STUDY AND DESIGN OF THE HIGH POWER RF COUPLER FOR THE CH-CAVITY OF THE FAIR pLINAC

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Abstract

At GSI a proton Linac has been designed and developed in order to provide a 70 MeV proton beam for the FAIR facility. The pLINAC consists of an RFQ followed by six CH-DTL accelerating cavities and the electromagnetic field inside each cavity is generated by seven Klystrons providing up to 2.8 MW power at 325.224 MHz. The high power RF coupling between the Klystron and the accelerating CH-cavity has been studied and an inductive coupling loop has been designed. The coupler insertion inside the cavity and the rotation angle with respect to the magnetic field lines have been adjusted and the results of the analysis of the coupler positioning are presented. A prototype coupler is under construction and the measurement of RF coupling with the CH-cavity is scheduled within this year.

INTRODUCTION

In the framework of the Facility for Antiproton and Ion Research (FAIR) project a linac is under construction to inject a 70 MeV proton beam into the SIS18. The FAIR proton injector consists of a microwave based ECR proton source delivering up to 100 mA protons to be accelerated by an RFQ and a normal conducting Drift Tube Linac (DTL). The DTL is composed by three Coupled Cross-bar H-mode (CCH) cavities, providing the acceleration up to the energy of 36 MeV, followed by three Cross-bar H-mode (CH) cavities. [1] [2]

In order to prove the concept of the CCH cavity, a prototype of the second accelerating unit, from 11.5 MeV to 24.2 MeV, has been manufactured, assembled and tuned with respect to the resonance frequency and to the electromagnetic field flatness along the beam axis. [3]

The RF power system of the proton linac consists of seven klystrons providing up to 3 MW saturated power at 325 MHz, in RF pulses of 200 µs at a repetition rate of 4 Hz, to the RFQ and to the two sections where the three CCH-cavities and the three CH-cavities are grouped [4].

The RF power transport system is composed by WR2300 waveguides, circulators and waveguide WR2300 to 6 1/8” coaxial adapters. In order to provide the RF power to the accelerators, seven couplers connected to 6 1/8” coaxial lines have to be designed and machined. Concerning the DTL section, it has been decided to make use of six inductive couplers. By means of the loop coupler type, the coupling factor can be easily tuned by adjusting the penetration inside the tank and the rotation angle with respect to the magnetic field lines.

The effect on the coupling factor and on the electromagnetic properties of the RF coupler insertion and rotation inside the coupling cell has been studied. The results of this study, together with the mechanical design of the prototype of the high power RF coupler, are here presented.

RF DESIGN

The high power RF coupler has the task to transfer the RF power to the CH-cavity. In order to reduce the reflected power to the RF generator it has to provide an impedance matching between the to 6 1/8” coaxial lines impedance (50 Ω) and the cavity one. When the matching condition is fullfilled the power is fully transferred to the cavity which is said to be *critically coupled*. In such a case the external quality factor Q_{ext} is equal to the unloaded quality factor Q_o. When this condition is achieved the loaded quality factor Q_L:

$$Q_L = \frac{Q_0}{1+Q_0/Q_{ext}} = \frac{Q_0}{1+\beta} \qquad (1)$$

is equal to $Q_o/2$. The conventional parameter β=Q_o/Q_{ext} indicates wheter the cavity is undercoupled (β <1), overcoupled (β >1) or critically coupled (β=1).[5] In order to properly desing the RF inductive coupler preliminary simulations of the electromagnetic field patterns of the CCH-DTL described in [3] have been carried out with CST MWS. Figure 1 shows the electromagnetic field of the mode H_{210} having a resonance frequency f=324.356 MHz and an unloaded quality factor Q_o=14280 (by assuming a copper internal surface). The fields are normalized to have 1 J of stored energy inside the structure. The following formula is used to calulate the area A_s of the coupling loop necessary to obtain the mathing condition [5] :

$$A_S = \frac{\sqrt{100P}}{2\pi f H_0 cos(\alpha)} \qquad (1)$$

This quantity can be calculated by using the simulations results concering the magnetic amplitude H_o as a function

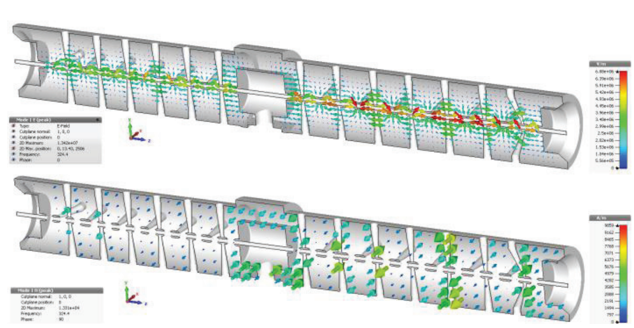

Figure 1: Electric field (up) and magnetic field (down) distribution for the H_{210} mode.

ISBN 978-3-95450-142-7

of the redius (see right Fig. 2) and the dissipated power $P=2\pi fW/Q_o$ (at an energy W=1 J). The minimum area of the loop fullfilling the critical coupling matching condition is shown in left Fig. 2 as a function of the penetration length. The angle between the magnetic field lines for the mode H_{210} and the normal direction to the coupler surface is assumed to be α=0 deg.

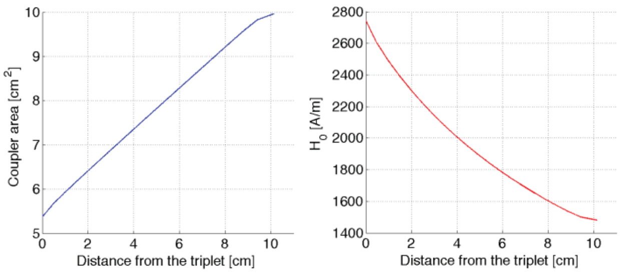

Figure 2: Coupling loop area (left) and magnetic field strength (right) as a function of the distance from the triplet lens inside the coupling cell.

The coupler structure is already used at GSI to transfer the RF high power to the Alvarez-DTL and to the IH-cavities. It is composed by a 6 1/8" coaxial type mechanical support rotating inside a ConFlat flange. Two inductive coupler loops are welded to this support. The dimensions of the loop are adjusted starting from a fixed geometry. The coupling loop, shown in Fig. 3 has a fixed distance between the two pipes of a=32 mm. In order to adapt this coupler design to the CCH-cavity a dedicated study has been carried out to determine the position and the orientation of the coupler in order to achieve the critical coupling. In fact the coupling to the cavity can be tuned by inserting the inductive loop at a certain distance *d* from the triplet housing inside the coupling cell [3] and by rotating it with respect to the magnetic field lines shown in Fig. 1.

In Fig. 4 the external quality factor simulated with CST MWS is shown at different positions with respect to the triplet housing and at different angles between the normal to the coupler surface and the direction of the magnetic field lines shown in the bottom Fig. 1. The critical coupling is obtained at a distance of about 32 mm with respect to the triplet housing, corresponding to a coupling area of about 21 cm² when the coupler area is almost parallel to the beam axis.

The effect of the coupler penetration and rotation inside the coupling cell on the resonance frequency is shown in Fig. 5. As expected, the rotation of the coupler does not affect the resonance frequency while the penetration inside the coupling cell shifts the resonance frequency. The deeper is the penetration length and the closer is the resonance frequency with the one calculated without the coupler.

The coupler insertion improves the electric field flatness along the beam axis even if at the distances from the triplet of 32 mm and 52 mm the difference in the field flatness along the axis is negligible. However, these two penetration lengths determine different results concerning

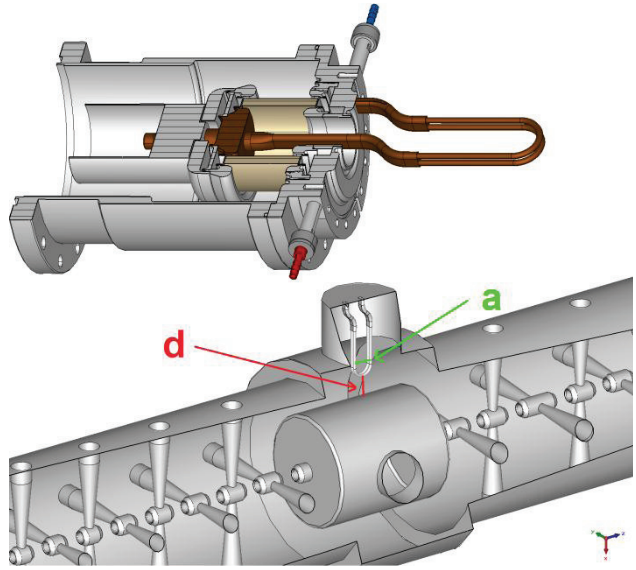

Figure 3: Cutview of the coupler (up) and of the second CCH-cavity with the inductive coplíng loop inserted inside the coupling cell (down).

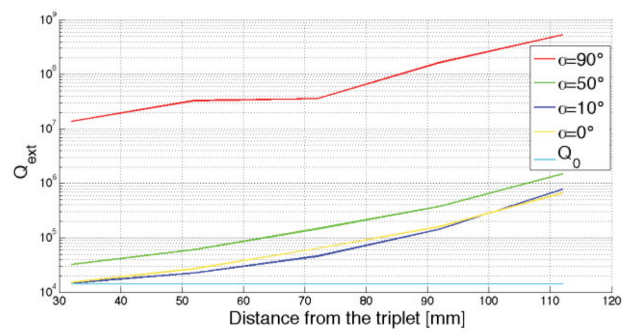

Figure 4: Q_{ext} (logarithmic scale) for the H_{210} mode as a function of the penetration length at different angles.

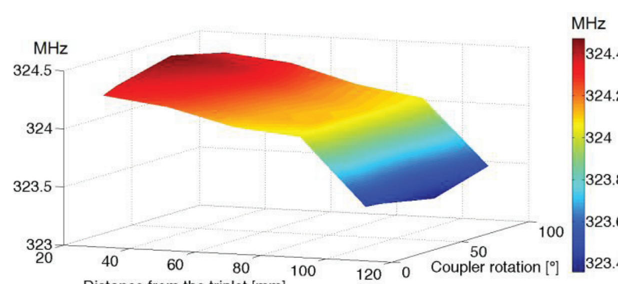

Figure 5: Resonance frequency for the H_{210} mode as a function of the penetration length at different angles.

the electric field strength along the coupling cell radius. In fact when the coupler surface is parallel to the beam axis and at distance of 32 mm the electric field strength arise could be critical as shown in Fig. 6. Here is shown the electric field strength when the coupler is parallel to the beam axis at different distances *d* from the triplet.

For this reason it has been decided to fix the coupler loop at a distance of d=52 mm from the triplet lens and to make use of larger pipe with a CF150 flange where the coupler support was adapted,

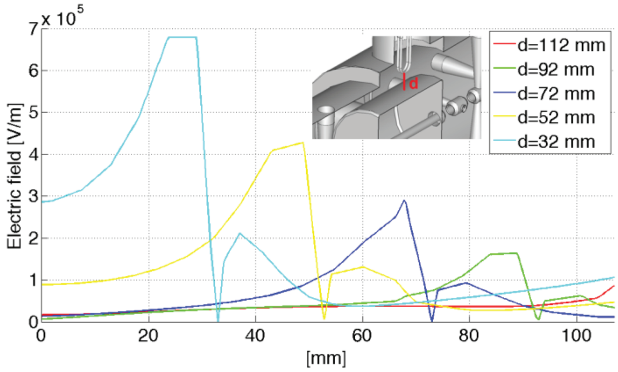

Figure 6: Electric field strength (normalized for 1 J energy) for the mode H_{210} along a line from the triplet surface in direction to the inner cavity wall.

The larger diameter allowed enlarging the pipes distance *a,* by shifting the grounding position of the pipe connected to the outer part, in order to maintain the same coupling area to achieve the critical coupling. This geometrical modification allowed to compensate the missing coupling surface to achieve the critical coupling. In fact at d=52 mm from the triplet lens, for a distance of the two water cooled pipes of 44 mm this condition was fulfilled when the coupler is rotated of 20° with respect to the beam axis. The results in terms of the beta factor are shown in Fig. 7. In this figure the beta parameter is also shown for the nearest mode thus confirming that this coupler design is suitable to transfer the RF power to the cavity only to feed the desired accelerating mode.

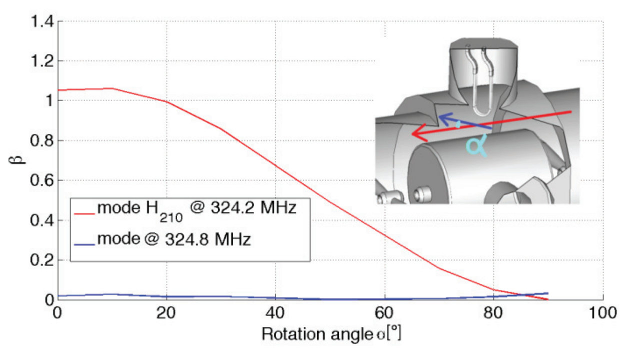

Figure 7: β parameter for the modes H_{210} and for the nearest mode at different angles to the beam axis.

As already mentioned, the coupler insertion improves the electric field flatness along the beam axis. This result is shown in Fig. 8 for the resumed cases: A is the longitudinal electric field strength as obtained from the simulation without the coupler; B is the case of the coupler loop large a=32 mm inserted up to a distance d=32 mm with respect to the triplet housing and almost parallel to the beam axis; C is the case of the larger coupler loop a=44 mm inserted up to a distance of d=52 mm to the triplet housing and rotated of 20° to the beam axis. According to the results above presented the design of the coupler loop C was started. For the correct penetration length and rotation angle, the reflection loss measurements will define the optimal position starting from the setting obtained with these results.

MECHANICAL DESIGN

The loop support will be machined to fit the 6 1/8" coaxial line and will be flanged with an ISO CF150 to fit the coupler flange of the coupling cell inside the CCH-cavity. A ceramic tube RF window is placed inside the support to keep the vacuum. The pipes realizing the loop will be machined over two OFHC copper tubes with diameters of 3/5mm. Two ports for the water cooling pipes are provided. Since the proton linac is going to operate at a low duty cycle, the heat dissipation inside the inductive loop is not a critical point for the design and operation of the coupler.

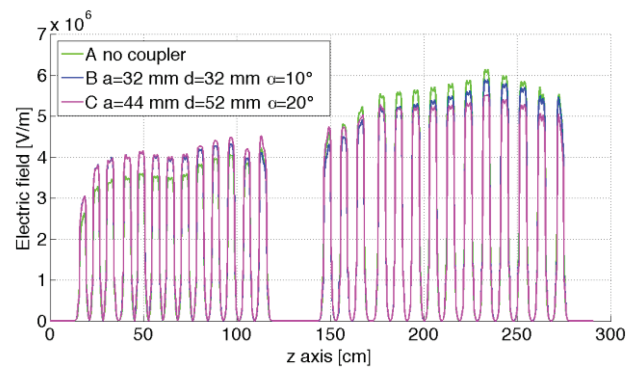

Figure 8: Electric field strength (normalized for 1 J energy) for the mode H_{210} along the beam axis.

CONCLUSIONS

A high power RF coupler for CCH and CH cavities of the FAIR proton linac has been designed. A dedicated study of the coupling factor and of the electromagnetic field for different penetration length of the coupler inside the coupling cell and for different angles with respect to the beam axis has been carried out. According to the results of this analysis, the RF power coupler will be manufactured at the GSI workshop. The preliminary test and measurements on the prototype of the second CCH-cavity have been planned to be performed within this year at the high power RF test bench [4] of GSI. The design of the inductive couplers of the remaining cavities and the study of the positioning inside the coupling cells are ongoing.

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ISBN 978-3-95450-142-7