IMPROVEMENTS TO RF CAVITY INPUT COUPLERS AT THE ADVANCED PHOTON SOURCE*

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Abstract

Work is underway to improve the reliability and power handling capability of input couplers used in the Advanced Photon Source single-cell and five-cell cavities. Analysis of past failures and coupler performance during conditioning in a test cavity suggest that ceramic material defects and field enhancements caused by a mechanical gap in the coupler design may be responsible for past coupler failures at high power. Simulation results and high-power test data will be discussed.

INTRODUCTION

The failure of input couplers used on the Advanced Photon Source (APS) rf cavities have resulted in significant downtime since APS operation began in 1995. The APS 350-MHz rf test stand has been utilized to study coupler failures and to implement coupler design and manufacturing process changes to improve the robustness and reliability of the couplers. The couplers are of H-loop design (see Figure 1), utilizing a ceramic cylinder positioned inside a ½-height WR2300 waveguide transition as the rf window and vacuum barrier. The APS storage ring utilizes sixteen single-cell rf cavities, each fitted with one input coupler and driven in two groups of eight cavities by four separate 1-MW cw klystrons. The APS booster synchrotron utilizes four 5-cell cavities driven by one 1-MW klystron, each utilizing one input coupler.

Figure 1: Photo of cavity input coupler.

COUPLER FAILURES

The majority of input coupler failures at the APS have involved the storage ring rf system. One coupler failure in the booster synchrotron rf system has occurred due to a pinhole leak that developed in the ceramic with no advanced warning or preceding vacuum activity or arcing. Coupler failures in the storage ring cavities have been caused by sudden arcing at high power levels (see Figure 2), which often results in copper vapor coating the inside surface of the ceramic and thereby causing elevated ceramic temperatures when rf power is applied to the coupler. This ceramic heating is quite often non-symmetric, which increases the possibility of cracking the ceramic if it is allowed to operate at greater than 200ºF for sustained periods of time. It is suspected that many of these failures and minor arcing damage noted on couplers removed from service in the storage ring cavities and also from the test stand are initiated by multipactor discharges occurring between the coupler center conductor and the ceramic, particularly at the rear of the ceramic.

The possibility that multipactor discharges are promoted due to ceramic charging, or localized heating either by x-ray bombardment or the effects of non-uniform titanium coating on the ceramic has been investigated but has not produced conclusive results. There have also been failures in the test stand during conditioning of new or rebuilt couplers due to pinhole leaks that have developed in the bulk ceramic material, some of which occurred after the coupler was successfully conditioned to 100 kW without incident. While it is suspected that past failures of this nature are related to material defects in the bulk ceramic material used to manufacture a series of coupler windows, subsequent microscopic examination of the failed ceramics has not indicated a specific cause of the leaks.

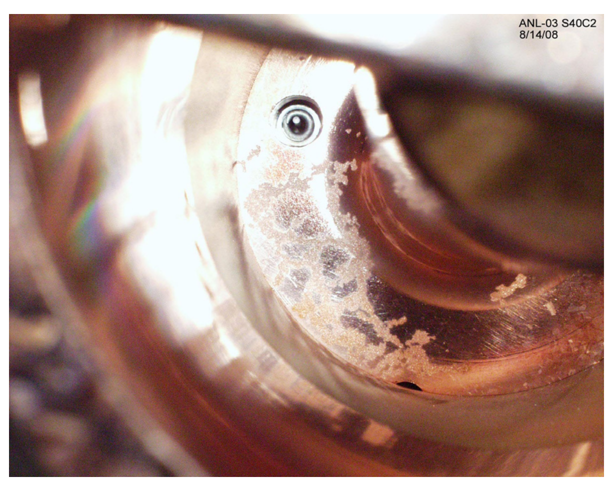

Figure 2: Arcing damage to rear of coupler and center conductor of a storage ring cavity coupler.

Field simulations of the full input coupler assembly and storage ring cavity have been performed using HFSS to determine if a correlation existed between peak field

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levels and locations of coupler and ceramic damage. Figure 3 shows the electric field magnitude along the metallic surfaces of the coupler body as it is mounted to the cavity port. Assuming a nominal rf input power level of 100 kW, the calculated ohmic losses were approximately 250 W. The volumetric loss in the ceramic was 5.3 W assuming a dissipation factor of 2e-4. Although there is some field enhancement on the brazing rings, as shown in Figure 3, the fields and power levels were not considered excessive and were unlikely to be a primary cause of coupler failures.

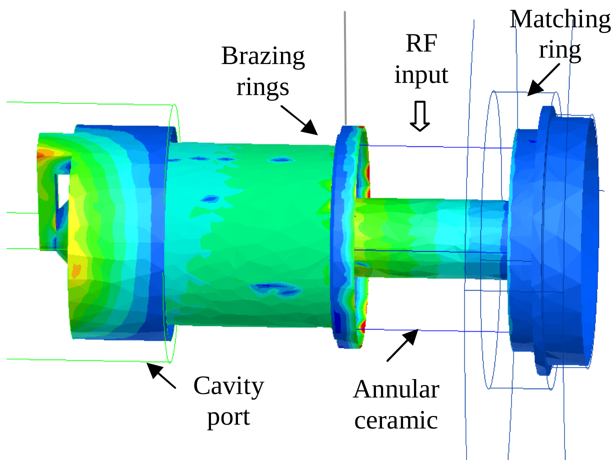

Figure 3: Electric field magnitude along coupler surfaces.

CERAMIC RE-DESIGN

Two versions of re-designed coupler ceramics are presently in production for evaluation to eliminate field enhancement between the ceramic and the brazing rings and to help prevent charge buildup on the ceramic surface. It is suspected that glow discharges seen at the rear of the coupler may be promoted by electric field enhancement caused by a 0.015-inch gap between the end of the ceramic and the waveguide end of the coupler, which results in an abrupt change in dielectric constant between the ceramic material and vacuum in the gap. The details of this gap are shown in Figure 4. The gap is formed by the Kovar brazing ring, which folds over the outer edge of the ceramic but does not continue completely across the ceramic thickness. Television camera images of the coupler taken from an opposing viewport on the test stand cavity have recorded a visible blue glow in the approximate area of the gap on some couplers at approximately 75-kW input power.

The first improvement in the ceramic design being evaluated involves metalizing the end face of the ceramic along its 0.22-inch thickness to prevent field enhancement across the gap. The second utilizes a full-width Kovar ring to fill the gap between the ceramic and the mating surface of the coupler body. Both modifications also result in a conductive path from the ceramic to the coupler body, which will help to alleviate window charging and prevent dielectric breakdown or pinhole leaks. Couplers will be assembled with both versions of the improved

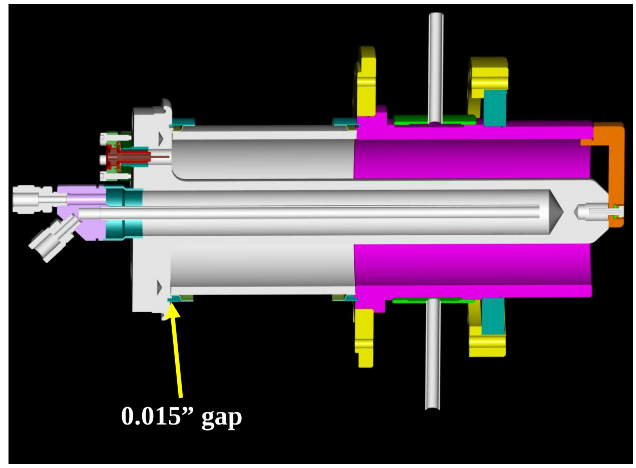

Figure 4: Details of coupler assembly and 0.015” gap at end of the ceramic.

ceramic and evaluated under power conditions in the APS rf test stand.

TITANIUM COATING FOR MULTIPACTOR SUPPRESSION

Titanium coating of the ceramic interior surface has been employed to suppress multipactor. The coating thickness is a nominal 30-50 Å, and was applied to the original couplers installed during APS construction using an on-site coating apparatus that utilized a titanium filament to achieve coating by the sublimation process [1]. The yield of conditioned couplers at that time was nearly 100%, with very few problems noted through the conditioning process at approximately 120 kW cw.

Subsequent coupler production has been achieved using an on-site titanium sputtering apparatus, but the yield of couplers had fallen to almost 60% over time due mainly to failures at power during conditioning. It was suspected that the titanium coating achieved using the sputtering process was either too thin or not uniform, resulting in susceptibility to multipactor. A number of ceramics were titanium coated at SLAC using the titanium-filament sublimation method to evaluate the effectiveness of both coating processes. Initial results based on the conditioning performance of green couplers rebuilt using ceramics coated by the filament-sublimation process indicate positive results, demonstrated by less vacuum activity during the conditioning process.

Another modification being evaluated involves titanium coating the inner conductor and inside outer conductor copper parts of the coupler at a thickness of approximately 100 Å (see Figure 5) to further suppress multipactor. Preliminary results of the first coupler coated in this fashion are favorable, with the coupler reaching 100-kW during conditioning in approximately half the time required for the average coupler and with less vacuum activity. To prevent contamination and deterioration of the titanium coating on the ceramic over time, conditioned spare couplers are now stored under vacuum in flanged canisters.

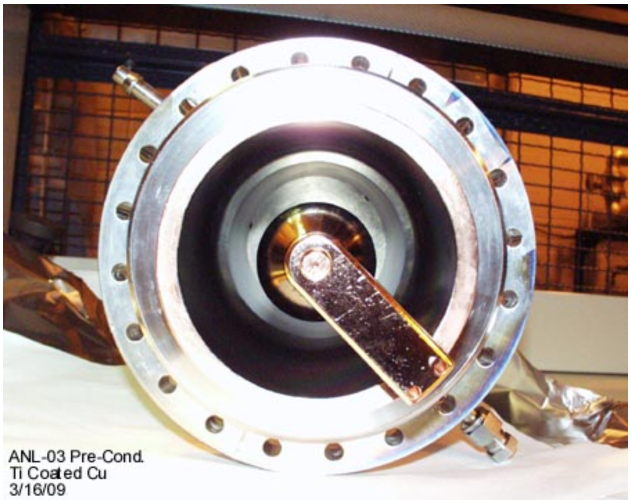

Figure 5: Storage ring coupler with titanium-coated copper center and outer conductors.

IMPROVED CONDITIONING PROCESS

New and rebuilt couplers in the "green" state are routinely conditioned in the 350-MHz rf test stand to 100-kW cw input power using a single-cell cavity identical to cavities used in the APS storage ring. Initial conditioning was performed manually with a test stand operator monitoring vacuum and coupler ceramic temperature and increasing rf power at a rate that the coupler tolerated. The manual process was very labor intensive and often resulted in inconsistent performance from coupler to coupler. An automated conditioning program has been developed that controls the process, monitoring cavity vacuum behavior, coupler ceramic temperature, and other process variables while controlling rf power input to automatically condition the coupler. The program safely mimics human operator responses to specific conditioning events, such as delaying conditioning when certain user-defined parameters are met or restarting and recovering the system to the previous power level in the event of a trip. It responds to variations in cavity vacuum to adjust the rate of conditioning, and monitors coupler ceramic temperature, reflected power, and other essential parameters to prevent stressing the coupler. During known difficult conditioning zones specific to this coupler design, typically in power bands 20-40 kW and 60-75 kW, the automated conditioning program utilizes customized conditioning parameters, such as "pulse mode" with a user-defined schedule to help condition the coupler more quickly and with fewer trips. Figure 6 shows a data plot from a recent coupler using a custom conditioning mode controlled by the program. The automated conditioning process provides more consistent results with reduced manual operator intervention and may operate with minimal oversight for extended lengths of time. In an effort to improve the chances of a green coupler surviving an arc event during conditioning, an optical arc detector has been added to the test stand cavity and is utilized to detect flashes of light inside the cavity. The arc detector removes power from the cavity within approximately 2 μs of the detection of light from an arc, effectively minimizing the arc energy and thereby preventing the coupler ceramic from being coated with copper vapor.

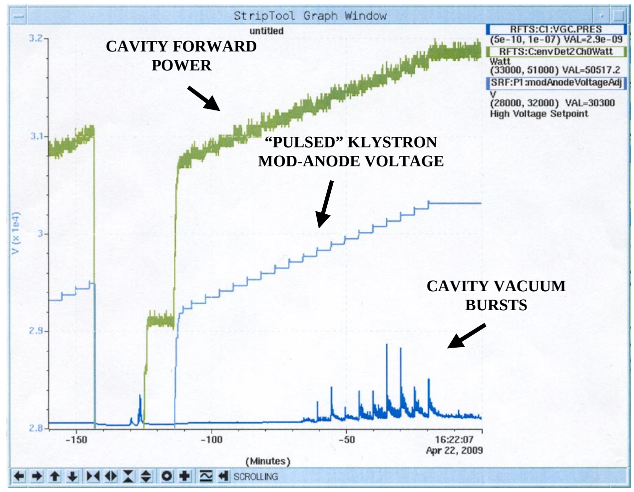

Figure 6: Data plot generated by an automated conditioning process on a coupler.

CONCLUSION

Several design changes on cavity input couplers used at the APS show promise in improving the power handling capability and operational lifetime of the couplers in accelerator service. Since implementation of the automated conditioning script, the yield of couplers through the conditioning process has increased substantially. Data taken during conditioning has indicated that recent tests of different titanium-coating processes on both the ceramic windows and the copper conductors of the coupler show promise in improving the conditioning process and reducing the likelihood of multipactor discharges.

REFERENCES

[1] K. Primdahl, R. Kustom, J. Maj, "Reduction in Multipactor in RF Ceramic Windows Using a Simple Titanium-Vapor Deposition System," Proc. Of PAC95, Dallas, Texas WPP13, p. 1687 (1996); http://www.JACoW.org.