SRF 2021

28 June 2021 – 02 July 2021

Development of Fundamental Power Couplers for Electron-Ion_Collider
Poster# WEPTEV002

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Abstract:

Electron Storage Ring at EIC needs to compensate up to 10 MW synchrotron loss with RF power. This relies on 34 fundamental power couplers to deliver RF power from power sources at room temperature to 17 SRF cavities at 2 K. Each power coupler will operate at CW 400 kW forward power, with ~8% of time full reflection due to beam abort gap. We developed two 1 MW FPCs at BNL: BeO window FPC and Al2O3 window FPC. This paper will briefly summarize test results of BeO window FPC first, and then describe the development of Al2O3 window FPC.

FPC requirement for EIC eSR SRF cavity

- EIC complex contains about 10 types of RF/SRF cavities to satisfy wide range of EIC operating scenarios.
- There are about 65 high power fundamental power couplers in EIC.
- Among these couplers, FPC for EIC eSR SRF cavity has the highest demand in terms of average and peak RF power, and its power requirement is listed in Table 1.
- Notice that the power in the table is CW traveling wave. As there is 8% of beam abort gap in EIC, when the power will full reflected. So the peak average power will be 800 kW (within beam abort gap), and peak power will be 1.5 MW
- Concept design of EIC eSR SRF cavity cryomodule is shown in Figure 1.
- At BNL, we work on R&D of two MW FPC couplers: BeO window FPC and a new design of alumina FPC

Table I. EIC eSR SRF cavity's FPC requirement

Parameters	Nominal maximum	Ultimate maximum
Frequency	591 MHz	591 MHz
Synchrotron radiation	8.8 MW	10 MW
HOM power per cavity	33.5 kW	43.3 kW
Total power requirement per cavity	551 kW	631.5 kW
Operational Overhead	20%	20%
Max. RF power per cavity	662 kW	758 kW
Couplers per cavity	2	2
Max. RF power per coupler	331 kW	379 kW

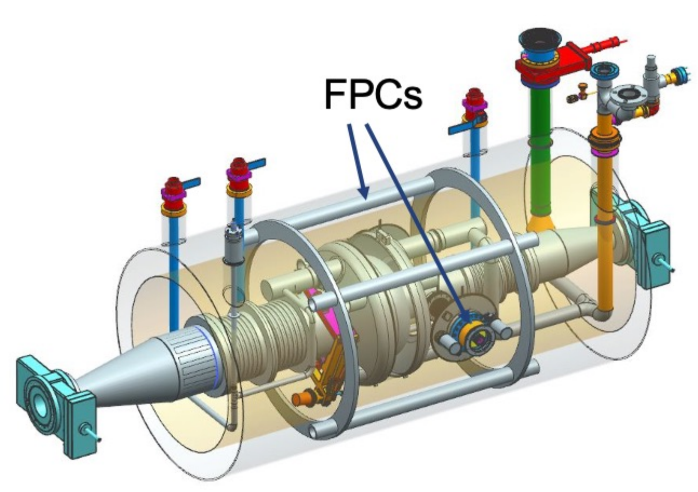


Figure I. Concept design of EIC eSR SRF cavity cryomodule

MW BeO FPC test results

Detailed design of MW BeO window FPC was described reference No. 2 in this paper. Although the FPC was designed for 1 MW travelling wave capability, however, it wasn't tested up to the 1 MW due to administration limit of the klystron power and also lower need of FPC operating power level. As MW FPCs are needed for EIC ESR SRF cavities, we decided to test the BeO window FPCs but up to EIC operating power level, i.e, MW level. So, several improvements were done in 2019 to prepare for the test.

- Upgraded the 704 MHz klystron to allow output power close to 1 MW.
- Reviewed and recalculated all the RF-thermal simulation of the FPCs and conditioning box.
- A pair of BeO window FPC were fabricated by CPI, with improvement of water cooling in airside and fabrication procedures
- Refurbished FPC conditioning setup, including rebuild of a FPC conditioning cart, renew pumping and control system.
- Refurbished FPC conditioning program, including improvement of data logging and interlock.

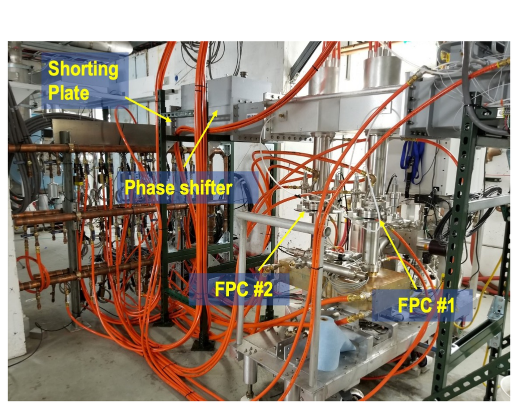


Figure 2: BeO window FPC test setup

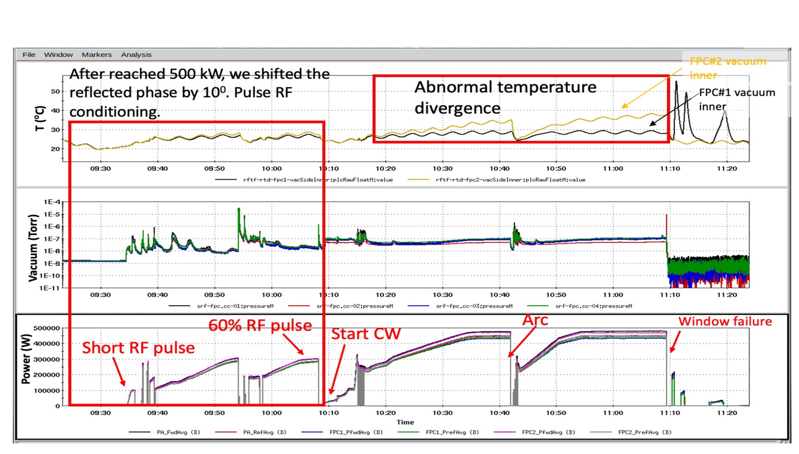


Figure 3: FPC conditioning prior to window failure at 480 kW, CW, standing wave.

The highlights of test results are listed in followings.

- The BeO window FPCs were successfully conditioned to 400 kW, CW, standing wave, all phases, with no troubles in vacuum, arcs, thermal.
- At the first phase of 500 kW power RF stop, the FPCs were successfully increased to 500 kW, CW, standing wave.
- Then, we moved the phase 10 degree away by phase shifter, in pulse mode, it went to 500 kW smoothly. However, one BeO window failure when RF power moved up to 480 kW, CW standing wave.

Great effort was made to investigate the root cause of failure. Except for correlation of traces found on ceramic during receiving inspection and window failure cracks., it is pretty sure that are side arc detector is too far away from window to catch all arcs in the air side. The original and improved instrumentation design is shown in Figure 4.

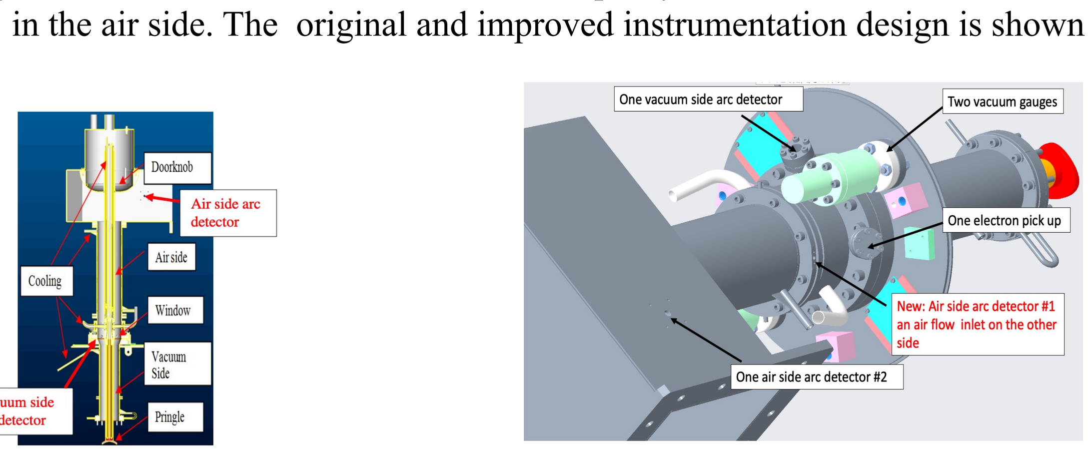


Figure 4: Original air side arc detector (Left); Added an arc detector near window, and a venting hole for dry air flow (Right).

New Alumina Window FPC design

Although BeO demonstrated the feasibility of EIC operating power level (proof of principle), however, strick regulations on handling BeO dramatically slowed down the process. The reason for using BeO for MW FPC design more than a decade ago was because of its better performance on loss tangent and thermal conductivity than 96% alumina, and the trade-off quality is mechanical strength. Recent development on brazing high purity alumina (99.5%) is mature, and it has a factor 4 lower loss tangent than BeO, and its mechanical strength is even better than 96% alumina. To benefit from development of technologies, we decided to development a 99.5% based alumina MW RF coupler.

Considerations for alumina window FPC design

In the past years, we learned a lot from high power FPCs' operating experience at BNL and over the world, we tried to integrate the experiences into new alumina FPC's optimization. The physics design consideration of RF window optimization includes lower normal components of electric field near window to reduce potential multipacting electron strike on window, reasonable total peak field in braze joint and choke, less multipacting zones in coaxial line and better coupling for low Qext requirement. While not compromising physics performance, engineering consideration for coupler design is crucial for application, such as requirement from road trip (5 g impact load from any direction), access of inspection, quality assurance of TiN coating.

Figure 5 shows RF window assembly of BeO window FPC and alumina window FPC side by side. The dimension changed are colour coded and they are highlighted as following. a). b). the window thickness was increased from 6.3 mm to 10.1 mm to boost the robustness of the window; c). the choke to window distance was increased from 3 mm to 10.1 mm for better access of TiN coating and inspecting braze joint; d). inner diameter of window was increased from 22.5 mm to 28 mm to increase the mechanical robustness of braze joint between inner sleeve and ceramic for potential 5g shock load from road trip; e). the diameter of FPC's transmission line was increased to push multipacting zone at higher level and stronger coupling to cavity (EIC needs Qext as low as 5e4).

Main properties of the new window design are shown in Figure 6, 7, 8.

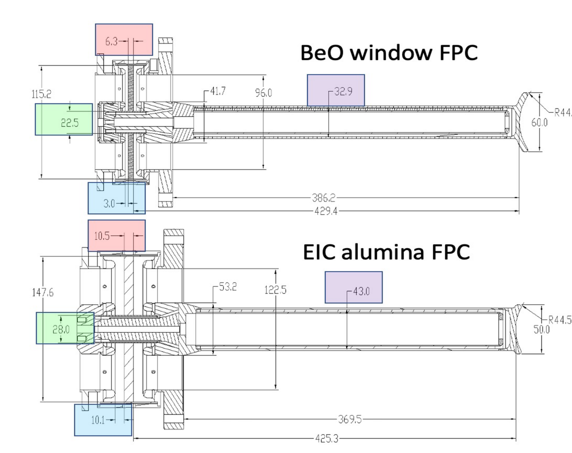


Figure 5: FPC window assembly: BeO window FPC (Top) and new alumina FPC (Bottom).

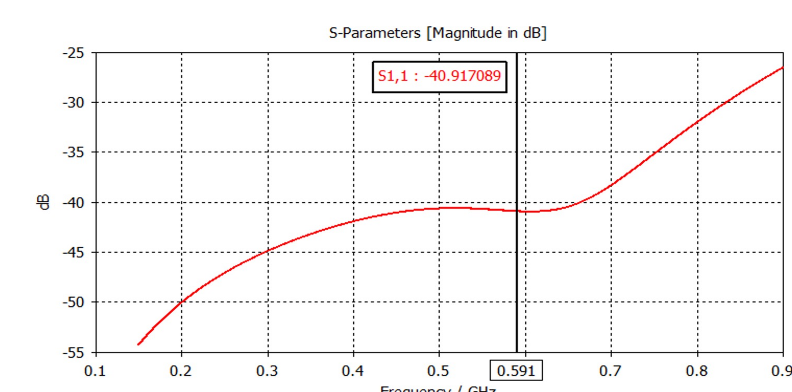
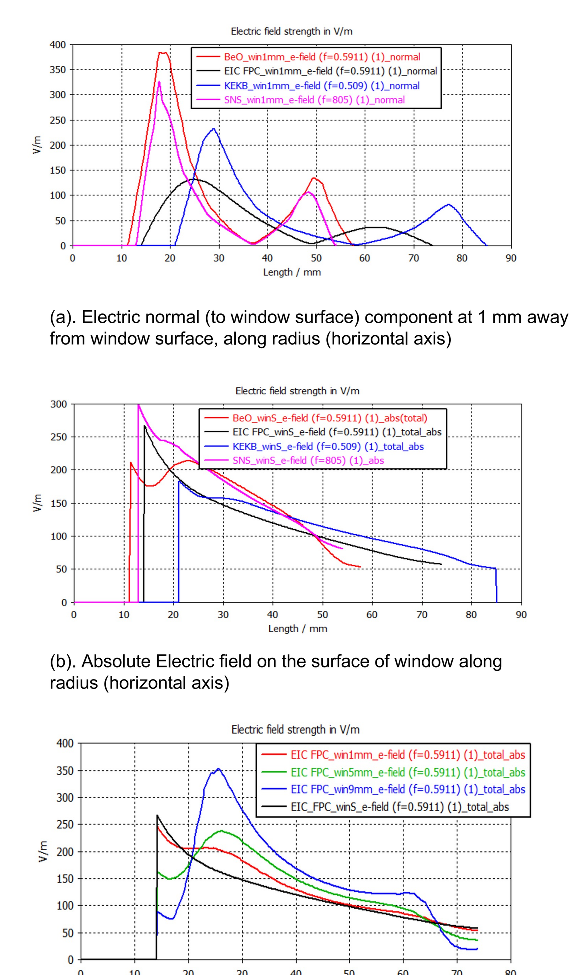


Figure 6: S11 of New Alumina FPC windoe

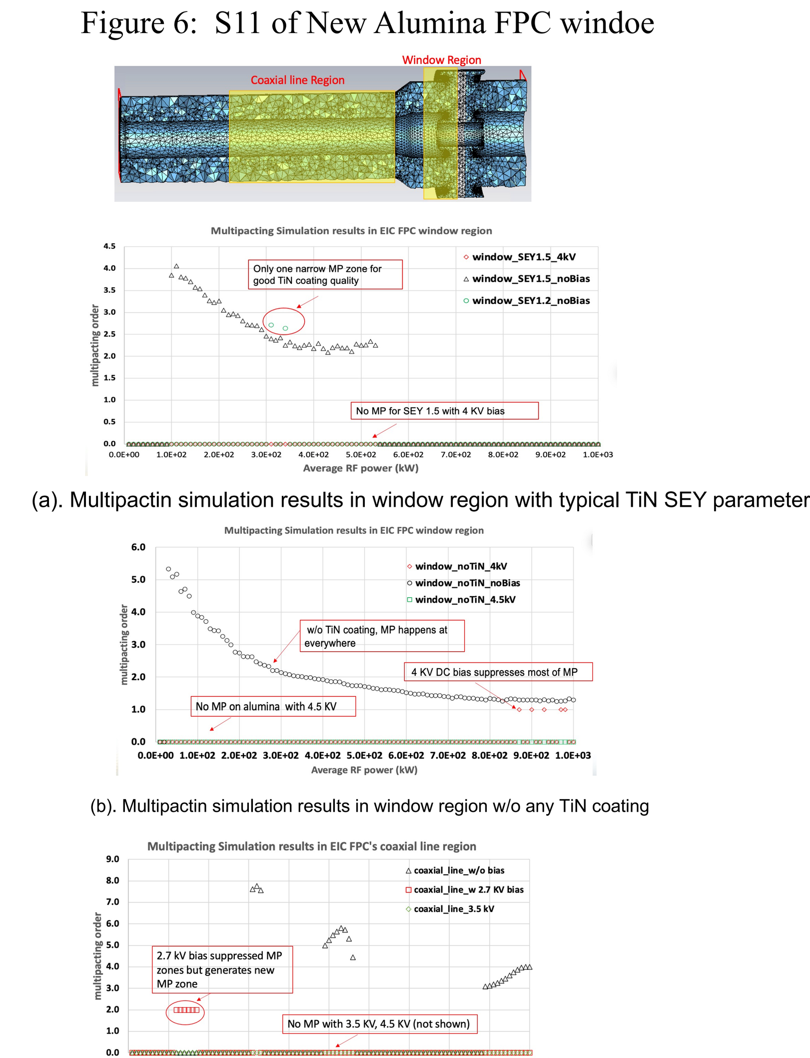


(a). Electric normal (to window surface) component at 1 mm away from window surface, along radius (horizontal axis)

(b). Absolute Electric field on the surface of window along radius (horizontal axis)

(c). Absolute field at various distances away from window surface

Figure 7. Field near RF window.



(a). Multipactin simulation results in window region with typical TiN SEY parameters

(b). Multipactin simulation results in window region w/o any TiN coating

(c). Multipactin simulation results in coaxial line region

Figure 8. Multipacting simulation results

Thermal and mechanical analysis

RF loss for thermal analysis is calculated by HFSS (cross check with CST) and its RF loss results were imported to ANSYS. The RF loss is based on 1 MW average power input, travelling wave. The water cooling channel's water cooling film co-efficiencies were calculated (conservatively) and applied separately. The RF window and choke area's temperature results are shown in Figure 9. The ΔT at ceramic is only 10 C from 24 to 34 C, and the choke tip has the highest temperature highest temperature is 34 C.

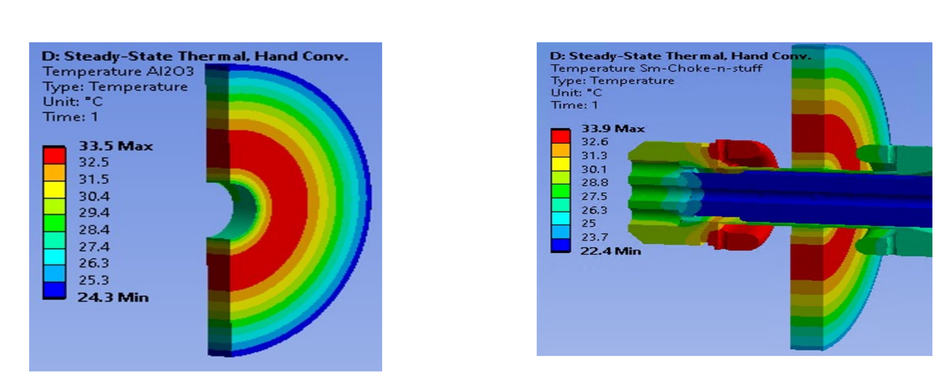


Figure 9. Temperature profile on RF window (left) and choke area (right)

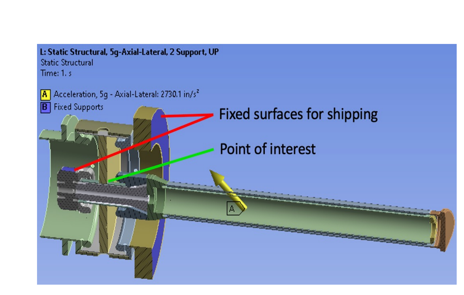


Figure 10. Boundary condition for mechanical simulation

Mechanical analysis was carried out with the same boundary condition when the FPC is shipped in a cryomodule, and 5g load was applied to simulated the shock load caused by road trip. Figure 10 shows the boundary conditions: flange on the outer conductor is mounted to cryomodule, and airside center conductor is fixed by a special designed tooling. Simulation results show that, with 5g load, center conductor tip only deflects 0.0073 inches and the maximum elastic strain on copper of 0.0003 in/in. The stresses are all below material yield strengths. Mechanical modal analysis under same boundary condition as well, and it showed that the first mechanical mode is 100 Hz, which is way above typical road trip oscillation frequency ~ 10 Hz and utility frequency ~60 Hz.

SUMMARY AND PLAN

EIC eSR SRF cavity requires up to MW level of FPCs to serve the need for various operating scenarios. A BeO FPCs were tested and demonstrated feasibility of EIC operating power level. Based on the experience of BeO window FPC and other FPCs over the world, a robust, broadband alumina FPC window was designed. Detailed RF, thermal, mechanical, multipacting study were carried out on the new FPC. The plan for next step is to prototype the new FPCs and verify the design.

ACKNOWLEDGEMENT

This work is supported by Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. DOE.

Many thanks to following people for encouraging discussion: Robert Rimmer, Jiquan Guo, Jim Henry, Frank Marhouser from Jlab.