. To allow future nuclear physics experiments with cw beam currents from 150 to 250 μA at electron energies of 14 MeV behind the injector rf power of up to 2 kW has to be transfered to the electron beam. The present coax-coax input power couplers at the S-DALINAC with variable coupling are limited to power operation below 500 W. To reach power operation up to 2 kW while keeping the emittance growth of the electron beam small waveguide power couplers [2, 3] with minimized transverse kick should be used in the accelerator upgrade.

In this paper the design of a single-waveguide-coax and a twin-waveguide-coax coupler, respectively, is presented. Electromagnetic simulations by means of CST MICROWAVE STUDIO ® [4] were applied to optimize the couplers for small transverse electromagnetic fields on the beam axis which would cause a coupler kick.

COUPLER DESIGN

Fig. 1 shows the single-waveguide coupler geometry and the electric field patterns of the two lowest coaxial (TEM, H_{11}) and circular waveguide (TM_{01}, TE_{11}) modes, respectively. At the 3 GHz operating frequency of the S-DALINAC the TEM mode and the H_{11} mode can propagate on the coaxial line while the TM_{01} and the TE_{11} mode of the circular waveguide (beam tube in Fig.1) are still evanescent modes. At transition 2 the TE_{11} mode with its asymmetric field distribution is mainly excited by the H_{11} mode. The asymmetric electromagnetic field of the TE_{11} mode generates an emittance growth and therefore the excitation of the H_{11} mode must be minimized at transition 1.

#kunze@temf.tu-darmstadt.de - This work is supported by the Deutsche Forschungsgemeinschaft (DFG) under contract SFB 634.

In Fig. 2a the geometry of the single-waveguide-to-coax transition (transition 1 in Fig. 1) and its parameters are given. The second input coupler presented here is a twin-waveguide coupler which is similar to the single-waveguide coupler but for which transition 1 is replaced by the twin-waveguide-to-coax transition in Fig. 2b. In order to minimize the transverse kick diaphragms are introduced in both designs. The excitation of the H_{11} mode can than be minimized by choosing the opening angle $\varphi_1+\varphi_2$ between the diaphragms. Once the angle $\varphi_1+\varphi_2$ is chosen the power transfer from the fundamental rectangular waveguide mode H_{10} to the TEM mode of the coaxial waveguide can be maximized by adjusting the height *h* and the stub length *s* for the single-waveguide-to-coax transition and additionally the gap width *g* and the waveguide width *w* for the twin-waveguide-to-coax transition, respectively.

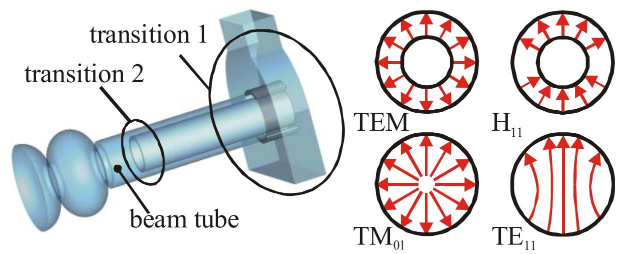

Figure 1: The single-waveguide coupler and the electric field patterns of the two lowest coaxial modes (TEM, H_{11}) and of the circular waveguide modes (TM_{01}, TE_{11}).

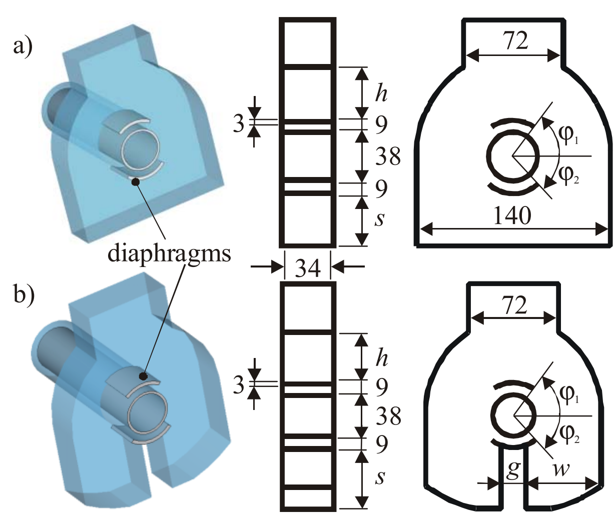

Figure 2: The single-waveguide-to-coax (a) and the twin-waveguide-to-coax (b) transition of the waveguide-to-coaxial couplers under investigation (units are mm).

WAVEGUIDE-TO-COAX TRANSITIONS

The excitation of the H_{11} coaxial mode can be minimized by choosing the opening angle $\varphi_1+\varphi_2$ of the waveguide-to-coax transitions in Fig. 2.

A first example is the single-waveguide-to-coax transition with symmetric ($\varphi_1 = \varphi_2$) and asymmetric diaphragms ($\varphi_1 \neq \varphi_2$). Fig. 3 provides the S parameter results as a function of frequency in the frequency range from 2.9 to 3.1 GHz. The opening angle $\varphi_1+\varphi_2$ of the transition is chosen to be 102°. In both cases the magnitude of the transmission parameter $|S_{TEM,H10}|$ is nearly 0 dB at 3 GHz. In the case of symmetric diaphragms (see Fig. 3a) the excitation of the H_{11} coaxial mode reflected by $|S_{H11,H10}|$ is about -20 dB. H_{10} is the fundamental mode of the rectangular waveguide. When choosing asymmetric diaphragms the excitation of the H_{11} coaxial mode can be further suppressed to about -30 dB (see Fig. 3b). Introducing asymmetric diaphragms increases reflection of the H_{10} mode but $|S_{H10,H10}|$ still remains smaller than -10 dB.

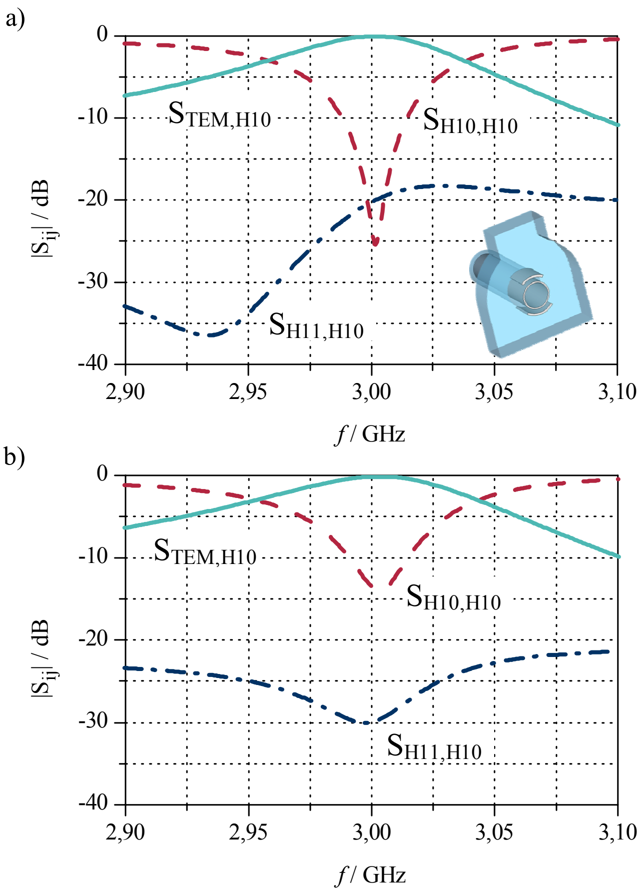

Figure 3: Reflection magnitude $|S_{H10,H10}|$ / dB and transmission magnitudes $|S_{TEM,H10}|$ / dB and $|S_{H11,H10}|$ / dB against frequency for two different single-waveguide-to-coax transitions with symmetric (a) and asymmetric (b) diaphragms (a: h = 36 mm, s = 36 mm, φ_1 = 51°, φ_2 = 51°; b: h = 37.3 mm, s = 36.1 mm, φ_1 = 55°, φ_2 = 47.9°, other data as in Fig. 2; H10 is the fundamental mode of the rectangular waveguide, other modes as in Fig. 1).

The behaviour of the single-waveguide-to-coax transition can be explained considerung the electric field plots in Fig. 4. The single-sided connection of the rectangular to the coaxial waveguide forces an asymmetric field distribution with respect to plane 1 and a symmetric distribution with respect to plane 2 (see Fig. 4 a, c). In order to mainly excite the TEM mode and to minimize the excitation of the H_{11} the coaxial waveguide must be mainly fed from the left and right side in Fig. 4 a, c and therefore diaphragms are used. To further compensate the asymmetric field distribution with respect to plane 1 the diaphragm should be chosen asymmetric with $\varphi_1 \neq \varphi_2$.

Fig. 4 also provides a more detailed view on the electric field of the coaxial waveguide of the single-waveguide-to-coax transitions in Fig. 3. It can easily be seen that for the transition with symmetric diaphragms and $|S_{H11,H10}| \approx$ -20 dB at 3 GHz the electric field has an asymmetric distribution (Fig. 4b) whereas for the transition with asymmetric diaphragms and $|S_{H11,H10}| \approx$ -30 dB at 3 GHz it has a nearly symmetric distribution (Fig. 4d).

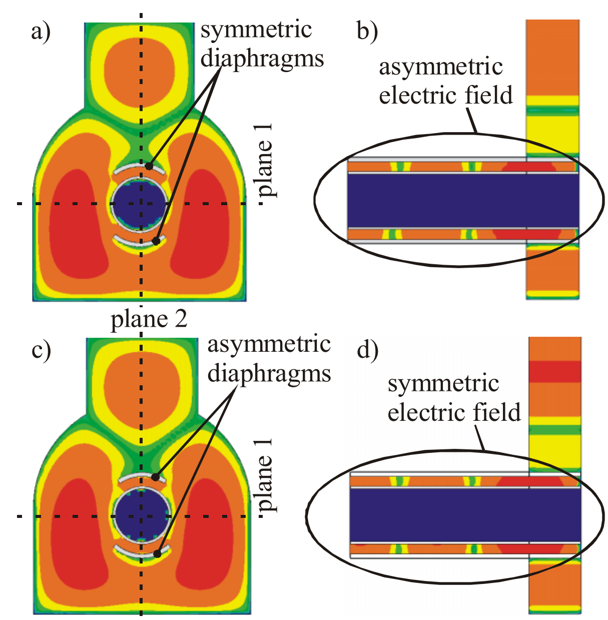

Figure 4: Magnitude of the electric field in the cross sections of the single-waveguide-to-coax transitions with symmetric (a, b) and asymmetric (c, d) diaphragms (data as in Fig. 3).

A more detailed view of the influence of the opening angle $\varphi_1+\varphi_2$ on the excitation of the H_{11} coaxial mode is provided in Fig. 5. Three single-waveguide-to-coax transitions with asymmetric diaphragms were designed with opening angles $\varphi_1+\varphi_2$ of about 60°, 80° and 100°, respectively. As can be seen decreasing the opening angle by 20 degrees reduces the excitation of the H_{11} ($|S_{H11,H10}|$) mode by some 5 dB. The excitation of the H_{11} mode is about –40 dB for an opening angle of 60°, what means that the excitation of the TE_{11} mode in the beam tube (see Fig. 1) is less than –40 dB.

The second example of a waveguide input coupler treated here makes use of the twin-waveguide-to-coax transition in Fig 2b. The S parameters of a twin-waveguide transition with an opening angle of about $\varphi_1+\varphi_2$ = 60° are provided in Fig. 6. In contrast to the single-waveguide-to-coax-transition in Fig. 3 the excitation of the H_{11} coaxial mode is about -40 dB at 3 GHz. The overall behavior of the twin-waveguide-to-coax transition is conform to that of the single-waveguide-to-coax transition. Anyhow, comparing the dimensions of the two transitions for the same opening angle $\varphi_1+\varphi_2$ shows that a more compact and simpler design is possible for the single-waveguide-to-coax coupler.

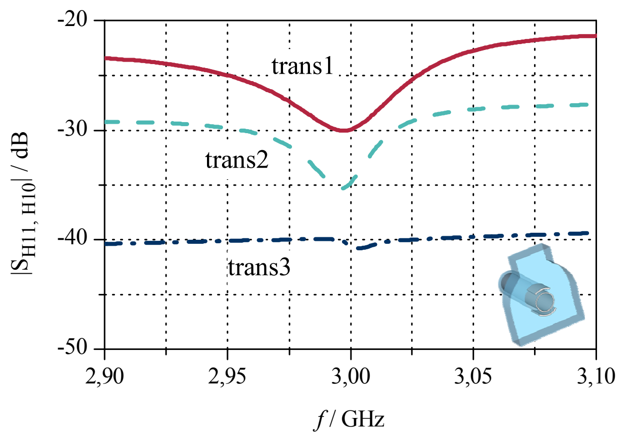

Figure 5: Transmission magnitudes $|S_{H11,H10}|$ / dB against frequency for three different single-waveguide-to-coax transition with asymmetric diaphragms (trans1: h = 37.3 mm, s = 36.1 mm, φ_1 = 55°, φ_2 = 47.9°; trans2: h = 36.9 mm, s = 39.5 mm, φ_1 = 45.3°, φ_2 = 39.8°; trans3: h = 33.4 mm, s = 42 mm, φ_1 = 34.2°, φ_2 = 30.1°, other data as in Fig. 2; H10 is the fundamental mode of the rectangular waveguide and H11 is the dipole mode of the coaxial waveguide).

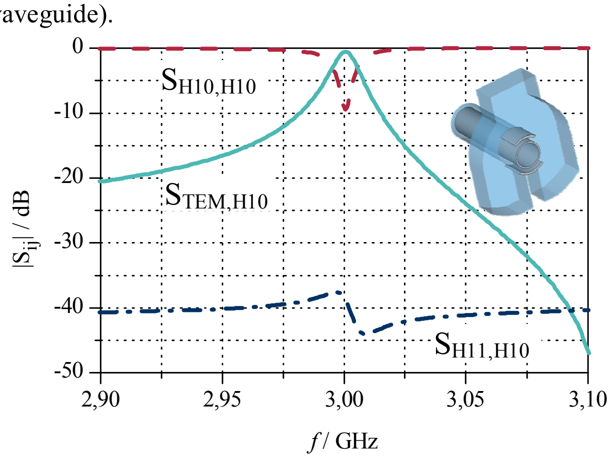

Figure 6: Reflection magnitude $|S_{H10,H10}|$ / dB and transmission magnitudes $|S_{TEM,H10}|$ / dB and $|S_{H11,H10}|$ / dB against frequency of the twin-waveguide-to-coax with asymmetric diaphragms (dimensions are h = 33 mm, s = 59.1 mm, g = 11.4 mm, w = 64.3 mm, φ_1 = 33.7°, φ_2 = 29.6°, other data as in Fig. 2; H10 is the fundamental mode of the rectangular waveguide, other modes as in Fig. 1).

EXTERNAL Q

Fig. 7 provides the external Q of a single-waveguide-to-coax coupler as a function of the length l of the inner tube of the coaxial waveguide. As waveguide-to-coax transion with asymmetric diaphragms the one of Fig. 3b was chosen. The method used to calculate the external Q is described in [5]. It can be seen that the coupling strength and with it the external Q can be adjusted changing the length l. The design value of $Q_{ext} \approx 5 \cdot 10^6$ which is necessary at the S-DALINAC to accelerate beam currents from 150 to 250 µA corresponds to a tube length l of 150 mm.

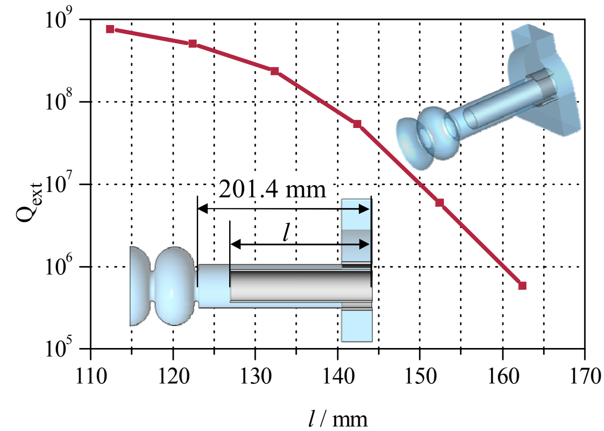

Figure 7: Single-waveguide coupler with asymmtric diaphragm (data as in Fig. 3b): External quality factor Q_{ext} of the 20 cell S-DALINAC cavity against the length l / mm of the inner tube of the coaxial waveguide.

CONCLUSIONS

Two possible designs of waveguide-to-coax couplers, a single-waveguide-to-coax and a twin- waveguide-to-coax coupler, are proposed for the S-DALINAC upgrade. An efficient method to minimize transverse electromagnetic fields on the beam axis makes use of asymmetric diaphragms in the waveguide-to-coax transitions of the coupler designs. The excitation of the TE_{11} mode in the beam tube can be minimized to less than -40 dB.

REFERENCES

[1] A. Richter, "Operational experience at the S-DALINAC," *in Proceedings of the 5th European Particle Accelerator Conference*, 1996, vol. 1, pp. 110 - 114.

[2] V. Shemelin, S. Belomestnykh, H. Padamsee, "Low-kick twin-coaxial and waveguide-coaxial couplers for ERL," *Cornell LEPP Report SRF 021028-08*, 2002.

[3] G. Bowden et al., "A compact rf power coupler for the NLC linac," *in Proceedings of the 18th Particle Accelerator Conference*, 1999, vol. 5, pp. 3426-3428.

[4] Computer Simulation Technology: www.cst.com.

[5] P. Balleyguier, "External Q studies for APT sc-cavity couplers," *in Proceedings of the 19th Int. Linac Conference*, 1998, pp. 133 - 136.