HIGH-POWER TESTS OF A SINGLE-CELL COPPER ACCELERATING CAVITY DRIVEN BY TWO INPUT COUPLERS*

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Abstract

High-power tests were conducted on a 350-MHz, single-cell copper accelerating cavity driven simultaneously by two H-loop input couplers for the purpose of determining the reliability, performance, and power-handling capability of the cavity and related components, which have routinely operated at 100-kW power levels. The test was carried out utilizing the APS 350-MHz RF Test Stand [1], which was modified to split the input rf power into two ½-power feeds, each supplying power to a separate H-loop coupler on the cavity. Electromagnetic simulations of the two-coupler feed system were used to determine coupler match, peak cavity fields, and the effect of phasing errors between the coupler feed lines. The test was conducted up to a maximum total rf input power of 164-kW CW. Test apparatus details and performance data will be presented.

INTRODUCTION

The Advanced Photon Source (APS) storage ring utilizes a total of sixteen single-cell rf cavities capable of generating a combined maximum rf gap voltage of approximately 12 MV at a rated rf power level of 100 kW/cavity and a nominal rf frequency of 351.93 MHz. The possibility of operating fewer cavities at a higher input power was considered as a way to provide extra space for injection and extraction schemes as part of future APS upgrade plans. Operating the storage ring with fewer cavities would call for individual cavity performance beyond what was specified in the original APS design. The decision was made to test the operation of the storage ring rf cavity with two input couplers in order to reduce stress on the couplers due to the higher power operation and therefore improve reliability. The APS 350-MHz RF Test Stand was utilized to perform the test, using a single-cell copper rf cavity, identical to those used in the APS storage ring, which is normally used for conditioning of spare couplers and tuners. Since new and reconditioned input couplers were routinely conditioned to 100-kW CW in the test stand cavity, a goal of 200-kW total rf power into the test cavity was set for this test.

CAVITY SIMULATIONS AND ASSEMBLY

Electromagnetic simulations using HFSS [2] were run on a model of the two-coupler cavity assembly in order to predict the optimum individual match of both input couplers for lowest total cavity return loss prior to assembly of the actual hardware (see Fig. 1). Coupler matching to the cavity during assembly was performed on each coupler individually, with both couplers oriented to achieve the predicted return loss of 7-dB with the opposite coupler terminated with a matched load. Phase delay in the waveguide feeding input coupler #1 was adjusted for 0º phase difference between the two couplers. Low-power tests on the fully-assembled cavity/coupler system confirmed simulation results, achieving a total cavity return loss of better than 20 dB.

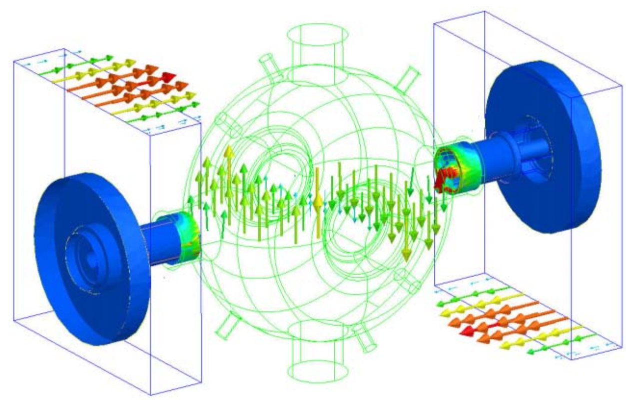

Figure 1: Simulation results of the cavity/two-coupler model showing vector plots of the cavity magnetic fields and properly phased electric fields in the input waveguide feeding each coupler. The contour plot shows the relative power density along the body of the coupler.

The gap voltage in the cavity was calculated to be 1.4 MV given 200-kW input power. Although the maximum transmitted power through each coupler would not exceed their rated value of 100 kW, additional thermal and electrical stress was deposited on areas of the coupler in proximity to the resonant fields in the cavity, such as on the H-field loop and nearby conductors (see Fig. 1).

TEST SYSTEM

Figure 2 shows a diagram of the two-coupler test system. Input power to the cavity is supplied by a WR2300 transmission system that includes a 3-dB, 90° hybrid to generate two ½-power feeds for each coupler, and mechanical phase shifters in one feed to optimize phase between the input couplers. A 300-kW water load is utilized as a terminating rf load for the hybrid. Directional couplers were installed at key points in the system to determine VSWR and power balance.

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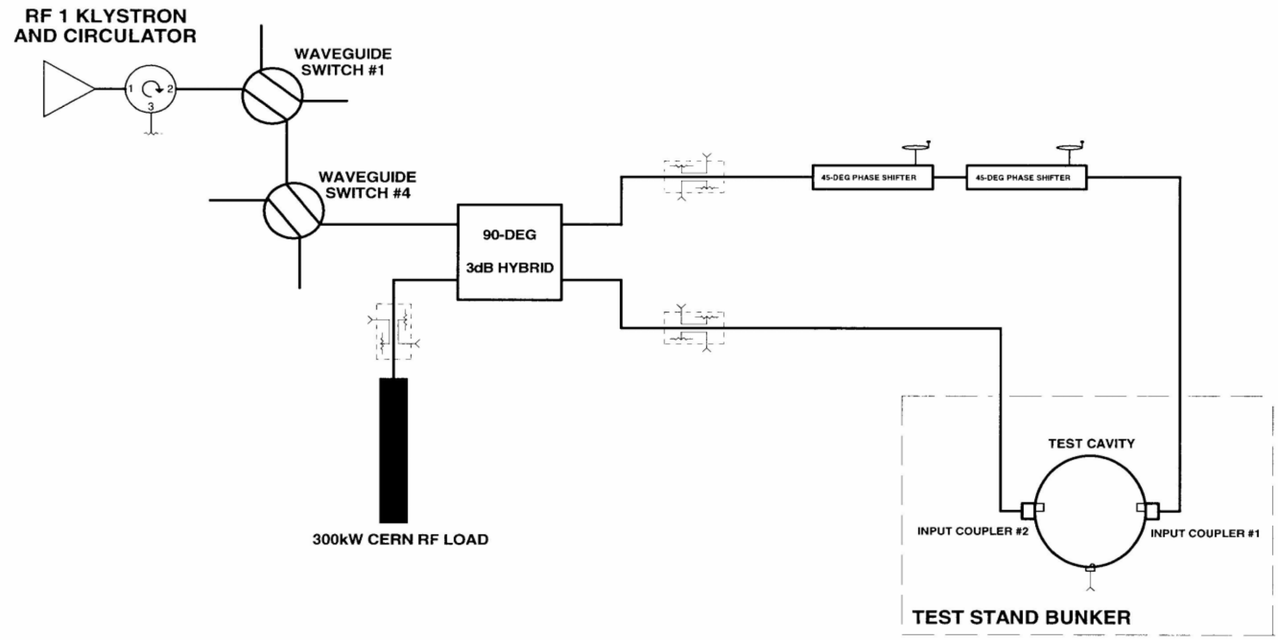

Figure 2: The two-coupler test system.

Figure 3 shows a drawing of the dual-feed waveguide system, including the hybrid and terminating load, and Figure 4 shows a photograph of the actual waveguide installation. The waveguide transitions to a ½-height WR2300 waveguide just prior to penetration through the bunker roof to reduce the aperture for x-ray shine from the cavity during operation. Figure 5 is a photo of the actual single-cell rf cavity fitted with two input couplers. Cavity resonance was maintained with a motor-driven piston tuner. All components in the test cavity assembly were previously conditioned to 100-kW CW to reduce the chance of unknown conditioning problems during the test.

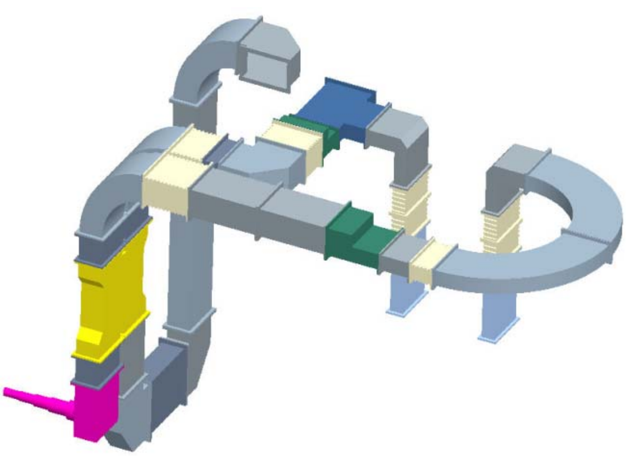

Figure 3: Drawing of the dual-feed waveguide system.

TEST PERFORMANCE

Operation of the test system began with few problems, with the cavity vacuum responding normally to power increases. The cavity input power was increased at a rate of approximately 5 kW per day, governed by the vacuum response.

Figure 4: Photo of waveguide system showing 3-dB hybrid and 300-kW reject load installed on test stand bunker.

Because the test stand bunker served as a radiation shielding component and was modified for this test with a second waveguide penetration, the x-ray shielding effectiveness of the bunker had to be re-validated during the test. This validation was carried out by performing manual radiation measurements around the outside of the bunker during the test at 10-kW increments in total cavity input power. Additional measurements were made continuously on the top of the bunker using remote-reading radiation monitors that were located near the waveguide penetrations. At approximately 60-kW total input power, the test was interrupted due to a vacuum leak that developed and was traced to the ceramic window on one of the input couplers. This failure was identical to that of several previous input couplers that had developed pinhole leaks in the rf window ceramic, possibly due to imperfections in the ceramic material. The leaking coupler was replaced with another pre-conditioned coupler, and the test was restarted. Operation with this coupler was much smoother, with power increases averaging approximately 10 kW per day. At approximately 105-kW total input power, the tuner piston return water temperature began to reach the interlock trip point of 45ºC, so operation was paused to increase water flow to the tuner piston and cavity by 50% and 5%, respectively. In response to higher than expected x-ray levels measured on the bunker roof, additional lead shielding was installed at the waveguide penetrations.

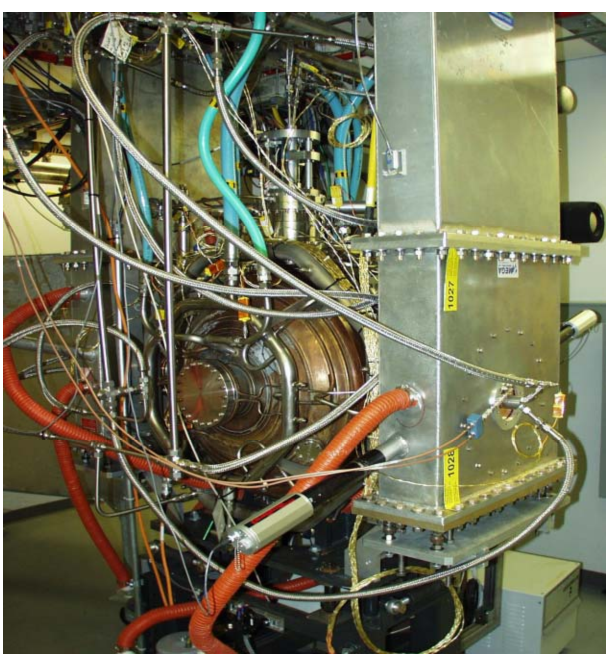

Figure 5: Photo of test cavity fitted with two input couplers.

Input power was steadily increased with little trouble. Above 100-kW total power input, the cavity center copper temperature increased at a rate of approximately 0.31ºC/kilowatt of input power. The maximum sustained total cavity input power achieved was 163 kW, resulting in a cavity center copper temperature of 81.2ºC, forward/reflected power readings from each coupler of 74.8kW/0.41kW and 73.8kW/1.31kW, 249 watts dissipated in the hybrid reject load, and 3 kw of reflected power at the input port of the hybrid. The additional reflected power at the input of the hybrid was attributed to the accumulated mismatch of the waveguide components in the transmission system. Remote-reading x-ray radiation monitors measured approximately 17-24 mr at the waveguide penetrations on the bunker roof. Immediately after a power increase to 164 kW, a large vacuum event occurred in the cavity, which interrupted operation. When the vacuum recovered and rf power was re-applied to the cavity, an increase in ceramic temperature in one of the input couplers was noted, indicating that an arc had occurred in or near that coupler, resulting in copper deposition on the ceramic. Operation was continued at increasing power levels in an attempt to re-condition the hot coupler and lower the ceramic temperature, which met with considerable success, eventually reaching a total cavity input power of 130 kW. The test stand was then shut down at the start of a scheduled APS maintenance period.

CONCLUSION

Operation of the APS cavity with two input couplers at 200-kW CW total input power is promising and should improve reliability over the single-coupler design. At this time it is suspected that the input couplers may be the limiting factor in power handling capability due to problems with the ceramic titanium coating. The cavity and couplers will be visually inspected at the completion of this test to determine where stresses are greatest. Additional radiation shielding may be required when operation at total cavity input power levels greater than approximately 120 kW is expected.

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REFERENCES

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[2] Ansoft HFSS, version 8.5, Ansoft Corporation, Pittsburg, PA, USA, June 2002.

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