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325 MHz HIGH POWER RF COUPLER FOR THE CH-CAVITIES OF THE FAIR p-LINAC

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Abstract

In order to supply the input RF power to the Cross-bar H-mode (CH) cavities of the p-LINAC for FAIR an inductive RF coupler has been studied. The designed RF coupler, and its water cooled inductive loop, has to withstand up to a 3 MW pulsed power (at 325 MHz). At GSI a prototype has been manufactured and tests were performed. The prototype of the designed high power RF coupler is presented together with the results of the coupling measurements at the CH-prototype cavity.

INTRODUCTION

The Facility for Antiproton and Ion Research (FAIR) requires an intense proton beam at 70 MeV serving the SIS18. For this purpose a dedicated proton LINAC has been designed and will be produced by GSI. The room temperature DTL of the p-LINAC is composed by three coupled CH cavities, providing the acceleration up to 35 MeV, followed by three single CH cavities [1].

A prototype of the coupled CH cavity corresponding to the second accelerating unit, from 11.5 MeV to 24.2 MeV, has been manufactured, assembled and recently copper plated successfully at the GSI galvanic workshop [2-3]. The layout of the coupling cell for the coupled CH structures is designed to let it oscillate in an Alvarez E-mode at the same resonance frequency as the H-mode of the CH-cavities. In order to realize the coupling between the 6 1/8” coaxial line and the coupled CH-cavity, an inductive coupler has been studied. The advantage of an inductive coupler is the possibility to tune the coupling factor by rotating the loop inside the coupling cell. The design of the coupler inserted inside the coupling cell of the prototype of the CH cavity is shown in Figure 1. In the figure the coupler is oriented at 0° and the coupler area is perpendicular to the magnetic field lines.

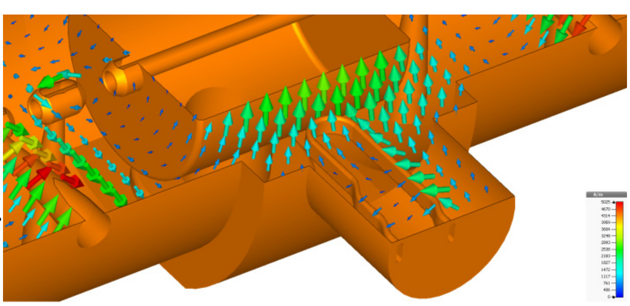

Figure 1: 3D-cut of the coupling cell of the second coupled CH cavity of the p-LINAC.

A prototype of the designed coupler has been assembled and tested. The mechanical construction steps of the prototype of the RF coupler are shown together with measurement results of the coupling to the coupled CH cavity.

INDUCTIVE COUPLER RF DESIGN

At GSI several inductive couplers are used for the UNILAC cavities at different frequencies (i.e. 36, 108 and 216 MHz) and also in other accelerator facilities (i.e. CERN Linac3, Heidelberg (HIT), Padova (CNAO) and at BNL). This design can be adapted to RFQs, IHs, Alvarez, Spirals and CH cavities covering a power range from some tens of kW up to 2 MW power (max 25% duty factor). Therefore a big number of flange-oriented types with respect to the dimensions of the used RF power lines can be realized [4]. The application of this type of coupler to the second coupled CH cavity of the p-LINAC has been studied with CST Microwave Studio. The coupling factor and the electromagnetic properties of the RF coupler insertion and rotation inside the coupling cell have been analysed for different effective loop areas [5]. However, the analysed solutions were not optimized to be used with a beam load. To take the cavity´s beam loading into account, the conventional parameter $\beta=Q_o/Q_{ext}$ has to be modified to include the contribution of the absorbed power by the beam:

$$\beta_{beam} = 1 + \frac{P_b}{P_{losses}} \qquad (1)$$

Where P_{losses} is the average power dissipation at the cavity walls and P_b is the averagedelivered power to the beam as a function of the beam current [6]. For this reason the area of the loop was increased to enhance the coupling factor. Figure 2 shows the design of the inductive loop. The shape of the loop has been adopted in order to reduce the electric field between the coupler and the flange walls.

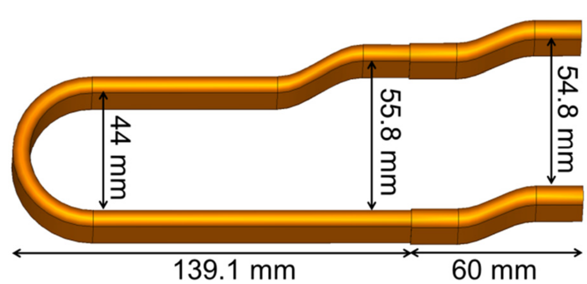

Figure 2: Inductive loop coupler.

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Figure 3 shows the simulation results in terms of the betafactor for the coupler placed at a distance of 42 mm from the triplet housing. This figure shows the beta parameter for the accelerating H-mode and for the closest H-mode. The 0° angle corresponds to the coupler orientation with the surface perpendicular to the magnetic field lines (as in Figure 1). The critical coupling without the beam can be obtained by clockwise rotating the coupler by an angle of 58°. Taking into account the beam load the angle must be smaller. By rotating the inductive loop to the angle of 42° a beta parameter of 1.7 is obtained. This condition is sufficient to obtain a critical coupling when a 70 mA proton beam loads the cavity. This setting allows to fully transfer the RF power to the beam loaded cavity. It is worth noting that the unwanted H-mode oscillating close to the accelerating H-mode (Δf=0.8 MHz) cannot be excited with the designed coupler.

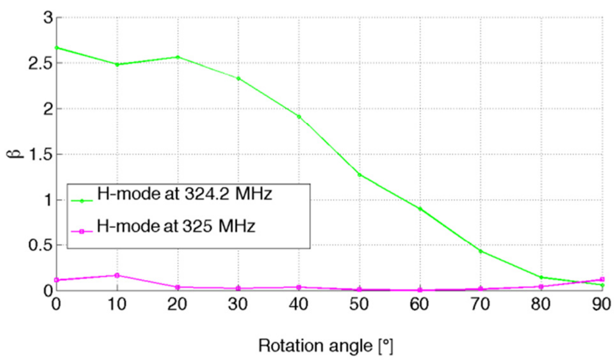

Figure 3: Coupling parameter β at different angles of the coupler.

The coupler itself does not perturb the electromagnetic field pattern significantly. The plungers to tune the resonance frequency and to improve the field flatness are not taken into account in this calculation.

During the coupler dimensioning studies [5] the effect of the coupler on the electric field strength was shown and it was decided to have a distance of 42 mm between the coupler and the triplet housing. With this distance the maximum of the radial electric field at this position can be reduced to 400 kV/m. The Figure 4 shows the electric field at the horizontal cut view with the coupler oriented at 0°.

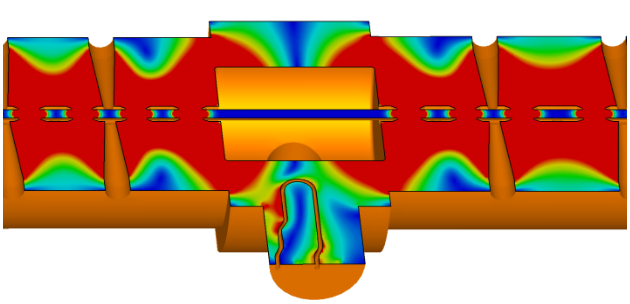

Figure 4: Electric field for the accelerating H-mode at the horizontal cut plane.

MECHANICAL CONSTRUCTION

Since the designed structure fulfilled all of the requirements in terms of RF coupling and preservation of the electromagnetic fields, the inductive coupler has been realized and assembled at GSI workshop.

An Alumina (>99.5%) ceramic cylinder is used as RF vacuum window. The metalized surface of the ceramic is brazed to the copper ring (Fig 5.a) to be welded to the OFHC copper flanges keeping the vacuum region (Fig. 5.b). A flange is then welded into the CF150 flange and the other one is screwed into the 6 1/8“ coaxial support (Fig 5.c).

A waveguide to coaxial adapter is used to connect the Klystron to the coupler through a 325 MHz waveguide line. The loop is then welded to the support (Fig 5.d). Inside the loop and the copper flanges water flowing at maximum 10 l/min is used for the cooling of the loop surfaces. However, the proton LINAC is going to operate at a low duty cycle, then the heat dissipation inside the inductive loop is not a critical point. This assembly is vacuum leak tested. The coupler is then screwed into the rotatable CF flange of the coupling cell of the coupled CH-cavity prototype (Fig 5.e).The shape and position of the ceramic window ensure the limitation of the multipacting phenomenon around the coupler. This is mainly due to the advantage of using cylindrical ceramic vacuum window instead of ceramic disk since the surface hit by X-rays is much smaller.

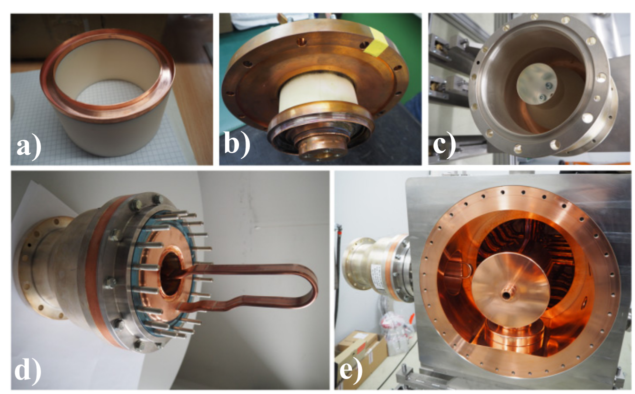

Figure 5: Coupler construction steps and final assembly.

MEASUREMENTS RESULTS

The performance of the optimized inductive coupler in terms of critical coupling with the prototype of the second CH accelerating cavity of the p-LINAC istested at GSI RF testbench. With a 6 1/8” to N coaxial adapter the Vector Network Analyzer was connected to the RF coupler mounted to the rotatable flange of the coupling cell (see Figure 5.e). Several S-parameter measurements were performed at different angles of the coupler with respect to the beam axis in order to find the angle where the critical coupling with the cavity (unloaded by any beam) is fulfilled. The S_{21} measurementsare obtained with a probe coupler to get the external quality factor at different angles of the coupler. The matching variation results are shown in Figure 6. A comparison with the

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simulation results described in the previous paragraph is shown in this figure.

The critical coupling (β=1) is obtained at the angles of about 125° and 230° both for the simulation results and for the measurement. A mismatch between simulations and experimental results was foundwhen the coupler lays at the semicircle of the CH3 cavity, like in Figure 1, at angles between 0° and 90° and between 270° and 360°. A possible explanation can be found in the frequency tuning of the prototype since the measurement is carried out without tuners. However, a further investigation to explain this mismatch will be carried out.

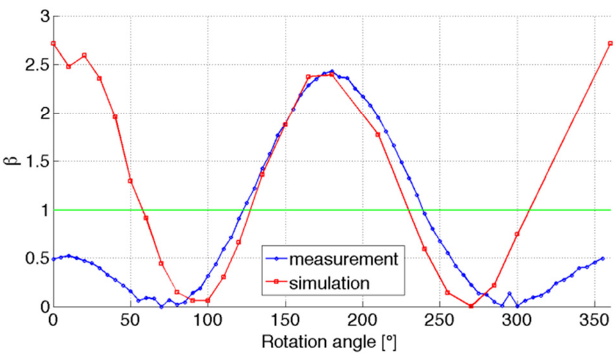

Figure 6: Cavity parameter β for the H-mode oscillating at 323.5 MHz at different angles of the coupler.

At 125° the reflection coefficient is measured and the measurement results are shown in Figure 7. The critical coupling is found at this position for the H-mode resonating at 323.5 MHz while the S_{11} is -3.1 dB at the closest H-mode (at 324.3 MHz). However, the scattering parameters measurement has to be repeated when the tuners (17 in total) are set at the final position. This setting is found by moving the plungers to find out the operating frequency in order to fulfill the best electric field distribution.

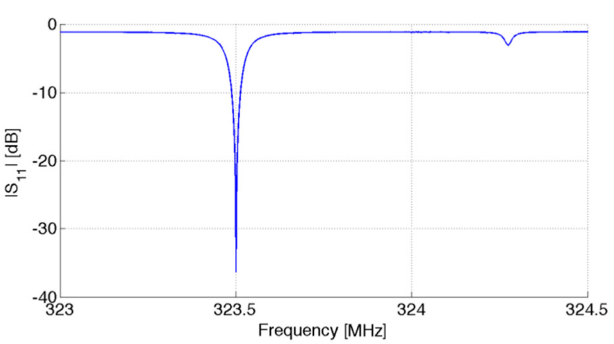

Figure 7: S_{11} Measurement with the coupler oriented at α=125°.

CONCLUSIONS

A design of ahigh power RF coupler for the coupled CH cavities of the FAIR proton LINAC has been developed. The simulated structure allows obtaining a critical coupling with the beam loaded coupled CH cavity corresponding to the second accelerating cavity of the proton LINAC. According to the results of this analysis, the RF power coupler has been manufactured at the GSI workshop and mounted on the rotatable flange of the coupling cell of the coupled CH prototype. The scattering parameters measurements confirmed the simulation results with a good agreement. A next measurement session will be carried out after the frequency and field flatness tuning. The high power test is scheduled to be performed within this year. The design of the inductive couplers of the remaining cavities of the p-LINAC and the study of the positioning inside the coupling cells are ongoing.

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