

HIGH-POWER TESTING OF RF CAVITIES FOR THE PEP-II B FACTORY*

R. A. Rimmer, LBNL, 1 Cyclotron Road, Berkeley, CA 94720, USA

M. A. Allen, K. Fant, A. Hill, M. Hoyt, J. Judkins, M. Neubauer, H. D. Schwarz, SLAC, Stanford University, Stanford, CA 94309 USA

Abstract

We describe the process of conditioning and high-power testing of RF cavities for PEP-II. Procedures for vacuum assembly, bakeout and automated processing are described. Interlocks and safety precautions for protection of equipment and personnel are discussed and performance data of tested cavity assemblies are reported. Performance of ancillary components such as windows, couplers and tuners is also discussed. Comments are included on handling, alignment, installation and commissioning issues where appropriate.

1 INTRODUCTION

The RF system for the PEP-II asymmetric B factory [1] uses 26 copper accelerating cavities to replenish the energy lost by the beams as they circulate in the high- and low-energy storage rings. The high-energy ring (HER), requires 20 cavities powered by five 1.2 MW klystrons. The low-energy ring (LER), which requires less voltage but more beam current, uses 6 cavities and 3 klystrons. Each cavity is installed on a raft along with all of the ancillary components, window, coupler, tuner, HOM loads, etc., and each completed assembly is individually power tested and conditioned in a dedicated test stand before installation in the tunnel. This reveals any possible faults before installation and greatly simplifies station commissioning in the rings because the pre-conditioned cavities can be brought back up to operating power in a short time.

2 CAVITY PREPARATION

Each cavity is cleaned for UHV operation, including a final mild chromic acid etch, and delivered to the assembly clean room filled with dry nitrogen to minimize reoxidization of the surface. Care is taken in the cleaning process to remove any particulates, high-points and evaporated coating from the final e-beam welding processes, which take place inside the cavity.

Vacuum assembly takes place in a class 100 clean room with a constant nitrogen purge through the chamber and care is taken to minimize the ingress of dust or contaminants. All openings are flanged off or covered with clean aluminum foil unless otherwise required for

assembly. The HOM loads, tuners, coupler, window, ion pump, vacuum gauge, pick-up loop and view-port flanges are all fitted at this stage, see figure 1, and the assembly is leak-checked with helium before moving to the bake-out oven.

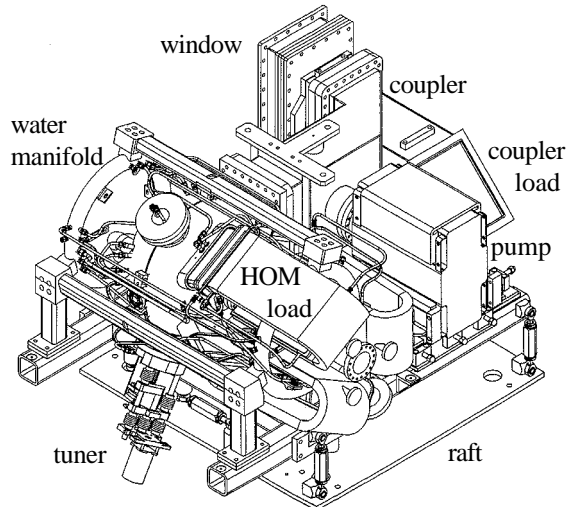


Figure 1. HER cavity raft assembly.

The completed raft assembly is installed in a panel oven with radiant heater elements that are shielded to prevent direct illumination of the cavity. The hot air is circulated with a fan to minimize temperature gradients within the cavity assembly and reduce the chance of vacuum leaks due to differential expansion of flanges. The oven follows a programmed ramp up to 155°C at 5°C/hour or slower if the vacuum pressure exceeds 2×10^{-6} Torr, see figure 2.

The temperature is held until the pressure stabilizes at less than 5×10^{-7} Torr and then ramps down at 5°C/hour. The base pressure at room temperature after bakeout is usually less than 5×10^{-9} Torr. The window and coupler flanges are retorqued after baking.

3 RF CONDITIONING

The baked cavity assembly is then made ready for high-power testing by fitting the water pipes, thermocouples and tuner actuator. The raft is installed in the test bunker and hooked up to the deionized water supply, which is stabilized at 35°C. The bunker is a concrete vault with a lead lined door and safety interlocks, including a search sequence, to prevent possible exposure

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of personnel to radiation during processing (the cavity produces low-levels of X-rays during processing and significant radiation from dark current at high fields). The power source for RF processing is a 500 kW PEP-I type klystron, rebuilt and retuned to operate at 476 MHz, and protected by a circulator. Processing of the cavities is controlled by a Macintosh™ computer running Labview™ software. Fast interlocks for vacuum pressure, klystron reflected power and arc detectors (window and cavity) are hard-wired into the test stand "crowbar" circuit, along with those interlocks required to protect the klystron and the Personnel Protection System (PPS) interlocks from the bunker.

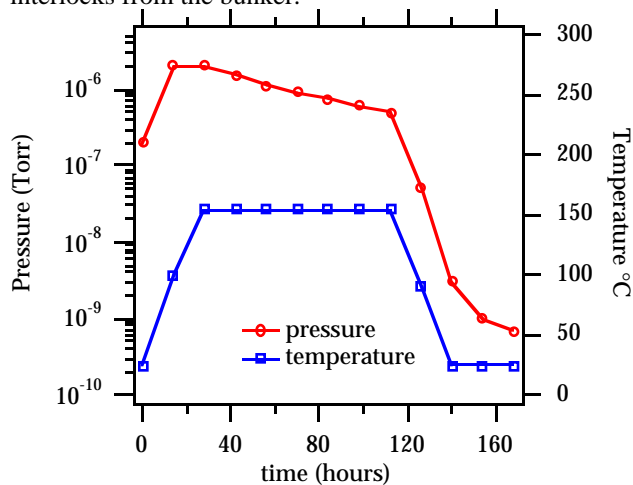


Figure 2. Typical cavity bakeout profile.

The computer can control the RF drive level to the klystron and monitors the cavity vacuum, cell voltage, forward and reflected power, window and body temperatures and turns off the drive if they go outside of acceptable ranges. It also registers which interlock signal triggered first in the event of a station trip. The interlock status can be reset from the computer but this is not done automatically for safety reasons. The RF source is a signal generator that can be operated in continuous wave (CW) or frequency modulated (FM) modes. The test stand can be operated manually from the computer interface or the cavities can be processed automatically by the control program. The computer interface can be monitored or controlled remotely (with password protection).

The initial conditioning of the cavity is done with FM sweeping about the cavity resonant frequency. This allows controlled outgassing of the cavity and processing through various multipactor levels with less risk of breakdown than in CW operation. FM sweeping achieves similar results to amplitude modulation (AM) with low duty factor, but is easier on the klystron since it produces a constant output. The power reflected from the cavity off resonance ends up in the circulator water load. Most FM processing is done with a 320 kHz frequency deviation at a 1 kHz sweep rate, although a 640 kHz deviation, 400 Hz rate is sometimes used to scrub out residual gas (this

covers a wider range of voltages and moves slightly more slowly through resonance giving a longer pulse length). The vacuum interlock is set to trip the station off at 5×10^{-7} Torr to prevent operation at high power with bad vacuum, which may be hazardous to the window. The automated processing algorithm slowly ramps up the drive power while keeping the vacuum pressure below a pre-set threshold, usually on the low 10^{-8} Torr scale. The gas is typically evolved in small bursts and by using a suitably slow ramp rate these can usually be kept below the trip level. If the vacuum goes above the user set-point the drive level ramps down and the vacuum quickly recovers. Once the pressure is good again the upward ramp resumes. Occasionally a larger gas burst or other fault will trip off the station and this must be manually reset by the operator.

Once the cavity has been conditioned through the low-voltage regime, where a lot of multipactor-induced outgassing occurs, the amplitude will usually increase more quickly until the maximum cell voltage required is attained. This is generally set a little higher than the desired CW operating voltage. This maximum FM amplitude is maintained until the vacuum pressure drops to a suitably low level, usually on the mid 10^{-9} Torr range. The base pressure without power at this stage is usually on the low 10^{-9} Torr scale.

Once FM processing is complete the source is switched to CW at 476 MHz and the auto processing loop ramps up as before. The vacuum threshold is usually set lower in this case (e.g.: 1×10^{-8} Torr), because of the increased power available in case of breakdown. A tuner feedback loop keeps the cavity on resonance.

During CW processing at high power there is occasional arcing in the cavity or the coupler which is picked up by photo-diode detectors which trip the RF power off within 15 μ s to prevent damage. Occasional arcing appears to be a normal part of high-power conditioning as small surface imperfections or dust particles are burned off and the frequency of arcs should decrease with processing. Persistent arcs in the cavity may indicate a more serious problem and repeated arcs or glowing at the window may indicate a defective or contaminated window coating.

A TV camera is used in the bunker to observe the movable tuner through a small viewport in the cavity. Occasionally some glowing in the tuner gap, outgassing with tuner movement or small incandescent sites on the wall of the cavity are observed during processing [2]. These generally diminish or disappear with time and do not appear to limit cavity performance.

Once full operating power has been achieved this level is held constant while the vacuum improves. Occasional arcs or gas bursts may trip off the station but the cavity can usually be brought back to full power very quickly, and the frequency of such trips generally decreases with running time. The cavities are processed in

the test stand until they can run for at least 24 hours without tripping. Reliability is expected to continue to improve with operation in the accelerator. Figure 3 shows the conditioning history for a typical HER cavity. Because of time lost to trips etc., the conditioning process usually takes about a week.

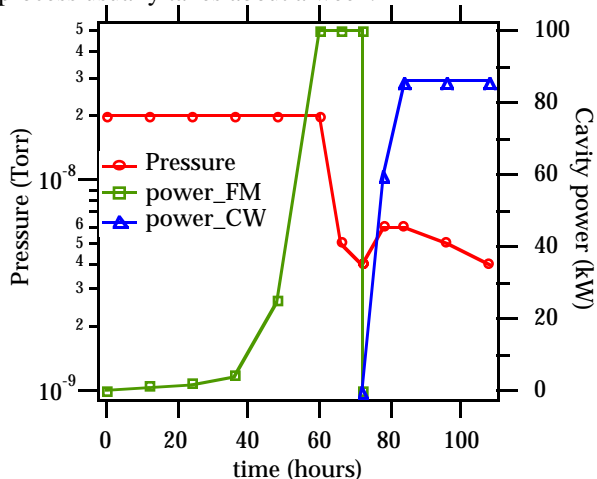


Figure 3. Typical HER cavity processing history

4 CAVITY PERFORMANCE

All of the 12 cavities tested so far have been successfully processed to the HER commissioning voltage of 800 kV (about 86 kW wall dissipation), or above in a reasonable time. About 700 kV per cavity will be required for normal HER operation. Some cavities have been processed up to LER voltage (850 kV, 103 kW), which takes a little longer but otherwise appears to be straightforward. The cavities were designed for a maximum of 1 MV at 150 kW dissipation.

The windows have all performed well, with temperature rises in the ceramic of 17 to 24 °C at HER power levels. One cavity assembly exhibited some air-side window arcing, possibly due to charging of the ceramic, but this conditioned away with further FM processing. All of the tuners have behaved well at full operating power with no sparking at the spring-finger contacts.

5 TUNNEL INSTALLATION

The tested RF cavity raft assemblies are delivered to the tunnel under vacuum, installed in the straight-sections, connected to the waveguides and the water supply and aligned using a six-strut support system. The cells are continuously purged with dry nitrogen while the connections are made to the neighboring vacuum chambers.

The cavity pick-up loops are connected to the low-level RF electronics upstairs via calibrated low-loss cables and the length of each arm of the waveguide network is adjusted to achieve the correct phases at the cavities.

6 STATION COMMISSIONING

Once the PPS interlocks for the tunnel are made up the RF cavities can be energized. The high-voltage power supplies are previously tested up to full power with the klystron output going into water loads. Once the stations are connected to the cavities a processing algorithm similar to that used in the test bunker is used to bring them back up to operating power levels. So far the first two HER stations (8 cavities) have been successfully commissioned. In the normal case of a controlled vent for installation this happens quickly, however if the cavities are accidentally exposed to tunnel air then several days of re-processing are required. The cavities appear to recover completely from such exposure although the long term effects, if any, on the cavity or window performance are not yet known.

7 CONCLUSIONS

The processes for cavity cleaning, bakeout and automated conditioning have been shown to be effective in achieving operational levels of performance in a reasonable time. Testing, installation and commissioning of high-energy ring cavities is proceeding smoothly and production of the remaining HER and LER raft assemblies is expected to continue in this vein. Careful bakeout following a prescribed temperature profile and with a sustained hold at greater than 150°C has proven valuable in speeding conditioning time compared to previous unbaked examples [3], especially with regards to window performance. Processing with FM sweeping to peak voltages above those required for operation allows for the controlled evolution of gas with minimal breakdown and safe window operation and permits rapid processing in CW mode with good vacuum.

8 ACKNOWLEDGMENTS

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