AN AUTOMATED 476 MHZ RF CAVITY PROCESSING FACILITY AT SLAC*

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Abstract

The 476 MHz accelerating cavities currently used at SLAC are those installed on the PEP-II B-Factory collider accelerator. They are designed to operate at a maximum accelerating voltage of 1 MV and are routinely utilised on PEP-II at voltages up to 750 kV. During the summer of 2003, SPEAR will undergo a substantial upgrade, part of which will be to replace the existing 358.54 MHz RF system with essentially a PEP-II high energy ring (HER) RF station operating at 476.3 MHz and 3.2 MV (or 800 kV/cavity). Prior to installation, cavity RF processing is required to prepare them for use. A dedicated high power test facility is employed at SLAC to provide the capability of conditioning each cavity up to the required accelerating voltage. An automated LabVIEW based interface controls and monitors various cavity and test stand parameters, increasing the RF fields accordingly such that stable operation is finally achieved. This paper describes the high power RF cavity processing facility, highlighting the features of the automated control system and illustrating its operation with some recent high power processing results.

INTRODUCTION

There are currently thirty, 476 MHz RF cavities [1] installed on PEP-II. The ten RF stations are split with 3 powering the LER (Low Energy Ring) and 7 powering the HER (High Energy Ring). HER station configuration typically consists of a single 1.2 MW klystron powering 4 cavities via a circulator and a network of WR2100 waveguide, whereas LER stations have 2 cavities powered by a single klystron. Recently, to enable more of the 1.2 MW of klystron power to be delivered to the beam, newer HER stations are being configured in the 2-cavity mode. More RF stations are to be installed on PEP-II, starting with a 2-cavity HER station this summer and a new LER station expected in the summer of 2004.

SPEAR3 [2], which is currently under construction at SSRL at SLAC, will adopt a 4-cavity HER station for their RF system. The cavities employed will be identical to those used on PEP-II, except that they will be tuned slightly higher in frequency to 476.3 MHz. Construction is scheduled to be completed by the end of September 2003. ACCEL Instruments GmbH in Germany is manufacturing the new cavities for PEP-II and SPEAR3, while accessories such as RF windows, tuners and coupling networks are being fabricated at SLAC.

RF processing of these cavities is initially performed in FM mode, with the RF signal swept in frequency across the fixed tuned cavity, which effectively pulses the RF at resonance. As the vacuum activity diminishes, the cavity tuner loop can be energized and CW mode processing performed up to a maximum gap voltage (V_{RF}) of 850 kV.

A dedicated test facility is utilized at SLAC to perform the RF processing and it is automated in such a way that the cavity processing can be monitored remotely and should the station trip off for any reason, can be re-energized. This enables the facility to remain on-line for significant periods of time and the RF processing can more effectively continue until the cavity reliably achieves full accelerating field.

TEST FACILITY CONFIGURATION

The 476 MHz RF cavity test facility at SLAC (see Figure 1) consists of a SLAC designed and built, 500 kW CW klystron feeding power via a WR2100 waveguide system through a circulator, to a bunker enclosure which houses the RF cavity. The feeder waveguide penetrates the roof of the bunker and couples to the RF cavity via its coupling network. The bunker itself has been designed to absorb potentially up to 1 MeV of ionizing radiation by way of its concrete walls, roof and sliding, lead lined door.

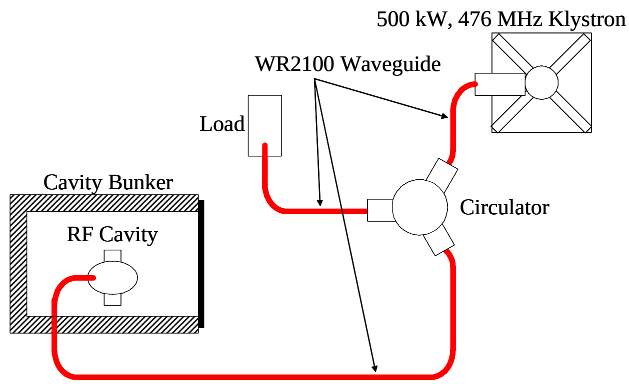

Figure 1 RF Cavity Processing Test Facility Layout

For 850 kV of gap voltage in the cavity, 93 kW of dissipated power in the cavity (P_{cav}) is required for the standard PEP-II type, HOM damped structure. The forward power into the cavity (P_{fwd}) needed to generate this accelerating field is derived from equation 1:

$$P_{fwd} = \frac{(1+\beta)^2}{4\beta} P_{cav} = \frac{(1+\beta)^2}{4\beta} \frac{V_{RF}^{\ 2}}{2R_s} \qquad \mathbf{1}$$

Table 1 shows nominal characteristics for the PEP-II RF cavity and from these, one can calculate for a V_{RF} = 850 kV, that P_{fwd} = 145 kW.

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Table 1 PEP-II Nominal Cavity Characteristics

Cavity Characteristics	Value
Frequency (MHz)	476.0
Unloaded Q-factor Q_o	33500
Loaded Q-factor Q_L	6700
Coupling Factor β	4.0
Shunt Impedance R_s (MΩ)	3.9
Effective Impedance R_s/Q_o (Ω)	116.4

A limit is placed on both the maximum cavity input power to the bunker and the peak accelerating voltage generated. These limits are designated as station MPS (Machine Protection System) interlocks. P_{fwd} is limited to 150 kW and is monitored through a WR2100 directional coupler at the entrance to the bunker penetration and the accelerating voltage is limited to 1 MV and is monitored via the cavity coupling loop. The HVPS (High Voltage Power Supply) is shut off rapidly (~30µs) should either of these limits be breached during RF processing.

AUTOMATED RF PROCESSING SYSTEM

RF processing of the cavity is performed using the National Instruments, high level graphical programming language - LabVIEW [3], which controls the input power to the cavity whilst monitoring various elements of its operation, such as vacuum pressure, cavity body temperatures, tuner position, resonant frequency, RF window temperature and forward and reverse powers. Other features of the test facility are monitored and interlocked which include; cavity window air side and vacuum side arc detectors, water flow and temperature, reverse power at the cavity as well as the MPS limits previously defined. A CCD camera is located on a cavity inspection port looking at the movable tuner; this is also read back into the LabVIEW system, via an image capturing interface which enables monitoring of breakdown events inside the tuner, should they occur.

A voltage feedback routine controls the cavity accelerating voltage and forward power and if the vacuum in the cavity is below a specified level, the RF power is steadily increased. As more gas is generated from the cavity, its coupling network and the RF window, the vacuum level inside the cavity will increase. If the cavity vacuum exceeds the vacuum limit set for RF processing, then the RF power is reduced automatically until the vacuum in the cavity improves again. The process is then repeated and P_{cav} is increased again until the cavity achieves its maximum defined field level of 850 kV. Typically then the cavity is held at this power level for 1-2 days, as its vacuum activity and stability improves.

The hardware used to perform the readback and control functions are shown in Figure 2. A PC system is configured with 4 National Instruments interface boards; **Board a)** a PCI-GPIB board is used to interface to a Marconi 2019 Signal Generator which controls the drive to the 500 kW klystron in either FM or CW modes. **Board b)** a PCI-6025E data acquisition (DAQ) board which is used to read and write digital I/O (DIO) control information to and from the test facility. The DIO interlock reads comprise cavity water flow, cavity arc detectors, cavity temperatures and cavity vacuum. The DIO writes include, switching the HVPS on and off, enabling the RF, activating the voltage feedback system and resetting interlocks. **Board c)** the 6025E board also connects to an AMUX-64T analog multiplexer board, which reads 13 temperature sensors positioned at various locations on the cavity body and its coupling network. It also reads the cavity forward and reverse power levels, the gap voltage, the tuner position and the cavity pressure. **Board d)** a PCI-1409 image acquisition board is connected to a CCD camera looking at the cavity movable tuner. The image acquisition (IMAQ) board is triggered from external sources and the images are buffered so that potential breakdown events occurring in the tuner gap can be captured.

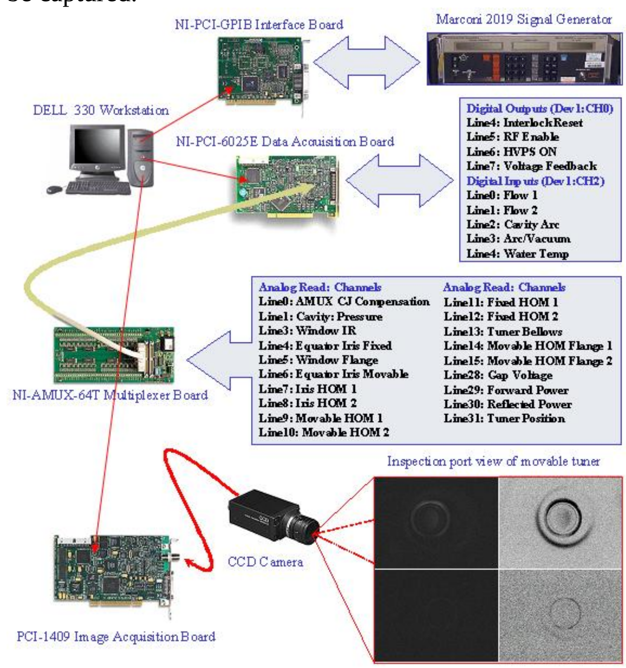

Figure 2 Analog and Digital Diagnostics and Controls

The LabVIEW front panel for the cavity processing or conditioning system allows for easy manipulation of the system controls and diagnostics as shown in Figure 3. It currently comprises 9 sections; **File Acquisition** which identifies the file to which data is being stored, **Interlocks** indicates the current interlock status, **Temperatures** whereby each of the 13 cavity body water cooling circuit temperatures including an infra red temperature reading of the RF window are indicated and limits are set which shut off the HVPS if exceeded, **Cavity Pressure** shows a real time plot of cavity pressure and allows for a pressure limit on cavity processing to be specified, **Misc Parameters** allows the users to monitor in real-time a specific cavity parameter, **RF Power** indicates the current cavity powers along with imposed limits, **Cavity Tuner** shows the tuner position, **Cavity Voltage** graphically shows the cavity voltage and **Voltage Feedback** enables the voltage feedback loop to be closed in order to increase the power from the klystron, the feedback loop monitors the cavity forward power with respect to its limit as well as the cavity pressure and if either limits are exceeded then the RF input power is reduced via a voltage controlled attenuator on the input to the klystron.

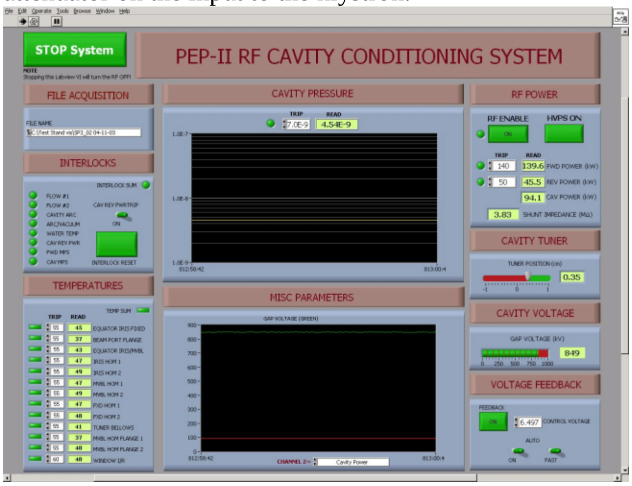

Figure 3 LabVIEW Cavity Conditioning Front Panel

Closed loop operation of this feedback loop has 2 modes; FAST and SLOW, which relates to the rate that each power iteration is made with FAST occurring every ~0.5 seconds and SLOW acting every ~2 seconds. This SLOW provision is implemented to assist in processing through particularly stubborn areas whereby large vacuum spikes would normally inhibit processing in FAST mode.

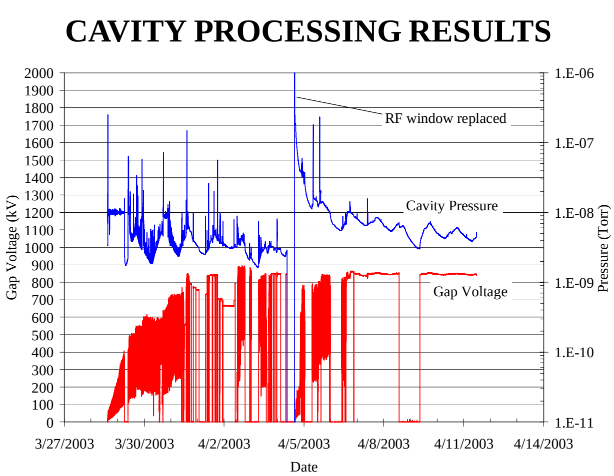

Figure 4 Cavity SP3-01 RF Processing History

A total of 6 PEP-II type cavities have been successfully processed using the system described here. The most recent were 2 cavities completed in March - April 2003 for SPEAR3. Figure 4 shows the 14 day processing history for the first SPEAR3 cavity SP3-01. Processing started in FM mode on 3/28, initially at 300 kHz modulation up to a peak voltage in the cavity of V_{RF} = 850 kV and left to run at this level for several hours, with the vacuum level in the cavity controlled to below 1 x 10^{-8} torr. Processing was then switched to CW mode at 476.3 MHz and the cavity took only 3 hours to process to full field on 3/31.

A problem then arose whereby the cavity could not sustain this level of field and repeatedly tripped off, after ~ 1 hour operation, on the RF window vacuum side arc detector interlock signal (LabVIEW interlock: Cavity/Arc). The imaging camera did not capture any arc or breakdown evidence inside the cavity when this event occurred. After 2 days of attempted processing CW at full field, the station was reverted back to FM processing mode to try and overcome this limit. A peak field of V_{RF} = 900 kV was set and the FM frequency was cycled under LabVIEW control from 150 kHz down to 20 kHz over several hours. Switching back to CW processing mode however did not improve the stability of the cavity at high field and it again repeatedly broke down on vacuum side window arcs.

On 4/04 the cavity was removed from the test facility and the RF window was taken off the coupling network and a pre-baked replacement window re-installed. The removed window was later diagnosed as having faulty copper plating as the cause for the repeated arcing. The cavity was then put back into the test facility bunker and FM processing resumed a few hours later when the vacuum level in the cavity reduced to a reasonable level. After ~24 hours, the cavity had reached V_{RF} = 850 kV at a pressure of 1.3 x 10^{-8} torr. Switching back to CW mode, the cavity reached full field in 2 hours and remained there, following a trip attributed to a circulator arc, for ~41 hours before tripping off again on another circulator arc. Processing was concluded for this cavity with a further ~49 hour run at full field.

CONCLUSIONS

As the RF processing of these accelerating structures up to full accelerating fields takes many days of continuous operation, it becomes necessary to incorporate a control system which can provide an automated mechanism of control. The LabVIEW control system utilised at SLAC allows for a reliable interface to a number of data acquisition and control boards which are configured to monitor system operation and react accordingly to various cavity parameters to ensure that RF processing continues efficiently whilst minimizing downtime due to station trips.

The system has proved invaluable in terms of being able to process these cavities rapidly and also having the inherent flexibility to include sufficient diagnostics that assist in identifying problems that may occur.

REFERENCES

[1] R A Rimmer, “High-Power RF Cavity R&D for the PEP-II B Factory”, Proc. EPAC’94, London, June 1994, pp 2101-2103.

[2] See: http://www-ssrl.slac.stanford.edu/spear3/SPEAR3_main_page.htm.

[3] LabVIEW can be obtained from National Instruments Corporation, Austin, Texas, USA.