HIGH POWER COUPLERS FOR PROJECT X*

S. Kazakov#, M. S. Champion, V. P. Yakovlev, O. Pronitchev, M. Kramp, S. Cheban, Y. Orlov, T. Khabiboulline

Fermi National Accelerator Laboratory, Batavia, IL 60510, USA

Abstract

Project X, is a multi-megawatt proton source under development at Fermi National Accelerator Laboratory. The key element of the project is a superconducting (SC) 3GeV continuous wave (CW) proton linac. The linac includes 5 types of SC accelerating cavities of two frequencies, 325 and 650MHz.The highest Beta cavities each consume up to 30 kW average RF power and need properly designed main couplers. This paper describes the requirements and approach to the coupler design for each cavity, presents results of electrodynamic and thermal simulations, and describes new schemes for increasing cost effectiveness.

COUPLERS REQUIREMENTS

The parameters of the five families of cavities in the 3 GeV Project X superconductive linac are presented in Table 1.

Table 1: Cavity Parameters

Cavity	Frequency	Number	Power*	Cryo-loss
SSR0	350 MHz	18	0.7 kW	1.3 W
SSR1	350 MHz	20	1.7 kW	1.7 W
SSR2	350 MHz	40	3.2 kW	3.7 W
LB	650 MHz	36	11.5 kW	24 W
HB	650 MHz	152	17.5 kW	25 W

*Maximal power consumed by the beam.

Using the cavity parameters, and taking into account the necessary overhead and that the coupler must sustain full reflection from the cavities for a short period of time, power levels of 6kW at 325MHz and 30kW at 650MHz have been chosen as the design criteria for the Project X couplers. In addition, the cryogenic loads of the couplers have to be minimized, and the couplers have to allow for assembly to cavities with a vacuum window in a clean room, followed by installation in a cryomodule. Finally, we have designed the couplers to be as simple and as similar as possible to make them cost-effective.

COUPLER CONFIGUTATION AND PARAMETERS

To make coupler production more effective, an approach of maximum unification was chosen. Couplers for both frequencies should contain maximum number of common (shared) parts. Both couplers will have coaxial structures. The outer diameter of coaxial structure is determined by compatibility with previously designed and built 325 MHz cavities. The outer conductor is made from standard seamless 3" stainless tube with its O.D. machined to obtain a 0.8mm wall thickness, and its I.D. coated with an ~10 micron copper layer. The inner conductor is made of 0.5" O.D. oxygen-free copper tube and is air-cooled. The conceptual design of the 2K-300K vacuum part of the couplers is presented in Fig.1.

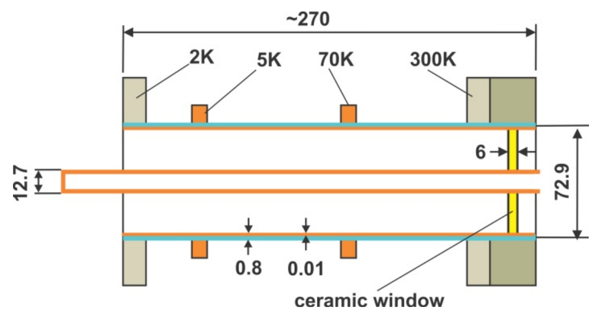

Figure 1: Structure of 2K-300K vacuum part of coupler.

The relatively small diameter of the inner conductor provides a high impedance of 108 Ohm. High impedance has two advantages: it provides lower RF current for fixed RF power and, thus, lower RF loss in outer conductor which is connected directly to low temperature 2K structure. Second, high impedance leads to higher multifactor power threshold and moves it beyond the operating range. Nevertheless, coupler design allows the application of a voltage bias to suppress multifactor if necessary.

The Project X linac is CW machine, so the couplers have a fixed coupling as the penalty for an error in the coupling is a small increase in RF power. Calculations show that the power is not sensitive to mis-coupling: it requires not more than 5% extra power if the coupling varies over the range 0.65 - 1.55, with 1.0 being optimal. It is suggested that cavities be overcoupled from the beginning to decrease microphonic detuning effects.

An antenna tip of a new shape will be used for 650 MHz coupler, Fig.2.

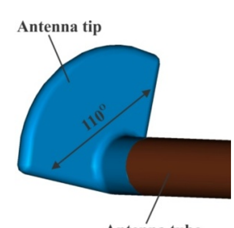

Figure 2: New shape of an antenna tip for 650 MHz coupler.

*Work supported by DOE
#skazakov@fnal.gov

This shape provides better coupling, is lighter, and allows tuning of the coupling by rotating the tip with respect to the cavity axis. A 180^O rotation changes the coupling by a factor of four.

In order to make the coupler simpler, a single window structure was chosen. Operation experience with high average power RF windows and couplers has shown that the single window can operate reliably with an average power flow density through ceramic up to 5.6 kW/cm^2 and more than 1MW of the total power flow in CW regime. [1-3]. By comparison, parameters of the Project X coupler window are moderate: 0.75kW/cm^2 power density, and 30kW total CW power. The window is made of 6 mm thick A_2O_3 ceramic. The window is at room temperature and is placed at the maximum distance from 2K structure. At the same time, the position of window has to allow an assembled cavity (with a cold part of coupler) to be installed inside the cryomodule. Calculations show that two thermo-anchors at 5K and 70K are necessary to minimize total cryogenic load. Thermal parameters of coupler are presented Table 2.

Table 2: Thermal Parameters of Couplers

Parameter	325MHz coupler	650MHz coupler
RF power	6 kW	30 kW
Static loss, 2K	0.029 W	0.029 W
Total loss, 2K	0.033 W	0.058 W
Static loss 5K,	1.53 W	1.53 W
Total lolss 5K	1.55 W	1.68 W
Static loss 70K	8.76 W	8.76 W
Total loss 70K	8.79 W	9.09 W

Fig. 3 and Fig. 4 present the schematics for the air parts of couplers. The 325 MHz coupler has a standard 4-1/16" coaxial input, while the 650MHz uses a 11.5" x 1.5” waveguide input. Fig. 5 and Fig. 6 show simulated passbands.

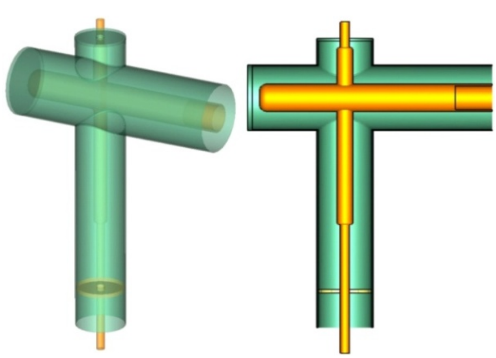

Figure 3: Schematic of air part of 325MHz coupler.

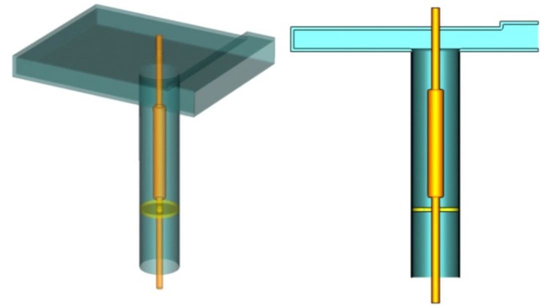

Figure 4: Schematic of air part of 650MHz coupler.

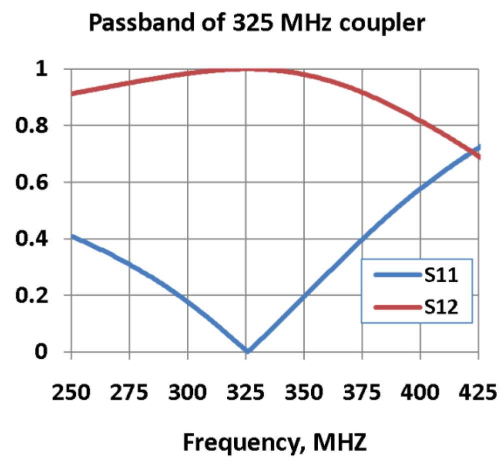

Figure 5: Passband of 325 MHz coupler.

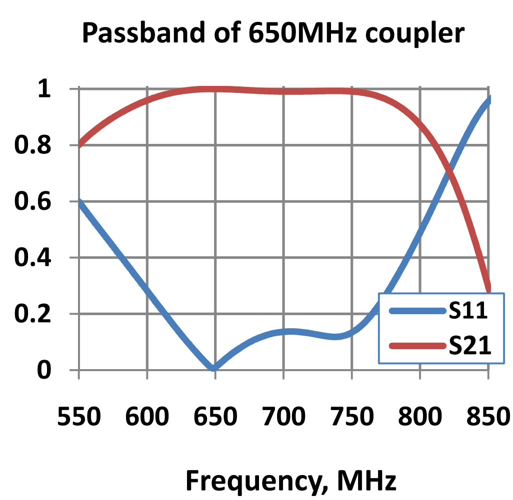

Figure 6: Passband of 650 MHz coupler.

ANTENNA COOLING

Maintaining the antenna temperature to reasonable values is critical for proper coupler operation. From a practical point of view it is seems reasonable to keep maximum temperature below 360K. Our design uses forced air convection for inner conductor cooling, see Fig.7.

The thermal behaviour of the inner conductor has been simulated using ANSYS CFX as well as the thermal code of ANSYS Workbench. Convection coefficients for the tube and air flow in the gap were calculated using empirical equations. Maximum inner conductor temperature was calculated as function of inlet pressure, mass flow and inlet velocity, Fig. 8. The calculations were made for two different modes, corresponding to input powers of 30kW and 120kW.

The inner conductor was found to be adequately cooled for both regimes by using 300 K air at 1.8 bar pressure, flowing at 1 g/s through a 1 mm annular space formed by a stainless-steel sleeve within the copper inner conductor, Fig 8. The outer conductor cooling approaches considered standard scheme localized thermal intercepts.

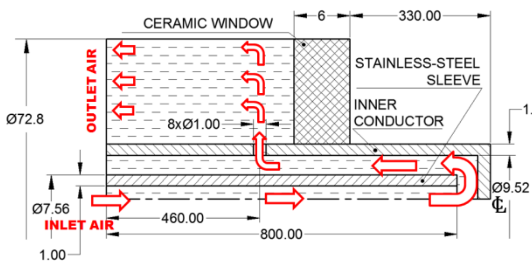

Figure 7: Antenna cooling scheme.

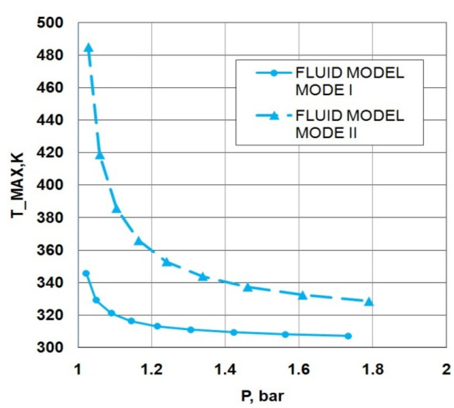

Figure 8: Maximum temperature of antenna tip vs. inlet pressure and power.

650 MHZ COUPLER-CRYOMODULE ASSEMBLY

Once the coupler is installed inside the cryomodule, it is expected to be subjected to minimal mechanical loads. The coupler should be able to support its own weight, thermal contractions and expansions of the SC cavity, and the force imposed by the pressure differential between atmosphere and vacuum.

The mass of assembled cavity is about 22 kg. This weight is primarily supported through the coupler bellow to the cryomodule and through the coupler flange to the SC cavity. In addition, a support bracket bolted to the outside of the cryomodule will carry some of the weight of the coupler assembly.

The total displacement of the SC cavity main coupler flange is 3.78 mm when the temperature inside cryomodule changes from room temperature to 2 K. The coupler is designed so that the compliance in the bellow between the coupler and the cryomodule will compensate for this displacement. Another load will be produced by the pressure of the atmosphere on the large flange of the outer conductor and ceramic window when the air inside the cryomodule is evacuated. Coupler assembled with cavity and cryomodule is shown in Fig. 9.

Analysis shows all these loads combined produce a negligible Von Mises stress inside of coupler components.

To minimize the load on the cavity flange, spring supports have been introduced, Fig.10

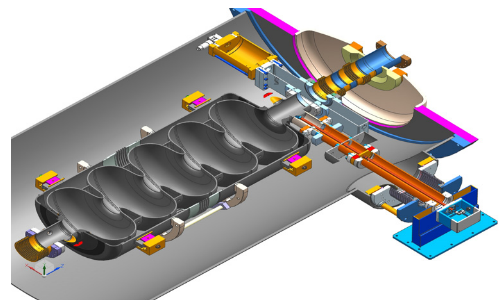

Figure 9: 650MHz coupler assembled with cavity and cryomodule.

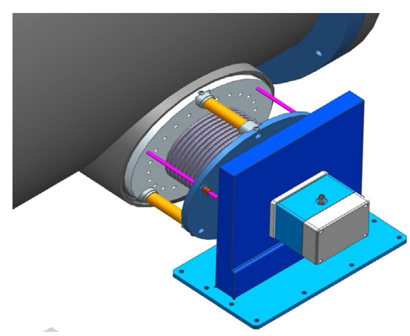

Figure 10: Spring supports (yellow) to compensate atmospheric pressure.

ACKNOWLEDGMENTS

We thank James Kerby for his help.

REFERENCES

[1] S. Isagawa et al., "Development of High Power CW Klystrons for TRISTAN", PAC' 87, Washington, D.C., USA, March 16-19, 1987, p. 1934.

[2] E. N. Schmierer et al., "Results of the APT Power Coupler Development for Superconducting Linacs", The 10th Workshop on RF Superconductivity, Tsukuba, Japan, p. 489.

[3] Tetsuo Abe, "ARES Upgrade for Super-KEKB", 30th Advanced ICFA Beam Dynamics Workshop on High Luminosity e+e- Collision", Stanford, CA, USA, October 13-16, 2003.