MAIN COUPLERS FOR PROJECT X*

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Abstract

325MHz and 650MHz multi-kilowatt CW main couplers for superconducting linac of Project X and their design parameters are presented. Experimentally measured effectiveness of antenna air cooling is introduced.

INTRODUCTION

A multi-megawatt proton/H$^-$ source, Projec X, is under development at Fermi National Accelerator Laboratory [1]. Main element of it is 3 GeV superconducting proton linac which includes 5 families of superconducting cavities of three frequencies: 162.5, 325 and 650 MHz. 162.5 MHz cavities and main couplers are under developing in Argonne National Laboratory. Scope of this paper is development of power couplers for 325 and 650 MHz at FNAL. Superconducting linac of Poject X is supposed to accelerate 1 mA average proton beam and it is considered a possibility to increase beam current up to 5mA in the future. This upgraded version of accelerator will require two types of couplers, which reliably can operate at CW power level ~ 25kW at 325MHz and ~100 kW at 650MHz respectevly. In this paper we are describing current design of these couplers.

COUPLERS DESIGN AND PARAMETERS

Recent Changes in the Design

There were several earlier publication on subject of Project X couplers [2,3]. Since the last publication, several changes were made in the design, which resulted in a change of some coupler parameters.

In the previous design there was a large bellows, which is housed outside the cryomodule. The purpose of the bellows was compensation an accelerating cavity shift and thermal shrink/expansion of coupler parts during cool down/warming up. Due to the bellows location outside of cryomodule, a sufficiently large force (~ 200kg) due to the atmospheric pressure was applied to the accelerating cavity. It had to be compensated by special springs. In this design a coupler had to be rigidly fixed to cryomodule body after completion of the cooling dawn/warming up and had to be unfixed during these procedures. It was deemed inconvenient and potential reason of accidents.

A large bellows was replaced by four bellows. Two of them are located on the outer conductor of coaxial coupler, two - in the internal conductor. Bellows are located inside the cryomodule and coupler does not require to be fixing/unfixing during cooling down and warming up. The atmospheric pressure difference driven force is reduced to 40 kg. The bellows are still located on the non-vacuum side of the coupler and requirements are not as high as if they were located in vacuum close to an accelerating cavity. Current set of bellows can accommodate ±3mm displacement in any direction.

The second important change: a copper plating was removed from coaxial outer conductor of vacuum side of 350 MHz coupler. It decreases static and increases dynamic cryo-loadings, but improves the reliability of the coupler. Previous experience shows that the copper coating often is a source of many problems. Dynamic cryo-loading still is in an acceptable range.

The third change: the temperatures of thermal interceptors were increased. Now temperature of interseptor nearest to 2 K cavity flange is considered as 15 K instead of 5 K and temperature of second interceptor is considered to be 125 K instead of 80 K. We think these values are more realistic, though perhaps are too conservative. It increases calculated static cryo-loading of the coupler.

The fourth change: in order to decrease a static cryo-loading, the thickness of stainless outer conductor of vacuum part of couplers was changed from 0.8mm to 0.4mm

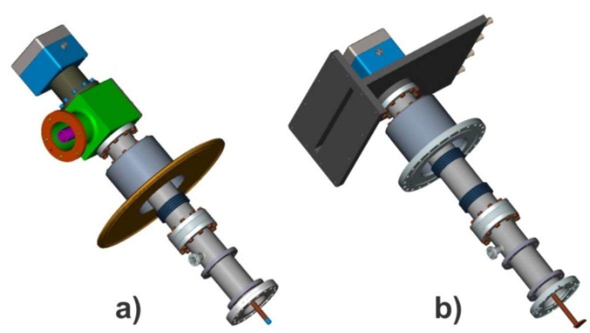

Figure 1: General view of a) 325MHz and b) 650 MHz couplers.

Current Design and Electrical Parameters

General views of 325 MHz and 650 MHz couplers are presented in Figure1. Couplers have similar structures and have many common parts and technologies. Cut view of 325 MHz coupler with details is shown in Figure 2. 650 MHz coupler has the same internal structure but waveguide input port instead of coaxial one. We would like to remind the design approach: to keep a geometry of vacuum part of couplers, which connected to superconducting cavity, as simple as possible. We think it should increase reliability. All complicated elements like a bellows and matching elements are moved to the air part of devices. Main features of the design: single RF window at room temperature, air cooled antenna, ability to apply HV bias to suppress multipactor, fixed coupling. Table 1 shows some electrical parameters of couplers.

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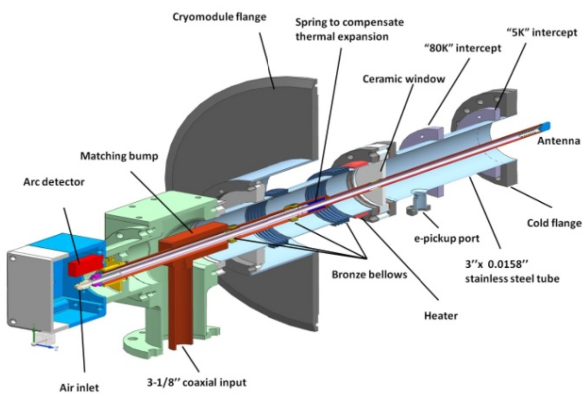

Figure 2: Cut view of 325 MHz coupler.

Table 1: Design parameters of couplers

Parameter	**325MHz coupler**	**650MHz coupler**
CW power	30 kW	120 kW
Maximum pulse power	0.4 MW	3 MW
Multipactor threshold	25 kW, TW	1 MW, TW
Passband	50 MHz	30 MHz
Input	3-1/8" coaxial	11.5" x 0.524" WG
Output	3" x 0.5" coaxial	3" x 0.5" coaxial
Output impedance	105 Ohm	105 Ohm

Thermal Parameters

Figure 3 shows a 2D model for calculation of thermal properties. Scheme is the same for both 325 and 650 MHz couplers.

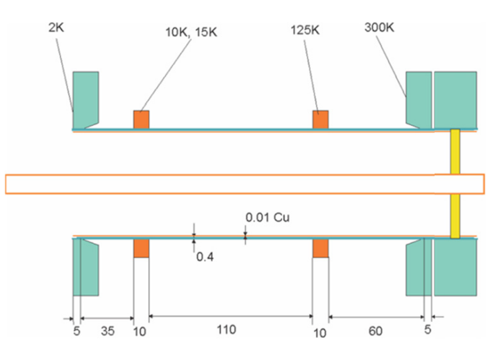

Figure 3: Scheme of vacuum part of coupler which was used for calculation of thermal properties.

For 325 MHz coupler two cases were considered: with 10 μm copper coating and without. 650 MHz coupler has to be used with copper coating only because of high dynamic cryo-loading at 120 kW power level. Results of thermal parameters calculations are presented in the tables 2 and 3.

Table 2: Thermal properties of 325 MHz coupler, columns 2, 3 - no copper, columns 4, 5 - 10 μm copper

Cryo-loading	**P = 0 kW**	**P = 30 kW**	**P = 0 kW**	**P = 30 kW**
2 K	0.06 W	0.50 W	0.24 W	0.28 W
5 K	0.58 W	2.82 W	1.76 W	1.91W
80 K	2.02 W	5.36 W	4.40 W	4.63 W

Table 3: Thermal properties of 650 MHz coupler

Cryo-loading	**P = 0 kW**	**P = 120 kW**
2 K	0.24 W	0.45 W
5 K	1.76 W	2.65 W
80 K	4.40 W	6.03 W

AIR COOLING OF ANTENNA

High average RF power coming through coupler requires forced cooling of antenna. Air was chosen as cooling media because of simplicity, easy availability and higher reliability. 325 MHz coupler is supposed to be used at 30 kW CW maximum power level and 650 MHz coupler at 120 kW CW level. Power losses in the copper antenna is 10W and 60W respectively. It is obvious that antenna will be heated to high temperature in vacuum without forced cooling. It will cause high thermal radiation from antenna tip into superconducting cavity. Therefore forced cooling is necessary.

Recently we made an experiment to measure a performance of air cooling of the antenna. Scheme of experiment is presented in Figure 4.

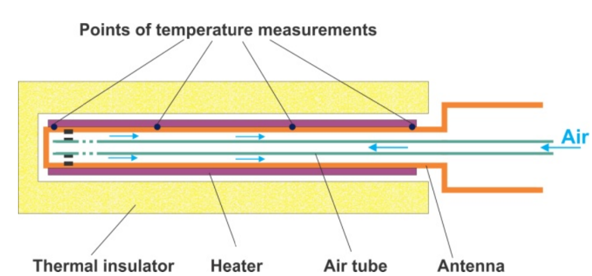

Figure 4: Scheme of measurements of antenna air cooling effectiveness.

Measured parameters were a power of heater, temperatures at four points along the antenna, air flow rate and pressure at the entrance of the air pipe. Knowing of the temperature distribution along the antenna without air cooling we could calculate a power flow through the

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antenna end (right at the drawing). This allow us to estimate an efficiency of thermal insulator and to find a power flow coming through it insulator as function of average antenna temperature.

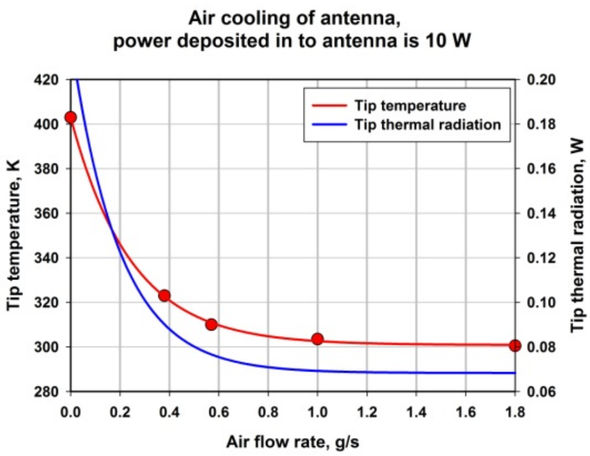

Figure 5: Antenna air cooling, case of 10 W deposition into antenna (325MHz, 30kW, TW). ~0.3 g/s flow rate provides acceptable temperature of antenna tip. Thermal radiation at this point ~0.1W.

Graph at Figure 5 shows dependences of antenna temperature and thermal radiation of the antenna tip on the air flow rate for 10 W power deposition to the antenna. Pressure of this range of flow rate was so small that we could not measure it with our pressure gauge. We can see that flow rate 0.3g/s is enough to cool the antenna if we accept 0.1 W of thermal radiation as a criterion. It corresponds to 330 K temperature of the antenna tip. Coefficient of emissivity was taken as 0.05 (polished copper).

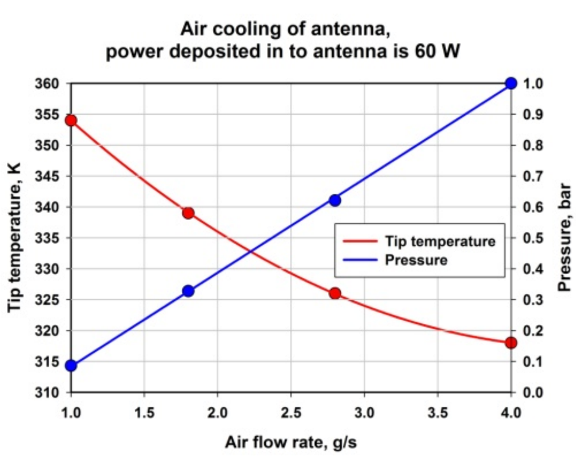

Figure 6: Antenna air cooling, case of 60 W deposition into antenna (650MHz, 120kW, TW). ~2.5g/s flow rate and ~0.5 bar pressure provide acceptable temperature of antenna tip. Thermal radiation at this point ~0.1W.

Graph at Figure 6 presents results of measurements for 60 W of deposited power. From this figure we can see that 2.5 g/s flow rate and 0.5 bar pressure is enough for 120 kW, 650MHz operation.

REFERENCES

[1] S. Holmes, "Project X: News, Strategy, Meeting Goals", Project X Document 1026-v2, April 2012.

[2] S. Kazakov et al., "High Power Couplers for Project X", PAC' 11, New York, March 2011, TUP072, p. 952

[3] S. Kazakov et al., "High Power Couplers for Project X Linac", SRF'11, Chicago, March 2011, TUPO006

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