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A U.S. Department of Energy laboratory managed by The University of Chicago High-Power Testing of a Normal-Conducting Single-Cell Copper RF Cavity Utilizing Two Input Couplers

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Presentation Outline

- 1. Purpose of the Two-Coupler Test
- 2. Test System Description
- 3. Test Results
- 4. Conclusion



Purpose of the Two-Coupler Test

- 1. Determine if the existing APS single-cell NC copper cavity hardware can operate reliably at 200kW CW input power.
 - → The proposed APS ERL upgrade may require elimination of some storage-ring rf cavities to make room for additional injection and extraction hardware. The power required to support 7GeV Storage-Ring operation will then exceed the original cavity and coupler specifications:

<u>Cavity: 150kW CW with 100mA stored beam</u> <u>Input coupler: 250kW CW with 300mA stored beam</u>

→ APS operation has shown that 100kW CW is the practical limit for input coupler power handling capability under no-beam conditions.



Purpose of the Two-Coupler Test

- 2. Identify potential problems related to operating the existing cavity design with two input couplers at greater than 100kW CW:
 - Cavity thermal load
 - Tuner rf power dissipation
 - Radiation shielding
 - Input coupler matching and isolation
 - Input power 3dB split methodology



- The APS 350-MHz RF Test Stand was utilized to perform the test, with some modifications to accommodate a second input coupler:
 - → Additional cooling water and related interlocks
 - → Additional arc detector and IR temperature monitor

→ A second WR2300 ½-ht waveguide feed



Photo of Test Stand Cavity with Two Input Couplers



- Electromagnetic simulation tools were used to model the two-coupler system
- → 0° relative phase at input couplers for maximum rf power input to cavity
- → Determined proper match for each coupler to achieve lowest overall cavity return loss
- → Simulation indicated ~ 1.4MV rf gap voltage at 183kW CW input power



Very good agreement between cavity system model and real system



- RF power provided by RF1 in "Test Stand" mode
- WR2300 full and half-height waveguide

RF 1 KLYSTRON AND CIRCULATOR

- Half-height waveguide phase shifters used on one coupler feed to optimize phase
- Maximum test rf power is 200kW CW at the input to the splitting hybrid



WAVEGUIDE SWITCH #1



INPUT COUPLER #1

- Full-height WR2300 hybrid used for power splitter
- Transition to ½-height WR2300 waveguide for penetration through bunker roof and connection to cavity input couplers
- A second waveguide penetration was cut into the test stand bunker roof





 Cutting the second waveguide penetration into the test stand bunker roof required significant safety and engineering analysis to secure approval, as the bunker is a radiation safety system.





Photo of second waveguide penetration

Test Stand as Built File: stsstd5



• Photos of Test Stand Waveguide System



3dB Hybrid Splitter, Directional Couplers, and 300kW Reject Load



Two WR2300 Waveguide Shutters At Input of Hybrid



Radiation generated by the cavity was a concern

- → Test stand bunker shielding was certified to 100kW cavity rf input.
- → Bunker roof was off limits during operation.
- → Radiation monitors were installed to measure radiation at waveguide penetrations to eliminate the need for manual radiation surveys on the roof.
- → Health Physics surveys of the test stand area and Building 420 roof were part of the test plan.



Radiation Monitors on Test Stand Bunker Roof



- Test Started on December 15, 2006 with low-power checkout of system:
 - → Cavity conditioned to ~ 1kW within eight minutes
 - → Coupler match and power
 balance looked good:
 Coupler #1 = 397W fwd/36W ref
 Coupler #2 = 440W fwd/6W ref
 Hybrid load power = ~ 9W
- Test resumed on December 18, increasing power with normal cavity conditioning behavior.





- Power increases continued with normal conditioning response until strange vacuum activity started at ~ 35kW......
 - → Repeated rf trips on very unusual vacuum bursts
 - → Vacuum would recover abnormally fast (as if infinite conduction)
- We struggled on, but the test was finally stopped at ~ 90kW due to a large vacuum event, followed by poor cavity vacuum.
 - → Vacuum never recovered from low 8's with rf off (leak suspected)





• The cavity was leak checked, <u>and a pinhole leak was</u> <u>detected in the coupler #2 ceramic window</u>.

→ Identical to previous coupler failures (This coupler had been previously conditioned to 100kW CW in the test stand!)

 \rightarrow Defective ceramic suspected

 \rightarrow The failure was unrelated to the Two-Coupler Test

• The defective coupler was replaced with another preconditioned spare coupler, and the test was re-started.



- After the leaking coupler was replaced, steady progress was made.....with a few minor difficulties:
 - → Arc in coupler #2 at ~ 140kW resulted in elevated ceramic temperatures due to copper deposition
 - → Elevated cavity and tuner temperatures forced an increase in cooling water flow and interlock trip points
 - → Higher than anticipated radiation levels from the cavity resulted in a delay to allow additional analysis of the test stand roof shielding!





<u>Radiation Shielding Analysis</u>

→ Radiation from cavity exceeded calculated estimates scaled from 100kW levels:

RF Power Input	Radiation Level at Waveguide Penetrations	
100kW	1.37mr	
130kW	7.4mr	
150kW	21mr	
170kW	44mr	

An experiment was devised with the radiation monitors to determine the effectiveness of an additional 0.25" of lead shielding on the bunker roof.



 One of the bunker roof radiation monitors was fitted with a lead cylinder over it's probe to determine the attenuation provided by 0.25" of lead:

Cavity RF Power Input	Radiation Level at Waveguide Penetrations	
	naked probe	0.25" Pb shielded probe
170kW	44mr	4.1mr

This test indicated that 0.25" of additional lead shielding on the bunker roof would reduce "skyshine" radiation from the cavity to acceptable levels



• <u>Slow and steady progress was</u> <u>made until 200kW was finally</u> <u>reached!</u>

- → No significant vacuum events above 150kW.....cavity conditioned very well and displayed remarkably calm response to power increases! (vacuum interlock trip point is 5E-8 torr)
- → Elevated coupler ceramic temperature due to previous coupler arc
- → 200kW held for ~30 minutes while data was taken





• FINAL 200kW TEST DATA

Total Cavity Input Power = 200.41kW fwd / 10.79kW ref Coupler #1 Power = 93.19kW fwd / 4.18kW ref Coupler #2 Power = 97.31kW fwd / 2.61kW ref Hybrid Reject Load Power = ~ 450 watts Cavity Vacuum Pressure after 30 minutes at 200kW = 1.1E-8 torr Cavity Center Temperature = 90.52° C (temp rise ~ + 0.314° C/kW RF) **Downstream Tuner Flange Temperature = 101.6°C** Tuner Piston Return Water Temperature = 39.3°C Radiation Level on Bunker Roof at Waveguide Penetration = 85.6mr



Two-Coupler Test Conclusion

<u>The APS Single-Cell RF Cavities Can Operate at 200kW</u> <u>CW Input Power</u>

- → The cavity conditioned very well to higher power (vacuum base pressure greatly improved)
- → Two input couplers will be required, but standard couplers are ok
- → Increased water flow to cavity and tuner will be required
- → Additional radiation shielding may be required around waveguide penetrations





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