SLAC-PUB-7852
June 1998

Commissioning of the PEP-II High Power RF Systems

R. A. Rimmer *et al.*

Contributed to 6th European Particle Accelerator Conference (EPAC 98),
Stockholm, Sweden, 6/22/98 - 6/26/98

Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309

Work supported by Department of Energy contract DE–AC03–76SF00515.

COMMISSIONING OF THE PEP-II HIGH POWER RF SYSTEMS*

R.A. Rimmer, LBNL, Berkeley, CA, USA
M. Allen, P. Corredoura, A. Hill, M. Hoyt, J. Judkins, M. Neubauer, H. Schwarz, R. Tighe
SLAC, Stanford, CA, USA

Abstract

We describe the commissioning of the high-power RF stations for the PEP-II B factory. This includes in-situ testing and conditioning of components after installation, phasing of cavities within each station and between stations in each ring, capture of first beam, stored-beam operation at low- and moderate- current, commissioning of feedback loops, and high-current operation. Performance of the overall system and of critical components such as klystrons, cavities, windows, tuners and the HOM suppression scheme is reported. Observation of beam motion and signals in the cavity and HOM loads suggest that the HOM impedance reduction necessary for high-current operation has been achieved.

1 INTRODUCTION

In the last year the PEP-II asymmetric collider has moved into the commissioning phase. The construction has been staged so that the high-energy ring (HER) was completed first with the low-energy ring (LER) completed later. The HER was operated for three runs of about one month each, in June '97, September '97 and January '98. A basic installation of two RF stations (8 cavities) was required to capture and store first beam in the HER with reasonable lifetime in the first run. Subsequent commissioning was performed with all 20 cavities installed and first three and then all five klystrons operating. Low-level controls and feedback loops were introduced and debugged during the runs enabling the stored beam current to be increased

2 STATION PROCESSING

All of the cavity raft assemblies and klystrons were tested to full operating power or above before installation, which greatly facilitated commissioning of the stations. The cavities were vented to dry nitrogen for connection to the machine vacuum chamber and required re-processing once the ring was under vacuum. Station processing was performed automatically by the low-level control software using a similar FM processing method to that used in the test stand for initial conditioning [1]. In general the re-processing went smoothly and normal CW operating power levels were attained after a few days.

Table 1: Typical HER parameters for commissioning

	Run 1	Run 2	Run 3
RF volts	6.4 MV	9.6 MV	12 MV
# cells	8	12	20
V/cell	800 kV	800 kV	600 kV
P/cell	86 kW	86 kW	48 kW
Ib	60 mA	300 mA	750 mA
Pb/cell	27	90	135
Ptot/cell	113	176	183

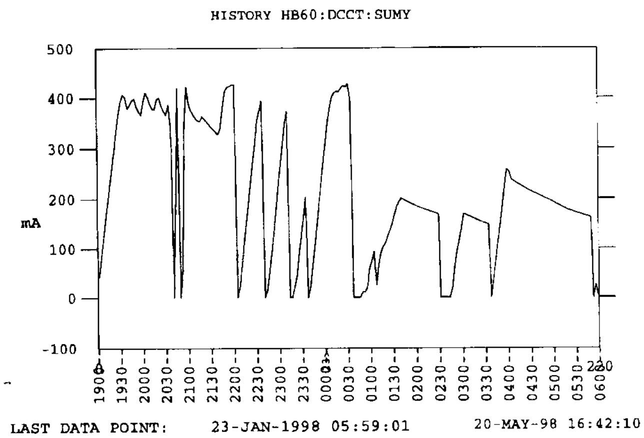

Figure 1. Sample of stored current history from run 3

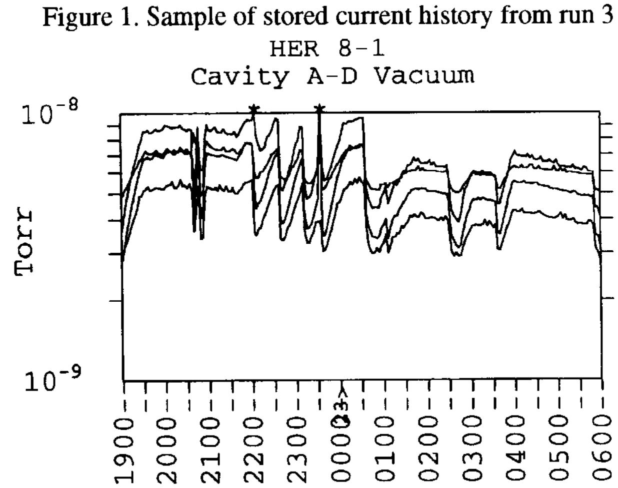

Figure 2. Sample of history buffer showing vacuum pressure increase with stored beam.

The base pressure in the cavities without RF was about 1e-9 Torr. The pressure rise with RF and beam was less than one order of magnitude in most cases and improved steadily with running and beam scrubbing of the vacuum chamber, see figures 1 and 2. One station had consistently higher pressure during the first run which was traced to a leak in a nearby vacuum chamber. In the second run the pressure was similar to all of the other stations.

*This work was supported by the U.S. Department of Energy under contracts DE-AC03-76SF00098 (LBNL), DE-AC03-76SF00515 (SLAC).

3 BEAM CAPTURE

Prior to beam injection the relative phases of the cavities within each station had been measured in the tunnel using a network analyzer. The phases of the cavities were adjusted by changing the lengths of the flexible waveguide sections in each branch of the waveguide network. Once the HER injection timing was established so that beam was observed on multiple turns around the ring the phase of the first station was adjusted to maximize the number of turns. The phase of the second station was then adjusted until capture was observed. Once beam was stored and a synchrotron tune measurement was possible then the relative phase of the RF stations was adjusted to maximize the synchrotron frequency. The absolute phases of both stations were then moved together to optimize injection efficiency. In subsequent runs the additional stations were similarly phased up to maximize the synchrotron tune. The maximum synchrotron tune was consistent with the indicated total RF voltage.

4 STORED BEAM OPERATION

Once it was possible to accumulate and store small beam currents spontaneous tune signals were visible on a spectrum analyzer attached to a bpm button. Both broad-band noise and harmonics of the 60 Hz line frequency from the klystron power supply were also observed. The ripple from the klystron power supply was reduced by temporary analog feedback loops on the first two stations until the digital filters in the low-level RF system were commissioned. The longitudinal and transverse multi-bunch feedback systems were also timed up and shown to operate. In the first run there was one unshielded bellows in the ring and the beam would become unstable at around 60 mA and be lost [2].

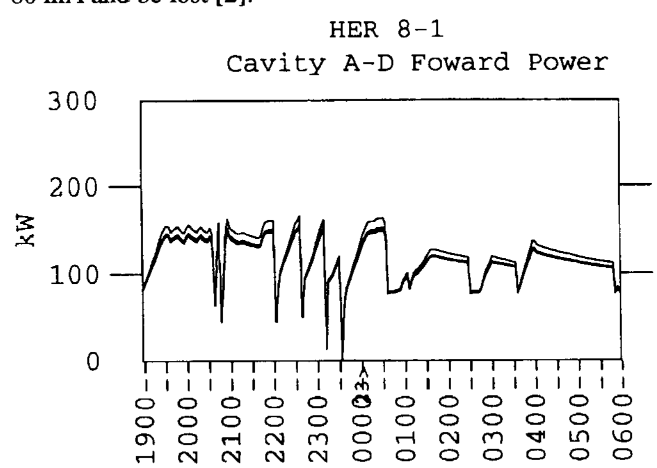

Figure 3. Forward power for cavities in station 8-1

In the second run, with all bellows shields in place the beam was more stable and up to 300 mA was stored, limited in part by noise on the RF system which prevented the feedback systems from maintaining control at high current. In the third run most of the low-level RF loops were commissioned which helped to raise the current to 750 mA. The accuracy of cavity and station phasing could be seen by observing the power balance between cavities within each station, see figure 3, and between stations.

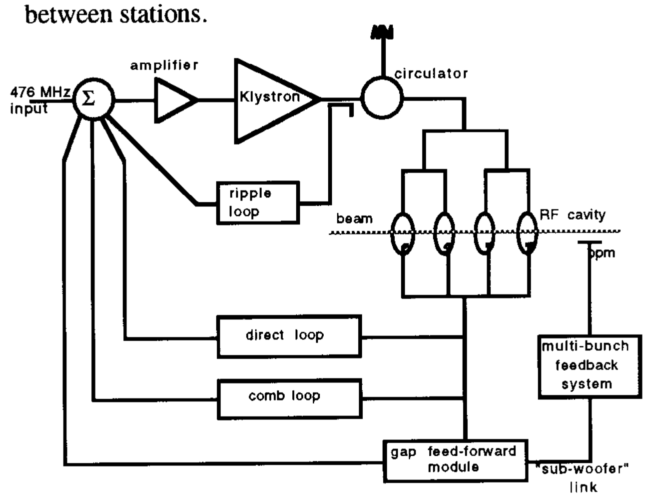

Figure 4 Low-level RF system block diagram

5 LOW-LEVEL RF SYSTEMS

Each PEP-II low-level RF (LLRF) system, figure 4, uses a combination of baseband analog and digital signal processing to damp the longitudinal coupled-bunch modes driven by the fundamental accelerating mode of the RF cavities [3]. The direct RF feedback loop reduces the driving impedance by 15 dB and a pair of digital comb filters provides an additional 17 dB of reduction. The direct RF loop contains an analog PID compensator providing additional gain (40 dB) around the RF carrier which eliminated ripple injected by the SCR controlled high voltage power supply which was not fully canceled by a DSP based loop around the klystron. A built-in network analyzer in conjunction with Matlab scripts allows fully automated configuration of all feedback loops. The network analyzer also functions as a programmable complex modulator allowing EPICS loops to auto-process the RF system with a swept FM (or CW) carrier. EPICS loops were commissioned which allowed a station to auto-reset after a fault with no operator intervention.

During the January '98 run all five HER RF stations were commissioned. The usual hardware glitches and software bugs were identified and corrected. At the end of the run 750 mA of beam was stored, which is consistent with the expected limit when the low-frequency "sub-woofer" connection with the longitudinal feedback system is not operating. This will be commissioned during the July '98 run. There was still longitudinal beam motion at high currents which we now attribute to insufficient gain in the DSP based adaptive feed-forward controller which prevents the direct loop from combating the beam induced gap transient. This has now been corrected with a software vernier delay.

6 HOM SPECTRUM

With stored beam it was possible to observe for the first time the spectrum of modes propagating out of the HOM ports of the cavity. Figure 5 shows the spectrum with a single 5 mA bunch in the machine, monitored by a pick-up probe near one of the HOM loads. The spectrum clearly shows the mode structure predicted from the low power measurements [4].

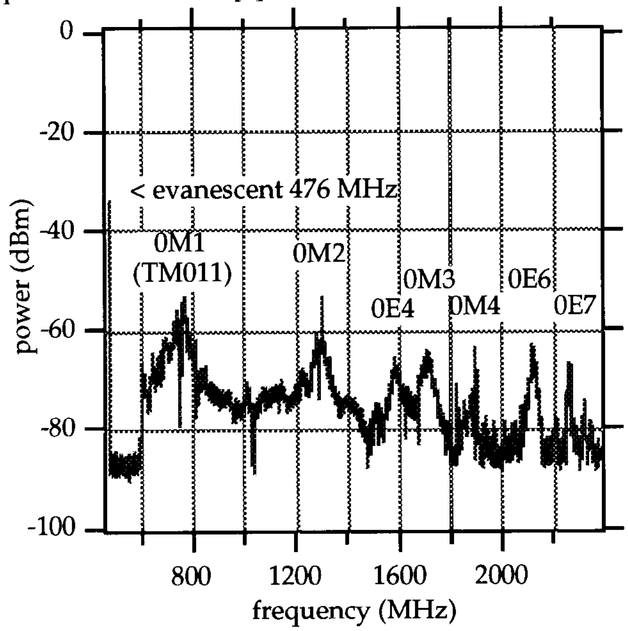

Figure 5. Mode spectrum reaching HOM load with 5 mA single bunch.

At 500 mA in 1651 bunches it was just possible to see some longitudinal coupled-bunch modes at the cavity HOM frequencies using the multi-bunch feedback system with strong positive feedback [5]. With no feedback all these longitudinal coupled-bunch modes were stable.

7 WINDOWS AND TUNERS

The RF cavity windows performed well during the commissioning. With the cavities powered the temperatures at the center of the ceramics rose on average about 10°C above the 35°C water. Because the windows are at the detuned-short position the electric field and therefore dielectric heating should not vary with beam current, only gap voltage. However because of the ohmic losses in the metallization and the window iris there is some further temperature increase with beam. Figure 8 shows the window temperatures in station 8-1 for the range of beam current in figure 1. Some air-side arcing was observed in one station after running with bad vacuum, believed to be caused by static charging due to multipactor. No failures occurred and the arcing stopped once the leak was fixed.

The tuners operated reliably in all of the runs and the EPICS control software that controls the cavity phasing and parking was commissioned.

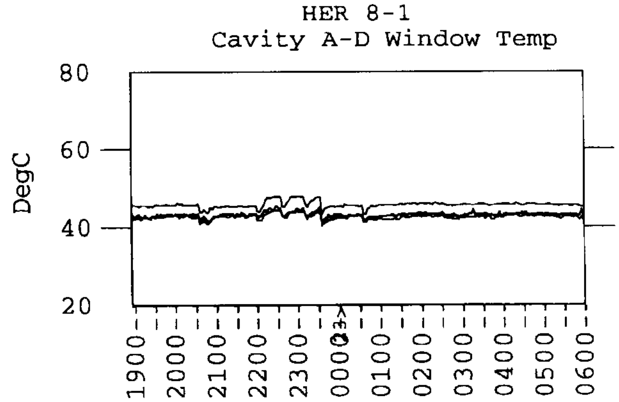

Figure 8. Window temperatures in station 8-1

8 FAULT DIAGNOSTICS

As with any new system of this complexity there were a number of interlock trips, some due to over cautious settings or noisy signals, some due to over zealous injection, others due to real conditioning of hardware. All RF system fault signals were logged through the control system and this was useful in working out the bugs and gradually improving system reliability The number of reflected power trips from cavity processing events declined steadily during the runs.

9 CONCLUSIONS

RF system commissioning has made good progress. The power supplies, klystrons and waveguide components were all tested at full power before connection to the cavities and performed very well during the beam runs. The LLRF system has turned a complicated set of tasks requiring many feedback loops into a turn-key operation. The HOM damped cavities worked very well with very large currents stored, even without longitudinal feedback. The transverse coupled bunch modes driven by the resistive wall and cavity dipole modes were successfully damped by the transverse feedback system. Combined HER/LER commissioning will continue in July '98.

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