# CW ROOM TEMPERATURE RE-BUNCHER FOR THE PORJECT X FRONT END*

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*Abstract*

At Fermilab there is a plan to construct the Project X Injector Experiment (PXIE) facility - a prototype of the front end of the Project X, a multi-MW proton source based on superconducting linac. The construction and successful operations of this facility will validate the concept for the Project X front end, thereby minimizing the primary technical risk element within the Project. The room temperature front end of the linac contains an ion source, an RFQ accelerator and a Medium Energy Beam Transport (MEBT) section comprising a high bandwidth bunch selective chopper. The MEBT length is about 10 m, so three re-bunching CW cavities are used to support the beam longitudinal dynamics. The paper reports a RF design of the re-bunchers along with preliminary beam dynamic and thermal analysis of the cavities.

The CW operation and high power dissipation along with common mechanical and spatial constraints have led to not a straight forward design process. An initial solution was based on a short 325 MHz pillbox cavity [2]. A further study has revealed many mechanical, cooling and manufacturing problems to say nothing of the cavity size, especially after switching operating frequency from 325 to 162.5 MHz. Thereafter, a quarter-wave 162.5 MHz resonator (QWR) has been studied and found more suitable solution for the PXIE re-buncher.

## RF DESIGN

The QWR dimensions, shape of stem and drift tubes have been optimized using CST MicroWave Studio (MWS) to meet the requirements and avoid excessive losses and peak surface fields. The cavity shape and the fields as simulated by MWS can be seen in Fig.2.

The power coupler and plunger tuner designs have been borrowed from the re-buncher cavity design for HINS [3]. Matching, preliminary thermal analyses for the power coupler and estimation of the plunger tuning range have been also performed using CST Studio Suite. The main parameters of the re-buncher are presented in Table 1.

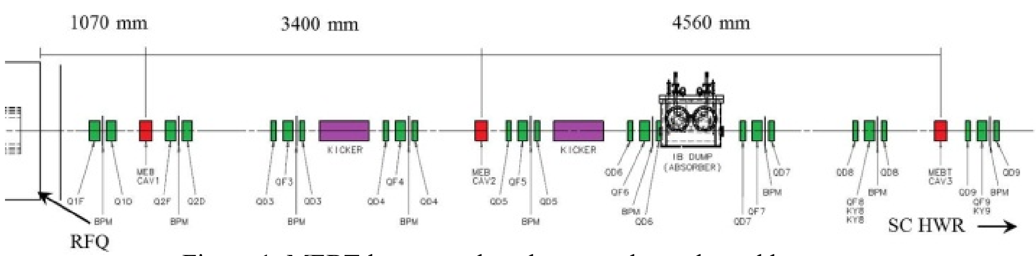


Figure 1: MEBT layout; re-bunchers are shown by red boxes.

## INTRODUCTION

We at Fermilab are planning the construction of a prototype of the front end of the Project X linac [1]. The construction and successful operations of this facility will validate the concept for the Project X front end, thereby minimizing the primary technical risk element within the Project. Successful operations of the facility will also demonstrate the viability of novel front end technologies that will find applications beyond Project X in the longer term.

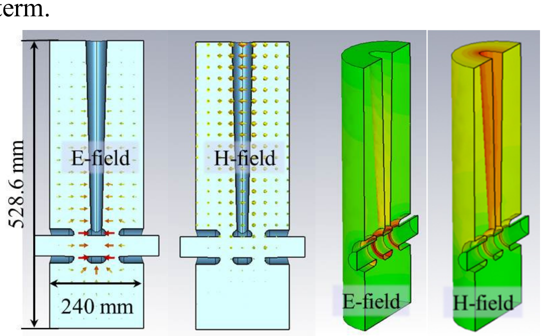


Figure 2: Field distributions (left) and surface field distributions (right) in the re-buncher cavity.

Table 1: Main RF Parameters

| | |
|---|---|
| Q factor | 10530 |
| Aperture radius, mm | 20 |
| Gap, mm | 2x23 |
| Effective voltage (β=0.067), kV | 70 |
| Power loss in copper, kW | 0.92 |
| Effective shunt impedance, Ohm | 5.3e6 |
| Max. electric surface field, MV/m | 4.2 |
| Tuning range, kHz | 440 |

Beam steering effect and probability of multipacting have been evaluated with CST Particle Studio

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simulations. It was found that steering effect is weak and can be ignored. But one-two multipacting barriers at lower power should be expected.

## MECHANICAL DESIGN

The main CW re-buncher mechanical considerations are:

- Development of the cooling system to remove 0.92 kW of the heat load to meet the thermal and stresses requirements.
- Design of the mechanical structure to meet the RF and mechanical stability requirements

The mechanical design of the CW re-buncher follows rules of ASME Boiler and Pressure Vessel Code. The main body of the cavity is made of OFE copper hollowed cylinder with standard 5/16" thick wall. Two half drift tubes are brazed to the inner cylinder wall. Central drift tube is supported by the stem brazed to the top plate. Both the top and the bottom plates are made of OFE copper with thickness of 3/8". The inside diameter of the cylinder is 240 mm. In this design, the outer steel wall is eliminated. The analysis shows that the maximum deformation and Von Mises stress occurred on the top and bottom plates with value of 0.044 mm and 18.7 MPa under 1 atm differential pressure. The frequency shift due to the cavity deformation of 4 kHz is acceptable.

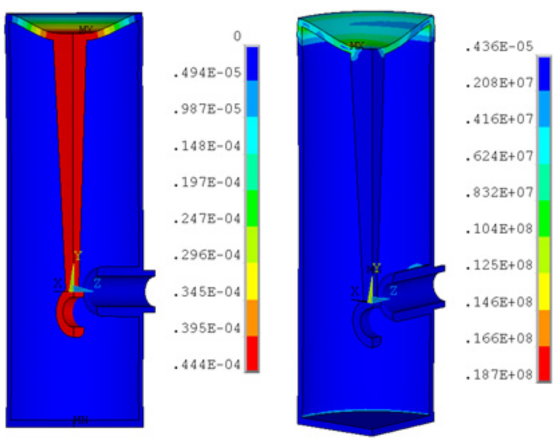


Figure 3: Total displacement (left) and von Mises stresses of CW re-buncher under 1 atm pressure.

The water pressure supplied by the existing facility is about 80-100 psig. The cavity will be operated at 30-45ºC. The temperature tolerance requirement is +/-1 ºC. The outside cooling channels use general copper tubes embedded in the cylinder wall. Figure 4 shows two possible options for the inside cooling of the drift tube and stem: V-shape channel (only inside the stem) and all around tubing. The advantages of the first design are that the drift tube and the stem can be made as one piece and no tubing is needed. But possible sudden change in the flow direction may cause significant pressure drop and turbulence in the local area. Plus the copper oxide released from copper surface as corrosion product of low conductivity water with minerals will accumulate in the "dead spots" and eventually may block the cooling channel. To avoid the risk of clogging, the all-around tubing is designed.

For the further simulation work, we considered that the flow rate of the cooling water is 2.5 GPM, the radiuses of inside and outside cooling channels are 3/16" and 1/4" and an inlet water temperature of 30° C. These values lead to the convection coefficients of 14700 and 14100 $W/m^2/K$ respectively that we used in the analyses.

The drift tube with the stem will consist of two identical halves. Each half will have cut-out recess on its inner surface along the stem and around the drift tube. These recesses will accommodate cooling tubing which is single formed general copper tube with inner diameter of 1/4" and wall thickness of 1/32". Two halves and the tube between them will be brazed all together combining complete central drift tube with stem and embedded tubing. This design completely excludes a risk of water-vacuum leaks.

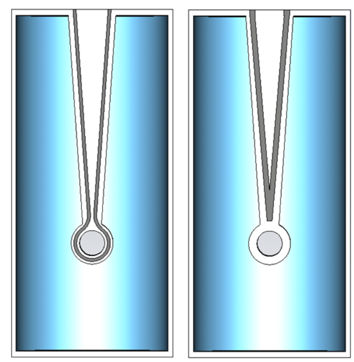

Figure 4: Two options of inside cooling. V-shape (right) and all around tubing (left).

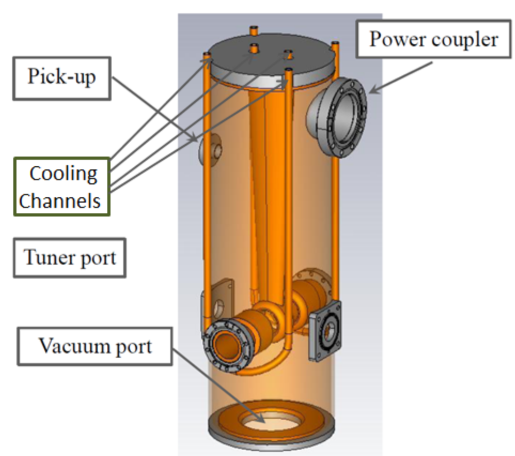


Figure 5: General view of the CW re-buncher.

## COUPLED RF, THERMAL AND STRESS ANALYSES

A series of ANSYS Multiphysics coupled RF and thermal-stress analyses have been performed to optimize the outside and inside cooling scheme of the CW re-buncher main body and central drift tube with stem.


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The analysis consists of combined RF and thermal-mechanical simulations. The power losses calculated by the RF module of ANSYS at effective voltage of 100 kV is used as input in the thermal-stress analysis to evaluate the temperature profile and the consequent mechanical stresses. The voltage of 100 kV instead of 70 kV shown in the Table 1 was used to have a good safe margin. The analysis is finalized with evaluation of the frequency shift due to the cavity deformations.

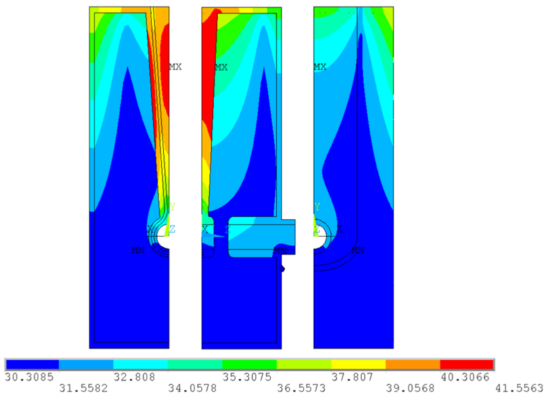

Figure 6: Temperature distribution inside the re-buncher; maximum 41.5° C, minimum 30 ° C.

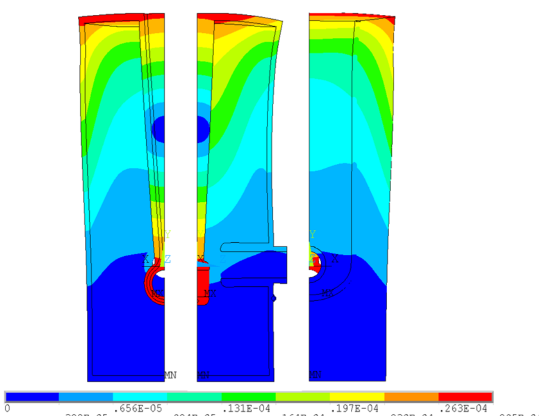

Figure 7: Deformation due to the Figure 6 temperature distribution.

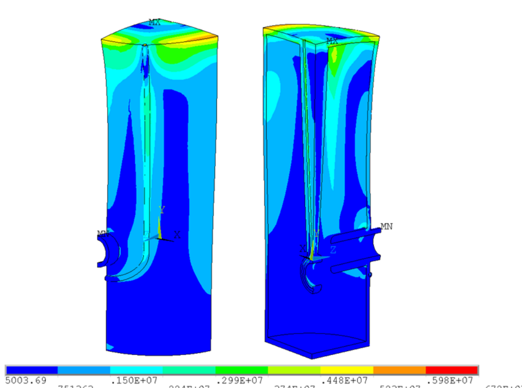

Figure 8: von Misses stresses.

Figure 6 shows the temperature distribution, Figs. 7 and 8 show the displacements and von Misses stresses in re-buncher body. The maximum of the temperature is in the upper part of the stem. The frequency shift due to the overall cavity deformation of -21 kHz is acceptable.

## MECHANICAL STABILUTY

One of the concerns for QWR cavity is the mechanical stability during operation. Figure 9 shows the lowest modal resonance F = 110 Hz calculated by ANSYS. According to Ref. [4] the allowable tolerances for amplitude and phase are 1 keV and 1° respectively. These values correspond to 0.6 and 0.66 mm deviation of central drift tube from the nominal position (see Fig. 10). Our estimations show that the amplitude of longitudinal mode is only about 0.6 μm and is well within the tolerances.

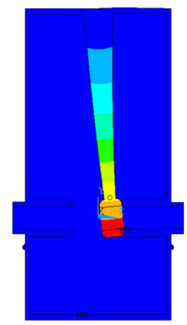
Figure 9: ANSYS F=110 Hz modal shape response.

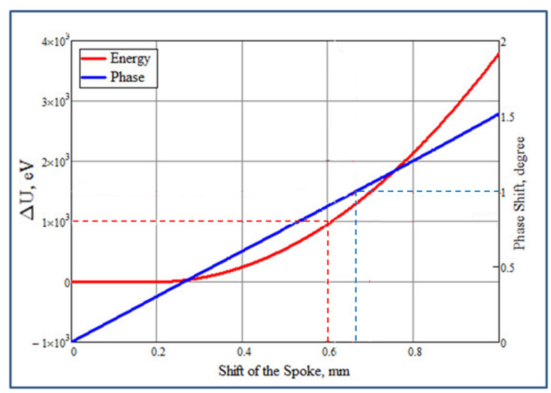

Figure 10: ΔU and phase shift due to the shift of central drift tube.

## CONLCUSION

Quarter-wave 162.5 MHz CW re-buncher RF and mechanical design has been developed to satisfy the major technical requirements.

## REFERENCES

[1] S. Holmes, "Project X Front End R&D Program – PXIE", Project X Document 966-v3, January 2012.
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