DESIGN OF RFQ COUPLER FOR PXIE PROJECT*

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Abstract

Design of a new coupler for the PXIE RFQ is reported. Two identical couplers will deliver ~100 kW of total CW RF power to the RFQ at 162.5 MHz. The design employs magnetic loop coupling with the RFQ cavity, thus allowing application of a HV bias to suppress multipacting Results of RF, multipacting and thermal simulations along with a preliminary mechanical design are presented.

INTRODUCTION

A multi-MW proton facility (Project X) has been proposed and is currently under development at Fermilab. A prototype of the Project X front end, the Project X Injector Experiment (PXIE), is planned to validate the conceptual design of Project X. PXIE will supply a 30 MeV 50 kW beam, and will include an H- ion source, a CW RFQ and two superconducting RF cryomodules providing up to 25 MeV energy gain at an average beam current of 1 mA (upgradable to 2 mA) [1]. The ion source will deliver up to 10 mA of H- at 30 keV to the RFQ. The 162.5 MHz RFQ (Fig. 1) accepts and accelerates this beam to 2.1 MeV. The RFQ will consume 95 kW of RF power under nominal operating conditions. To achieve operational stability, two power couplers will be integrated with the RFQ [2].

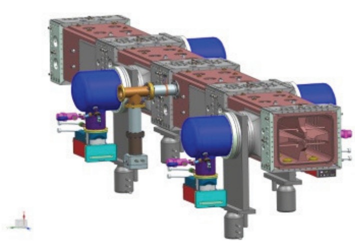

Figure 1: CAD view of the RFQ.

Table 1: RFQ parameters.

Parameter	Value
Ion type	H-
Beam current	1-10 mA
Beam energy	0.03-2.1 MeV
Frequency	162.5 MHz
Duty factor (CW)	100%
Total RF power	≤ 130 kW
Number of couplers	2

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RFQ COUPLER

Requirements

Parameters of the RFQ (Table 1) define requirements for the two couplers. They are listed in Table 2.

Table 2: Coupler requirements.

Parameter	Value
Frequency	162.5 MHz
Operating power	65 kW
Coupling type	Loop
Output port diameter	~3"
Input impedance	50 Ohm

Coupler Structure

Fig. 2 presents a schematic of the coupler, showing its main dimensions and internal structure. The coupler includes an alumina ceramic window with 77mm outer diameter, 28.6mm inner diameter and 6mm thickness. The coupling loop consists of two parallel 1/4" copper pipes through which cooling air flows. The loop is not grounded (not connected to the outer conductor). It allows applying a high voltage (HV) bias to the inner conductor and loop to suppress multipacting. Standard, commercially available components were used when possible to reduce costs. The outer conductor is a standard 3-1/8" size. The coupler has a 50 Ohm input impedance. It is assumed that the coupler will be connected to a larger size feed line by means of an adapter.

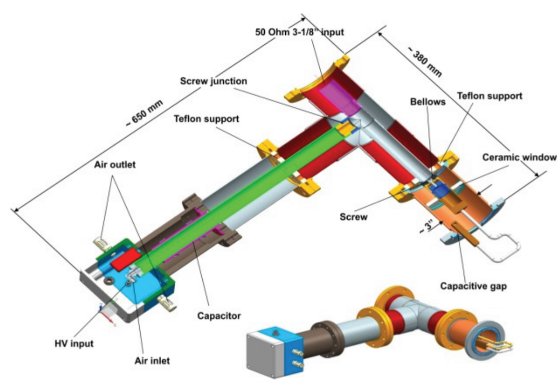

Figure 2: Coupler internal structure, main dimensions and appearance.

RF Properties of Coupler

The RF structure of the coupler is simple and is shown in Fig. 3. It is a coaxial line with ~1/4 λ coaxial support.

Support is necessary to provide cooling air and to apply a HV bias to the inner conductor and a loop. As shown in the graph in Fig. 4, the coupler has a rather wide passband of ~30MHz, ~18.5%, (S11 < 0.1). This indicates that high precision is not required during manufacture of the coupler components.

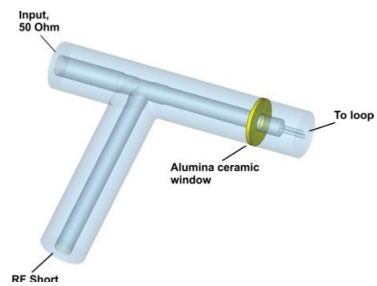

Figure 3: RF structure of the coupler.

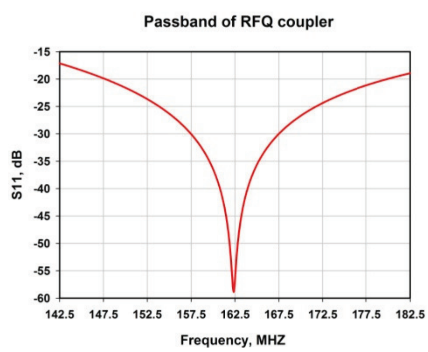

Figure 4: Passband of the coupler.

Fig. 5 shows the position of the coupling loop inside the RFQ cavity. The loop can be rotated without changing the orientation of the input port. The operating loop orientation is 45^{o} relative to the position of max/min coupling. This allows the coupler to be tuned to compensate for both simulation and manufacturing inaccuracies.

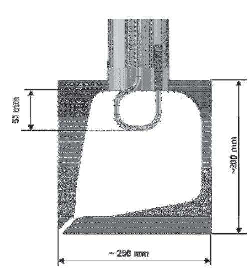

Figure 5: Loop position inside RFQ cavity.

Air Cooling and Thermal Simulations

The largest power losses in the coupler occur in the loop. Loop losses are due mostly to the magnetic field of the RFQ cavity and are about 130W under operating conditions. The loop must be cooled internally. Air was chosen as the cooling medium for several reasons: simplicity, the ability to apply HV bias, and less severe consequences in the case of a leak. Fig.6 shows the air cooling scheme. Simulations indicate that an air flow rate of 3g/s is enough to provide acceptable cooling. The expected pressure drop is ~0.6 bar and maximum air flow speed in the loop tubes is ~140 m/s.

For 80 kW transmitted RF power, total power loss depends on losses in the ceramic window and amounts to 185W and 212W for loss tangents of 10^{-4} and 10^{-3} respectively.

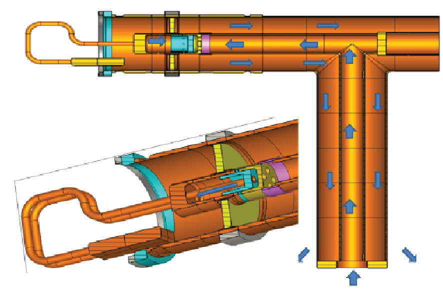

Figure 6: Scheme for air cooling.

Fig. 7 shows the temperature distribution in the coupler obtained by simulations at an air flow rate of 3g/c. In the model the temperature of the flange connected to the RFQ cavity (35 ^{o}C) and the temperature around the ceramic window (30 ^{o}C - temperature of cooling water) were fixed.

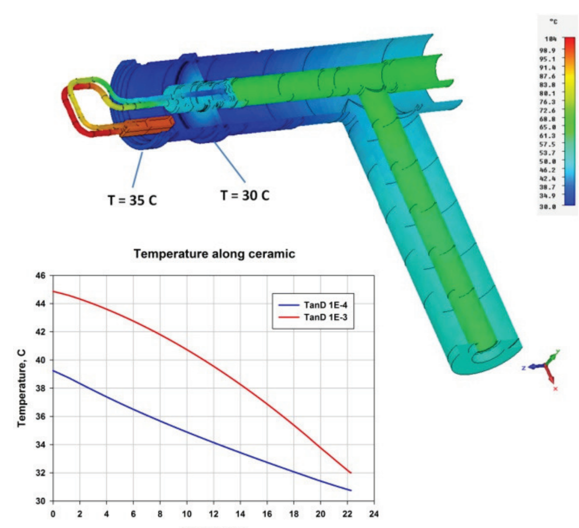

Figure 7: Temperature distribution in the coupler. RF power - 80 kW, air flow rate - 3g/s, ceramic loss tangent - 10^{-3}.

The graph in Fig.7 shows temperature distributions along the radius of the ceramic window. The blue curve corresponds to the case of a loss tangent of 10^{-4} and the red curve to the case of 10^{-3}. Maximum temperature gradients in the ceramic are 0.5 ^{o}C/mm and 0.8 ^{o}C/mm, respectively.

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Stress Analyses

As mentioned above, the RF power creates a non-uniform temperature distribution in the coupler components. Additionally, some components are made of copper alloy and ceramic which have different mechanical and electrical properties. All of these factors create complicated but predictable coupler deformation and stress distributions, shown in Figs. 8 and 9. The gravity load does not have a significant effect on the coupler structure deformation.

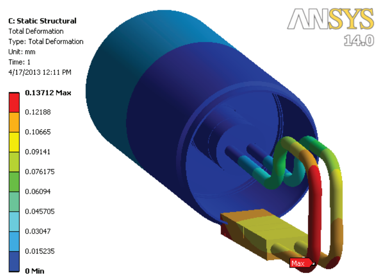

Figure 8: Deformation of the coupler due to non-uniform temperature distribution.

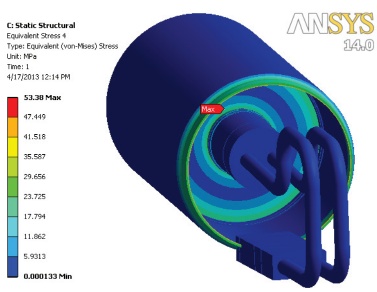

Figure 9: The equivalent stress of the coupler under applied non-uniform temperature distribution. The maximum stress is in the copper coupler component and is about 25% of yield stress.

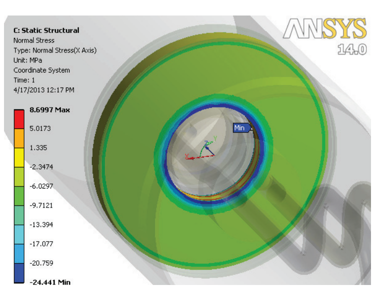

Figure 10: The normal stresses in the radial direction for the ceramic window.

One of the critical components of the coupler is the ceramic window. Ceramic material has considerably different properties under compression and tension. Fig. 10 shows the radial stress distribution in the window. The maximum stress is a compressive stress which is dozens of times less than the critical compressive stress.

Multipacting Suppression

Simulations show that multipacting is possible in a power range close to the operational level. Multipacting occurs in the coaxial part of the cavity input port. However, multipacting can be effectively suppressed by applying a high voltage (HV) bias. Simulations show that a +4kV bias suppresses multipacting in all power ranges. Additionally, the surface of the ceramic will be coated with TiN to reduce secondary emission. Fig. 11 displays particle trajectories during multipacting simulation and demonstrates how the number of particles increases in time with multipacting (red curve), and decreases in the case when multipacting is suppressed by a +4 kV bias. Bias effectively suppresses multipacting.

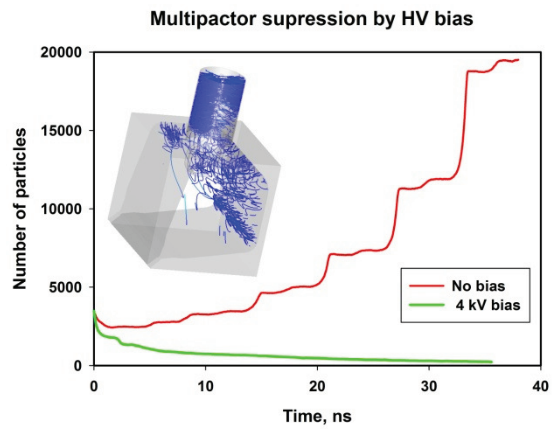

Figure 11: Particle trajectories in multipacting simulation and graphs of particle number vs. time for no bias and for +4kV bias.

CONCLUSIONS

The RFQ coupler was designed for a frequency of 162.5 MHz and ~80kW CW power. The coupler has a simple structure. Not grounding the loop and implementing air cooling allows applying a HV bias to the inner conductor and loop to suppress multipacting. Design work including all risk factors is complete. Manufacturing will begin soon.

REFERENCES

[1] Project X Reference Design Report (January 30, 2013), http://projectx-docdb.fnal.gov:8080/cgi-bin/ShowDocument?docid=776

[2] Progress of the RFQ Accelerator for PXIE. D. Li et al, THPME047, this conference.