DESIGN OF RFQ COUPLER FOR PXIE PROJECT*
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Abstract
Design of new coupler for PXIE RFQ is reported. Two identical couplers are supposed to deliver ~100 kW total CW RF power to RFQ at 162.5 MHz. Coupler has a magnetic loop coupling with the RFQ cavity. Nevertheless it allows applying a HV bias to suppress a multipactor due to original design of the coupling loop. Results of RF, multipactor and thermal simulations along with preliminary mechanical design are presented.

INTRODUCTION
A multi-MW proton facility, Project X, has been proposed and is currently under development at Fermilab. A 30 MeV, 50 kW beam will be used to validate the design concept of Project X in the Project X Injector Experiment (PXIE) - a prototype of the Project X front end. PXIE will include an H- ion source, a CW RFQ and two superconductive 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 delivers to RFQ up to 10 mA of H- at 30 keV. The 162.5 MHz RFQ accepts and accelerates this beam to 2.1 MeV, Fig. 1. 95 kW RF power is consumed by RFQ at nominal operating conditions. To achieve operation stability, two power couplers are integrated to RFQ [2].

Table 1: RFQ parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion type</td>
<td>H-</td>
</tr>
<tr>
<td>Beam current</td>
<td>1-10 mA</td>
</tr>
<tr>
<td>Beam energy</td>
<td>0.03-2.1 MeV</td>
</tr>
<tr>
<td>Frequency</td>
<td>162.5 MHz</td>
</tr>
<tr>
<td>Duty factor (CW)</td>
<td>100%</td>
</tr>
<tr>
<td>Total RF power</td>
<td>≤ 130 kW</td>
</tr>
<tr>
<td>Number of couplers</td>
<td>2</td>
</tr>
</tbody>
</table>

Figure 1: CAD view of the RFQ.

Table 2: Coupler requirements.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>162.5 MHz</td>
</tr>
<tr>
<td>Operating power</td>
<td>65 kW</td>
</tr>
<tr>
<td>Coupling type</td>
<td>Loop</td>
</tr>
<tr>
<td>Output port diameter</td>
<td>~3&quot;</td>
</tr>
<tr>
<td>Input impedance</td>
<td>50 Ohm</td>
</tr>
</tbody>
</table>

Coupler structure
Fig. 2 presents a schematic of coupler, showing its main dimensions and internal structure. Coupler includes alumina ceramic window with 77mm outer diameters, 28.6mm inner diameter and 6mm thickness. Coupling loop consist of two parallel 1/4" copper pipes through which cooling air flows. Loop is not grounded (not connected to outer conductor). It allows applying high voltage (HV) bias to inner conductor and loop to suppress multipactor. To reduce cost of coupler we tried to use standard, commercial elements as much as possible. Outer conductor has standard 3-1/8" size. Coupler has 50 Ohm input impedance. It is supposed that coupler will be connected to bigger size feeding line through adapter.

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

RFQ COUPLER
Requirements
Parameters of RFQ (Table 1) define requirements to couplers. They are listed in Table 2.

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**RF properties of coupler**

RF structure of the coupler is simple and presented in Fig. 3. It is a coaxial line with ~1/4 λ coaxial support. Support is necessary to provide cooling air and to apply HV bias to an inner conductor and a loop. As we see from 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 coupler elements.

![RF structure of the coupler.](image1)

**Air cooling and thermal simulations**

The part of coupler with biggest power losses is loop. Loop losses are caused mostly by magnetic field of RFQ cavity and are about 130W at operating field. Loop must be cooled internally. Air was chosen as cooling medium for several reasons: simplicity, the ability to apply HV bias and less severe consequences in case of a leak. Fig.6 presents air cooling scheme. Simulations show that air flow rate of 3g/s is enough to provide acceptable cooling. Expected pressure drop is ~0.6 bars and maximum air flow speed in loop tubes is ~140 m/s.

Total power loss depends on loss in ceramic window and amount to 185W and 212W for loss tangents 10^{-4} and 10^{-3} respectively for 80 kW RF transmitted power.

![Scheme of air cooling.](image2)

**Fig. 4: Passband of the coupler.**

![Temperature distribution in the coupler.](image3)

Fig. 5 presents position of coupling loop inside of RFQ cavity. Loop can be rotated without changing the orientation of input port. Operating loop orientation is 45° relative to position of max/min coupling. This allows tuning of coupling to compensate for inaccuracies of simulation and manufacturing.

![Loop position inside RFQ cavity.](image4)

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

![Temperature along ceramic.](image5)

**Figure 3:** RF structure of the coupler.

**Figure 4:** Passband of the coupler.

**Figure 5:** Loop position inside RFQ cavity.

**Figure 6:** Scheme of air cooling.

**Figure 7:** Temperature distribution in the coupler.

<table>
<thead>
<tr>
<th>TF 0 4</th>
<th>TF 0 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>35°C</td>
<td>30°C</td>
</tr>
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</table>
Graph in Fig. 7 shows temperature distributions at ceramic window along radius. Blue curve corresponds to the case of loss tangent $10^{-4}$ and red one to the case $10^{-3}$. Maximum temperature gradients in ceramic are 0.5 °C/mm and 0.8 °C/mm, respectively.

**Stress analyses**

As mentioned above, the RF power creates 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 distribution, shown in Figs. 8 and 9. The gravity load does not have considerable effect on the coupler structure deformation.

![Figure 8: Deformation of the coupler due to non-uniform temperature distribution.](image)

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 radial stress distribution in the window. The maximum stress is compression stress and it is dozens of times less than the critical compression stress.

**Multipactor suppression**

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

![Figure 11: Particle trajectories in multipactor simulation and graphs of particle number vs. time for no bias and for 4kV bias.](image)

**CONCLUSIONS**

We designed RFQ coupler for 162.5 MHz frequency and power ~80kW CW. Coupler has simple structure. Not grounding the loop and implementing air cooling allows applying HV bias to inner conductor and loop to suppress multipactor. Design work including all risk factors is complete. We are planning to start manufacturing soon.

**REFERENCES**


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