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THE IMPROVEMENT OF THE POWER COUPLER FOR CADS SC SPOKE CAVITIES*

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Abstract

Twenty superconducting spoke cavities mounted in three cryomodules (CM1, CM2 and CM4) were installed in the CADS, a test facility of 10 mA, 25 MeV CW proton linac. Each cavity was equipped with one coaxial type fundamental power coupler (FPC). Fatal window crack was observed during the test cryomodule (TCM) commissioning. A series of experiments were subsequently implemented and eventually attributed the window crack to the electron bombardment from cavity field emission (FE). Improvements covering the coupler cleaning and assembly procedure, the structure and position modifications were thus implemented, aiming to reduce the cavity contamination and avoid the window damaged by cavity FE electrons.

This paper will describe how the coupler window damaged by cavity field emission and the improvements for cure. In addition, the performances of FPCs for CM1, CM2 and CM4 were compared.

INTRODUCTION

Accelerator Driven sub-critical System (ADS) is a proton accelerator-based facility to produce energy and to destroy nuclear waste efficiently. The China ADS (CADS) project, started in 2011, aiming to construct a 15 MW continuous wave (CW) proton linac of 1.5 GeV and 10 mA from 2011 to 2030s. As a pilot project, the goal of the R&D phase is to build a 25 MeV proton linac by 2016 and to solve some critical technical problems. Figure 1 shows the schematic of the R&D phase of CADS. Two different Injector schemes are proposed: IHEP (Institute of High Energy Physics) is responsible for Injector-I and IMP (Institute of Modern Physic) is responsible for Injector-II [1]. Fourteen beta=0.12 superconducting spoke cavities mounted in two cryomodules (CM1 and CM2) were installed in the CADS Injector-I; and each cavity was equipped with one 10 kW fundamental power coupler (FPC). The main linac section consists of two cryomodules (CM3 and CM4). Six beta=0.21 superconducting spoke cavities were adopted in CM4; and each cavity was fed by one 20 kW FPC.

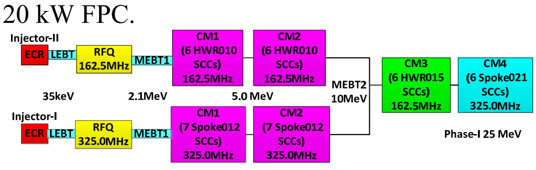

Figure 1: The schematic of the R&D phase of CADS.

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In accordance to the progress of construction and technical difficulties, the commissioning of Injector-I was carried out in several steps. Firstly, two spoke cavities with two FPCs were installed in a test cryomodule (TCM). Fatal window crack was observed during the TCM commissioning. A series of experiments were subsequently implemented and eventually attributed the window crack to the electron bombardment from cavity field emission. The assembly procedure of the FPCs for CM1 cavities was thus optimized to avoid the cavity contamination; along with the coupler clean procedure, the structure and position modifications for CM2 and CM4 cavities. This paper will describe how the coupler window damaged by cavity field emission and the improvements for cure. In addition, the performances of FPCs for CM1, CM2 and CM4 were compared.

WINDOW DAMAGE BY CAVITY FIELD EMISSION

The RF processing of the TCM housing two cavities and two FPCs started in January, 2015. While unexpected fatal window crack were encountered during the RF processing. The following characteristics were observed based on further inspection and experiments:

- The ceramic crack usually happened at a RF power level of less than 1 kW, even with very tight vacuum interlock of 1E-6 Pa;
- Power can easily reach to 3 kW when the cavity detuned; however, once cavity tuned, ceramic cracked after several times of periodically triggered arc events. So we deduce that the fatal crack might have something to do with the cavity performance;
- Large X-ray dose was measured near the window when cavity gradient above 3 MV/m, which indicated serious field emission (FE) happened within the cavity;
- There is no electron or iron bombarding trace on the RF surface of the coupler, which indicated no serious Multipacting and discharging inside the coupler.

Based on above characteristics, we speculate the reason of the ceramic crack is as follows: first, serious FE happened in the cavity, then electrons flied out from the coupling port and impacted directly on the vacuum side of the ceramic, which made the ceramic charged; and then electrostatic discharging happened once exceeding the ceramic breakdown voltage; Finally, the strong energy released from the discharging made the ceramic punctured along the thickness direction and resulted in fatal vacuum leak.

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Experiments were carried out to verify the above speculation. Firstly, a piece of Teflon plate were put into the space between the ceramic and the coupling port to barrier the FE electrons (Fig. 2); then the cavity gradient were increased to the level of ceramic crack happened before (>3.5MV/m). We found that the ceramic never cracked after Teflon plate shielding. Secondly, considering the pickup port is geometry symmetry with the power coupler port, a "bias network" was connected with the pickup signal to capture the voltage produced by FE electrons (Fig. 3). Figure 4 gives the DC voltage and X-ray dose at different cavity gradients, as can be seen the expected DC voltage was detected once the X-ray dose arising. The experiments well proved the above speculation.

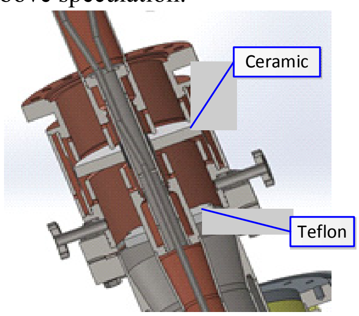

Figure 2: A piece of Teflon plate were put into the area between the ceramic and the coupling port to barrier the FE electrons.

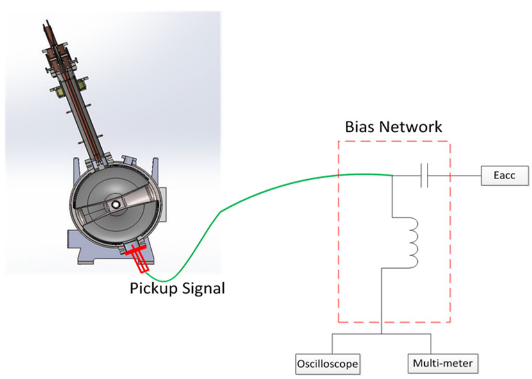

Figure 3: A "bias network" was used to pick up the DC voltage from the pickup port.

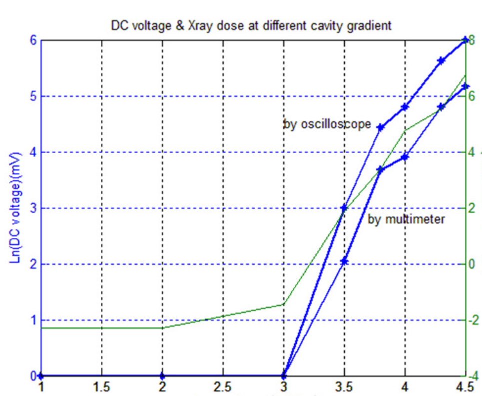

Figure 4: The DC voltage and X-ray dose at different cavity gradients.

Furthermore, the trajectory of the FE electrons facing the coupler port was simulated for different accelerating gradients and phases. As can be seen from the result shown in Fig. 5, the electrons can fly into the FPC through the coupler port and arrive at the window ceramic due to strong transverse electric field.

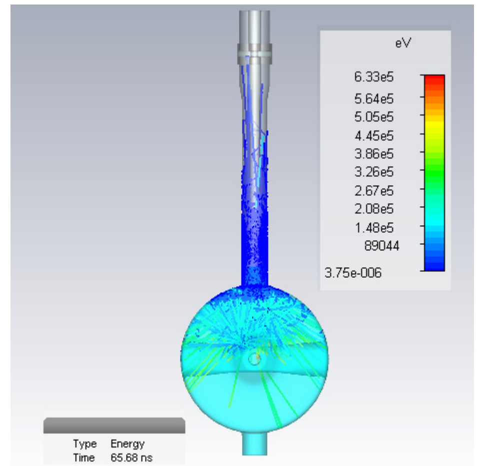

Figure 5: The simulated trajectory of the FE electrons facing the coupler port.

All in all, both the experiments and simulation attributed the window crack to electron bombardment from cavity FE.

FPCS IMPROVEMETNS

In order to cure the above window damage, a series of improvements were processed aiming to reduce the cavity contamination from FPC and avoid the cavity FE at the operation gradient.

Since the fabrication of both the coupler, cavity and other auxilires inside CM1 were completed before the above damage observed and proved, the improvements of CM1 FPC were passive and limited. Firstly, both special gasket and enlarged antenna tip shown in Fig. 6 were designed to shield the FE electrons; Secondly, the coupler and cavity assembly procedure was optimized: window-inner conductor and outer conductor were assembled in a class 100 clean room, then the whole coupler except the T-box was assembled onto the cavity in a local clean booth, which assured the cavity exposing to atmosphere one time instead of two times during the TCM coupler assembly.

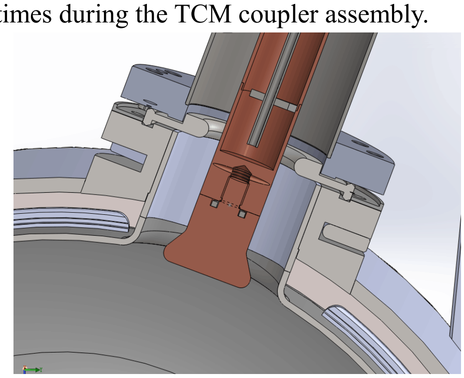

Figure 6: Both special gasket and enlarged antenna tip shown were designed to shield the FE electrons for CM1 FPC.

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For the FPCs of CM2, the improvements are as follows: first, the diameter of the coupler port was reduced from 80 mm to 40 mm (shown in Fig. 7), helps to shield the FE electrons; second, ultrasonic cleaning referred to the clean recipe for TTF Coupler was adopted before the ultra-pure water rinsing [2]; third, the length of the vacuum part was reduced from 740 mm to 310 mm to assure the coupler and cavity assembled in a class 10 clean room (ISO4) instead of local clean booth.

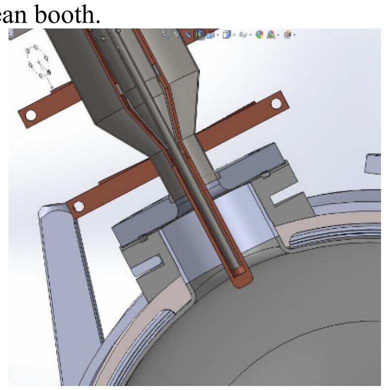
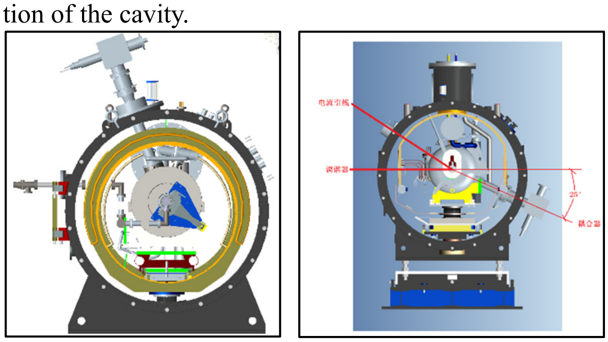


Figure 7: The diameter of the coupler port was changed from 80 mm to 40 mm for CM2 FPC.

For the FPCs of CM4, the position of the coupler changed from upside to downside of the cavity (as shown in Fig. 8), which helps reducing the potential contamination of the cavity.



(a) (b)

Figure 8: (a) The cross section of TCM, CM1 and CM2; (b) the cross section of CM4.

Furthermore, radiation dose was monitored and interlocked during the online operation to assure the cavity operating at the gradient without FE and protect the window from damage.

The main modifications are summarized in the Table 1.

Table 1: The Modifications of FPCs

	FPCs for CM1	FPCs for CM2	FPCs for CM4
Ultra sonic clean	No	Yes	Yes
Position arranged on cavity	Upside	Upside	Downside
Coupler assembled with cavity in class 10 clean room	No	Yes	Yes

After assembled on the cavity, room temperature (RT) conditioning of the FPCs was implemented. Figure 9 shows the average conditioning time of each coupler. As can be seen that the conditioning time was reduced continuously, which benefited from the above improvements.

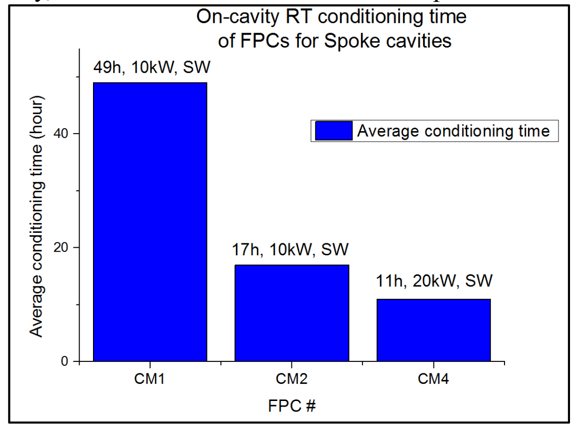


Figure 9: The on-cavity room temperature conditioning time of FPCs for CADS Spoke cavities.

CONCLUSION

FPCs for CADS SC spoke cavities have been developed at IHEP. In the initial phase, fatal window ceramic crack occurred during the TCM commissioning. Both experiments and simulation attributed the window crack to the electron bombardment from cavity FE effect. A series of improvements covering the coupler cleaning and assembly procedure, the structure and position modifications were thus implemented, aiming to cure the window problem and improve the coupler performance. Both the decreasing conditioning time and vacuum activities from CM1 to CM4 indicate that the improvements are effective. Now twenty FPCs of Spoke cavities are attending the beam commissioning operation and showing good performance.

ACKNOWLEDGEMENT

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