

## High-Power Testing of the First PEP-II RF Cavity

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## HIGH-POWER TESTING OF THE FIRST PEP-II RF CAVITY\*

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### Abstract

This paper describes the high-power testing of the first RF cavity for the PEP-II B-factory. The cavity is designed for continuous operation at 476 MHz with up to 150 kW wall dissipation and heavy beam loading. Three rectangular waveguides and broad-band loads are used to damp the cavity higher-order modes. The test configuration, RF conditioning history and high-power performance are described and plans for processing of the production run of cavities are discussed.

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## 1 INTRODUCTION

The PEP-II B factory is a machine designed to achieve a high integrated luminosity through the use of many bunches and high average current in both rings. This requires a substantial RF system capable of simultaneously delivering a high voltage and large beam power with high reliability. The PEP-II RF system employs single-cell copper cavities [1] with strong HOM damping, designed to deliver up to 1 MV per cell with 150 kW maximum wall dissipation. Each cell will be assembled with its ancillaries and pre-tested on a raft, as in figure 1, before installation in the tunnel. The high-energy ring (HER), will use 20 cavities powered by 5 klystrons, with 6 cavities and 3 klystrons in the low-energy ring (LER). The nominal operating parameters are shown in table 1.

## 2 CAVITY TESTING

The first high-power PEP-II RF cavity has been tested to above operational power levels in several phases. The first phase tested only the cavity body, with a simplified coupler, fixed tuners and no HOM waveguides, in order to validate the basic design. Subsequent phases tested in addition a full input coupler, movable tuner and HOM load. The tests were performed in a new bunker using an existing 500 kW test stand. The first tests were conducted before the completion of the cavity bake-out station and so required longer processing. Subsequent tests were conducted after bakeout or controlled vents.

## 3 RF CONDITIONING

The first phase of the cavity testing was performed after final cleaning but with considerable exposure to atmosphere during handling and assembly. No bake-out

was performed as the production cavity bake station was not yet completed and no suitable alternative was available. This prolonged the processing time for the first test as a large quantity of gas was evolved as soon as RF was applied. During this period the drive signal was frequency modulated (FM), to sweep back and forth through the cavity resonance in order to process away the gas in a controlled manner. About 72 hours of FM processing was required before more than a few kW of CW power could be applied to the cavity, see figure 2.

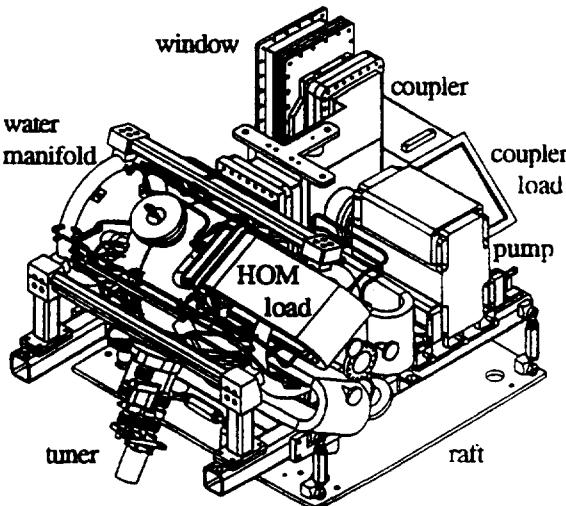


Figure 1. High-power cavity raft assembly

Table 1: PEP-II RF parameters.

	HER	LER
total voltage	14 MV	5.3 MV
total RF power	5.3 MW	2.6 MW
beam current*	1.03 A	2.25 A
number of cells	20	6
voltage per cell	700 kV	850 kV
cavity wall pwr	70 kW	103 kW
power per cell†	256 kW	413 kW

\* including the effect of a 5% gap in the beam

† after waveguide losses

The cavity then quickly processed up to about 40 kW, after which amplitude modulation (AM), of the drive at the resonant frequency was used to condition up to HER operational power levels. This was achieved after about 160 hours, however intermittent tripping of the station due to cavity or window arcs accompanied by strong outgassing suggested that further processing was required. The test was run for a further 50 hours before the test stand was shut down for a scheduled klystron test, which

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could not be conducted concurrently. Before the shut-down the frequency of the trips had decreased but they did not cease altogether.

When the test stand was once again available high power processing was resumed and operation at above the nominal power level of both rings was demonstrated, see figure 3. After this the frequency of arcs at the nominal settings was greatly reduced. The cavity ran as high as 125 kW but it was not possible to test to the full design power of 150 kW because of the failure of a temporary fixed tuner which had poorly cooled spring finger contacts.

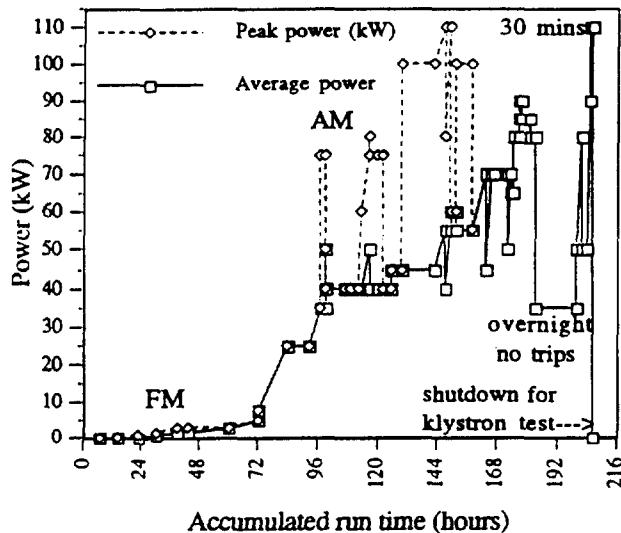


Figure 2. Phase 1 cavity test processing history, part 1.

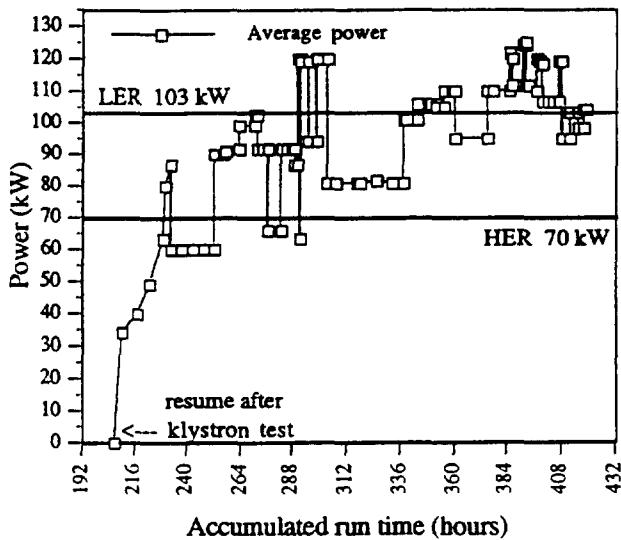


Figure 3. Phase 1 cavity test processing history, part 2.

The second phase of testing introduced more of the high-power components that will be installed on the production cavity rafts. These included a production coupler box and window module, one HOM load and a

pre-production movable tuner. This time the cavity was baked to approx 140 °C for 24 hours, which considerably improved the vacuum pressure and reduced the initial processing time. The cavity was FM processed up to about 70 kW peak power with controlled outgassing, at which point the modulation was gradually decreased until CW operation was possible. The CW power was then increased slowly to 120 kW with intermittent trips due to cavity arcs accompanied by further outgassing (FM operation was limited to less than 80 kW because of a temporary load on the circulator which has since been replaced with a 500 kW unit). At high power levels some arcing was observed in the movable tuner spring fingers, which were of an experimental high-conductivity (low beryllium content) copper alloy. This was observed with a TV camera through a viewport directly opposite the tuner. The arcing was most prominent when the tuner was in motion, often triggering a breakdown of the cavity field and tripping the station off. Suspecting that the spring fingers might have been improperly bedded in, the tuner was cycled overnight without RF. However when power was re-applied the arcing was much worse and the test stopped so the tuner could be removed and inspected. Some of the spring fingers were found to have failed and there was evidence of arc damage to the tuner and inside the tuner port. The movable tuner was replaced with a fixed tuner from the production cavity inventory and after this vent to dry nitrogen processing was resumed. The cavity was quickly processed back up to 120 kW and briefly tested to 150 kW, corresponding to slightly more than 1 MV in this configuration. Subsequent operation at the nominal 103 kW level was quite stable although occasional small arcs in the cavity were still visible.

A modified movable tuner was tested which used two rows of spring fingers each having half the contact pressure of the previous design. This worked better, however some mechanical problems were still experienced with the fingers. The tuner has now been redesigned to use a high-precision external alignment fixture and Glidcop® fingers of a different shape.

#### 4 WINDOW PERFORMANCE

The cavity window performed well during these tests, with only a few arc trips during conditioning. No glowing was observed and the temperature, measured with an infrared monitor, remained low. Figure 4 shows the time response of the window and body temperatures to a step increase in power of 110 kW. The copper body stabilizes in a few minutes while the temperature of the window takes at least half an hour to reach equilibrium.

The electric field at the window with 120 kW cavity dissipation is equivalent to 465 kW throughput into a matched load (the cavity is mismatched with no beam). The field at the window is effectively tied to that in the cavity gap, due to its location at a detuned-short position, so increased power due to beam loading in the machine should not increase the power loss in the ceramic although there will be an increase in ohmic losses in the metallization and copper-plated flange due to the increase in waveguide magnetic field. This will cause a small increase in temperature between the edge of the window

and the water channel due to the thermal resistance of the flange material. The PEP-II RF cavity windows have been designed for 500 kW operation and tested to full power into a matched load in a separate experiment [2].

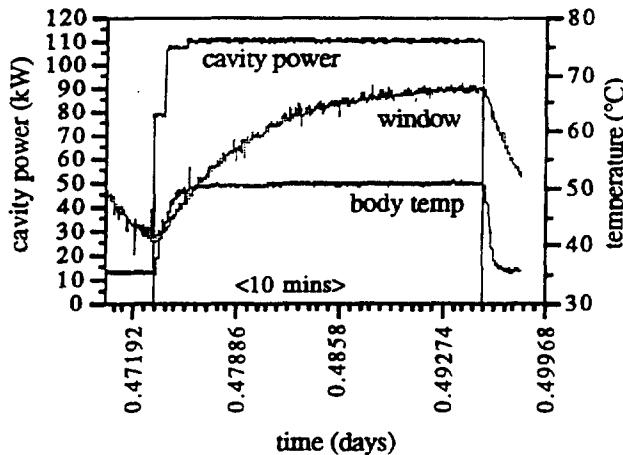


Figure 4. Window and body temperature at high power.

## 5 PRODUCTION TESTING PLANS

The testing of the first high-power cavity was useful in developing procedures for assembly and test of the production run of cavities starting this summer. A new clean room was assembled and all major assembly work will be performed in this area. Controlled venting in the bunker to change small components such as pickups or tuners, with a constant purge of dry nitrogen, was shown to be acceptable. The cavity conditioning recovered quite quickly after such activity. Any major reassembly will require moving the cavity back into the clean room. The bake-out process was shown to be beneficial in speeding up cavity conditioning and it is planned to bake all of the production units to 150 °C before high-power testing. This will help to outgass the ceramics of the HOM loads and the window as well as cleaning up the metal surfaces. It is important to control the rate of temperature increase and the uniformity of temperature in the oven to minimize the stresses on flanges and the window, so the ramp rate will be slow and a stirring fan has been included to circulate the air in the oven. The cavity assembly will also be instrumented with thermocouples to monitor the temperature distribution.

Two dedicated panel ovens have been built so that one cavity may be in the process of installation or removal while another is in bake. This will help to prevent a backlog forming, since the bake-out is one of the more time consuming steps in the assembly process.

A system has been developed which allows for automatic processing of the cavities under computer control. The test stand can be operated manually and all essential safety interlocks are handled in hardware, but the drive level to the klystron can be controlled by the computer in response to various operating parameters. A control and monitoring system has been implemented using the Labview™ package on an Apple Macintosh™ platform using National Instruments I/O cards. This system has been used to automatically ramp up the

amplitude during RF conditioning with frequency modulation while keeping the pressure to below a fixed level. The program monitors the vacuum pressure and turns down the RF drive to the klystron if the pressure rises too high. Once the pressure recovers the drive is ramped up again at a controlled rate. Figure 5 shows a typical automated voltage ramp after a controlled vent to nitrogen. The system also monitors various temperatures including the window, and logs all the parameters to disk.

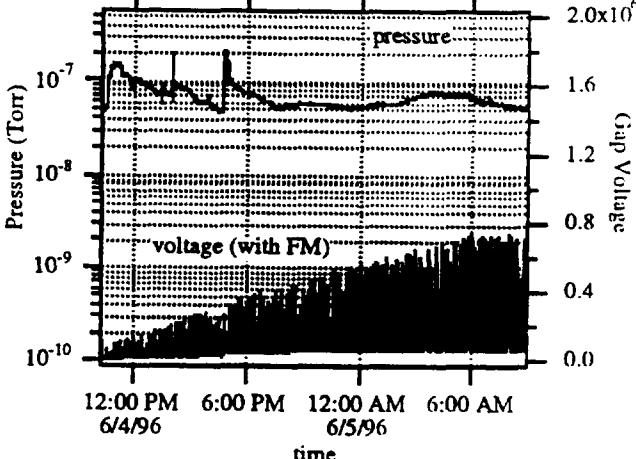


Figure 5. Recorded data from automated RF processing with FM after a controlled vent.

## 6 CONCLUSIONS

The first high-power cavity has been tested both in a basic configuration and with various production-cavity ancillaries attached. Power levels above those required for operation of either ring have been demonstrated, and the cavity body itself has been tested briefly to its full design power and voltage with no ill effects. Bake-out has been shown to be beneficial to the speed of processing, and FM modulation about the resonant frequency has been demonstrated as an efficient method for controlling the evolution of the remaining gas during conditioning.

As with other machines some problems have been experienced with spring-finger contacts in the tuners due to the high circulating currents and these are being addressed with an improved finger design and better materials and alignment.

The window assembly has performed successfully to above the highest field levels it will be expected to see in operation. Increased power due to beam loading in the machine should not increase the power loss in the ceramic although there will be a small increase in temperature from ohmic losses in the metallization and flange due to the waveguide magnetic field.

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