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MECHANICAL DESIGN OF 112 MHz SRF GUN FPC FOR CeC PoP EXPERIMENT*

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Abstract

A Quarter-Wave Resonator (QWR) type SRF gun operating at 112 MHz will be used for Coherent Electron Cooling Proof of Principle (CeC PoP) system under development for the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL). The CeC PoP experiment will demonstrate the new technique of cooling proton and ion beams that may increase the beam luminosity in certain cases, by as much as tenfold. The 112 MHz cavity is designed to generate a 2 MeV, high charge (several nC), low repetition rate (78 kHz) electron beam using a new fundamental power coupler (FPC) design approach. Structural and thermal analysis, using ANSYS were performed to confirm the FPC structural stability and to calculate the deflection due to heat load from RF power generation. This paper provides an overview of the design, structural and thermal analysis, test results, and FPC tuning drive system for the 112 MHz gun.

INTRODUCTION

A 112 MHz superconducting quarter-wave resonator will be used as the injector for CeC PoP experiment under construction at IP2 of RHIC at BNL [1]. Phase I of this experiment is to be completed by the end of RHIC shutdown 2013 and will include the 112 MHz superconducting QWR and the fundamental power coupler that will be discussed in details in this paper. The paper provides an overview of the design, structural and thermal analysis, test results, and FPC tuning drive system for the 112 MHz gun.

112 MHZ FPC DESIGN AND FABRICATION

Design

The FPC is a coaxial structure, which provides tunable RF coupling and presents small interference to the electron beam output [2]. The FPC design couples the RF power into the cavity from the exit beam pipe of the cavity and allows the electron beam to travel through the hollow inner conductor of the FPC. An external linear motion system will be used to adjust the penetration of the coupling tube in order to fine tune the frequency of the cavity as well as to adjust the coupling strength [2]. The FPC was design to meet all the parameters listed in Table 1.

Table 1: Parameters of the Fundamental Power Coupler for 112 MHz QWR SRF gun

RF frequency	112 MHz
Frequency tuning range with FPC	3 kHz
FPC travel range	40 mm
Q_{ext} of FPC, min.	1.25×10^{7}
Max. RF power loss on the FPC inner conductor	898.6 W
Max. RF power loss on the FPC outer conductor	554.6 W
Available RF power	2 kW

The complete and detailed layout of the 112 MHz QWR and the FPC are shown in Figure 1 and Figure 2.

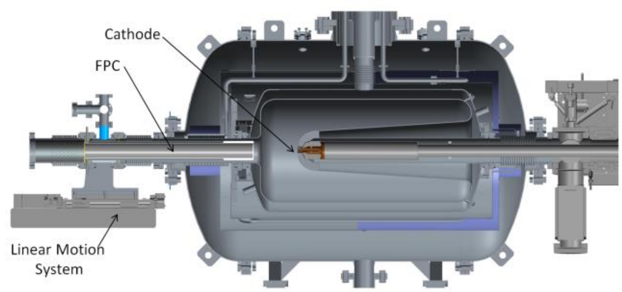

Figure 1: Layout of 112 MHz FPC in the QWR.

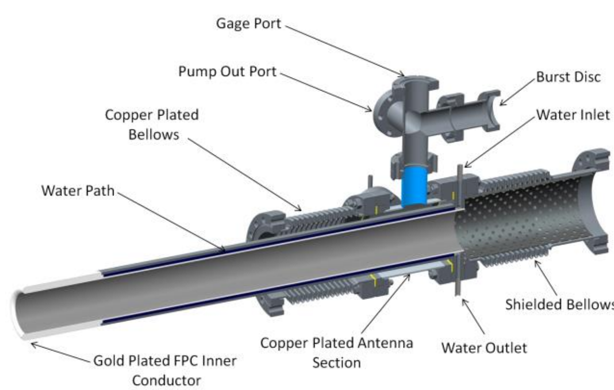

Figure 2: Detailed Layout of 112 MHz FPC.

In order to power the FPC, a BeCu connector was designed. The connector threads into the inner conductor of the FPC and slides inside an air cooled 7/16 UHF UHV cryogenic feedthrough designed by BNL. The FPC will be powered on both sides as shown in Figure 3.

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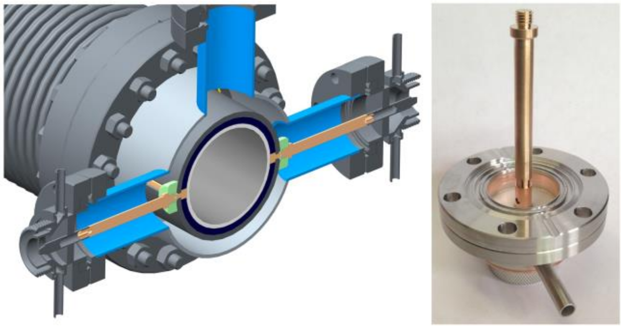

Figure 3: View of the vacuum feedthrough for connection of the coaxial cable to the FPC.

Analysis

One issue with the FPC design was to provide adequate cooling for removing heat due to RF power losses on the surfaces of the inner and outer conductor when the gun is operating. The outer conductor includes the copper plated bellows. Structural and thermal analyses, using ANSYS, were performed to confirm the FPC structural stability and to calculate the deflection and maximum temperature due to heat load from RF power generation. The distribution of RF power dissipated on the FPC inner and outer conductors is shown in Table 2.

Table 2: Distribution of RF power loses on the FPC

RF Power Loses	**Value**
On inner conductor hollow section	894.3 W
On inner conductor solid section	4.3 W
On bellows of outer conductor	554.6 W
On flange	21.9 W

In order to find out if cooling was needed for the bellows on the outer conductor of the FPC, ANSYS was used to determine the maximum temperature on the overall system. Several heat fluxes were applied on the inner surfaces corresponding to the values in Table 1 and a natural convection by air. A heat transfer coefficient of 15 W/m^{2}K was applied on the outer surfaces. A maximum temperature of 460 K was observed at the depth of the convolution. The result from ANSYS for the natural convection cooling of the outer conduction of the FPC is shown in Figure 4.

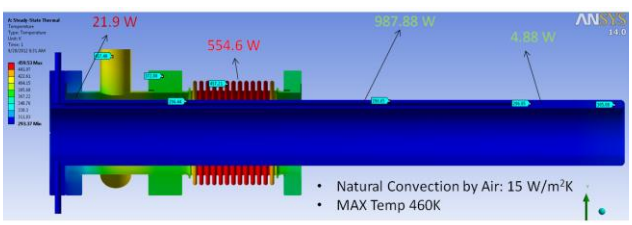

Figure 4: Temperature profile on the overall FPC.

The inner conductor of the FPC will be cooled using a temperature controlled water source. As shown in Figure 1, the inner conductor has a solid and hollow section. The solid section is designed to stiffen the structure and space out the channels from the 4K region of the QWR. The hollow section consists of two water channels, one on the upper half and the other one on the lower half. Both channels are connected towards the solid end of the FPC. The water flows through the upper half first and exits through the lower half of the FPC with a calculated temperature difference of approximately 1 K between inlet and outlet. The cooling system parameters are shown in Table 3.

Table 3: Cooling System Parameters FPC

Parameters	**Value**
Water volume flow rate, Q	4 GPM
Pressure drop	< 2 PSI
Local heat transfer coefficient, h	3217.4 W/m^{2}K
Inlet-Outlet temperature difference	0.88 K

The ANSYS results shown below in Figures 5, 6, and 7 indicate that the FPC will reach a maximum temperature of 305 K and a maximum deflection of 0.001".

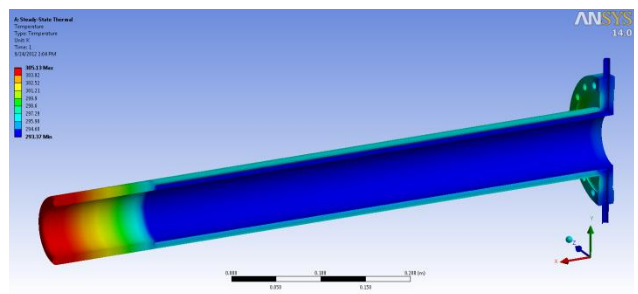

Figure 5: Temperature profile on the FPC inner conductor.

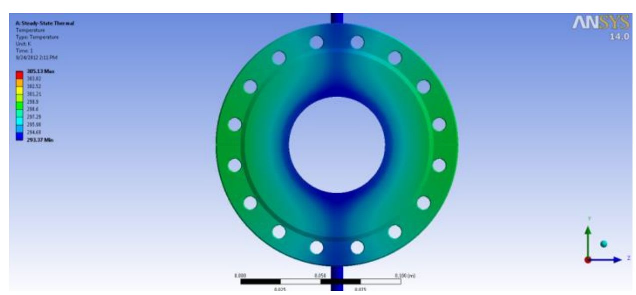

Figure 6: Temperature profile on the FPC water inlet/outlet flange.

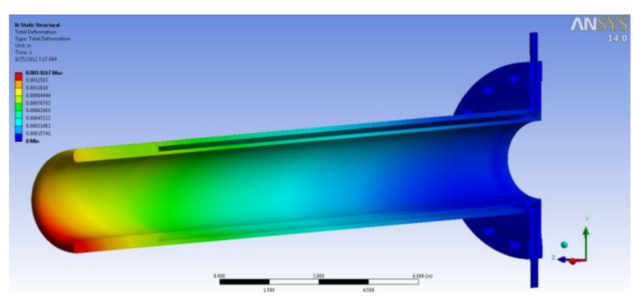

Figure 7: Deflection of FPC under thermal and structural load.

Fabrication

The FPC was designed by BNL and fabricated in collaboration with Stony Brook University. The copper plated and the shielded bellows of the outer conductor of the FPC shown in Figure 2 were designed to provide a 1 inch travel with a low spring constant of 84 lbs/in in order to reduce the moments on the linear motion system. The plated bellows shown in Figure 8 have a minimum of 25 µm thick layer of copper on the inside of the convolutions.

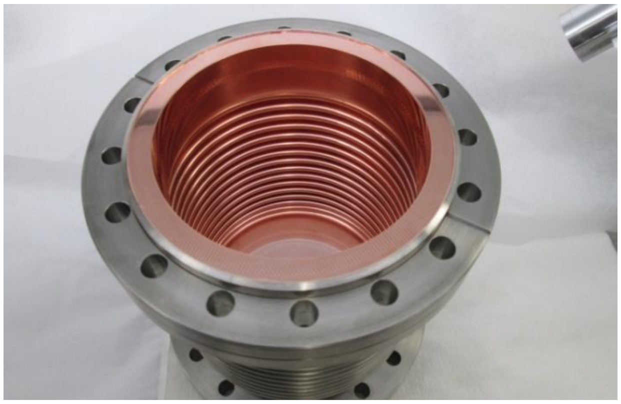

Figure 8: 112 MHz FPC copper plated bellows.

The inner conductor of the FPC was fabricated using 304 stainless steel because of its mechanical properties and for manufacturing purposes. The final assembly was copper plated with a 25 µm thick layer for the RF path, then plated with a 1 µm thick layer of gold to maintain a mirrored surface finish and bring the emissivity to as low as 0.02. This is done in order to reduce heat radiation to the 4 K environment of the 112 MHz superconducting QWR gun and prevent the cooling water from freezing in case of a failure.

Figure 9: 112 MHz FPC gold plated inner conductor.

112 MHZ FPC MOTION SYSTEM

The linear stage motion system for the FPC was designed and fabricated in collaboration between BNL and Ibex Engineering. The design uses a granite base in order to reduce deflection and vibration. The linear stage was successfully tested and met all the requirements listed in Table 4.

Table 4: Parameters of 112 MHz FPC linear stage

Parameters	**Value**
Travel range	40 mm
Response frequency	10 Hz
Position resolution	500 nm
Positioning accuracy	± 5 µm
Repeatability (no backlash- and hysteresis-free)	< ±500 nm
Straightness over travel range	± 5 mm
Flatness over travel range	± 5 mm
Speed	> 1 mm/s
Acceleration	> 60 mm/s^2
Position readback resolution	< 1 µm
Moment M1 transverse to the direction of travel	250 lbs.in
Moment M2 in the direction of travel	1000 lbs.in

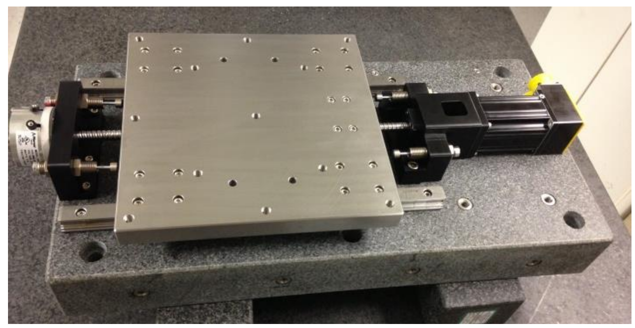

Figure 10: 112 MHz FPC linear motion system.

CONCLUSION

We successfully designed and manufactured all the components of the FPC. Most of the components have been tested individually to ensure that they meet all the requirements. The 112 MHz superconducting QWR gun is scheduled to be tested with the FPC and the cathode stalk during RHIC Run14. A safety interlock system is being designed to blow the cooling water in the FPC to prevent catastrophic failure, with the water freezing, in case of RF power loss.

REFERENCES

[1] V. N. Litvinenko, et al., "Proof-of-Principle Experiment for FEL-Based Coherent Electron Cooling," PAC'2011, p. 2065.

[2] T. Xin, et al., "Design of the Fundamental Power Coupler and Photocathode Inserts for the 112 MHz Superconducting Electron Gun," SRF2011, MOPO014.

[3] ANSYS Multiphysics Finite Element Code, ANSYS, Inc. Canonsburg, PA 15317.