DAMPING RING
S-BAND BEAM PHASE LOCK SYSTEM

J.G. JUDKINS

ABSTRACT

This presentation describes the existing S-Band beam phase lock system for the SLC damping rings and possible upgrades utilizing newly developed devices. The general beam parameters are described that necessitate phase locking the extracted beam from the damping ring to the LINAC. The system phase locks the 2856 MHz Damping Ring rotation harmonic with sector 2 2856 MHz of the LINAC. The system utilizes IF limiting amplifiers with less than 1 degree phase shift over 40 dB dynamic range. Beam phase measurements correlated with RTI orbit distortion verified the low phase shift versus beam intensity. A phase shift of 0.2 degrees for an intensity change of 4 E10 to 1 E9 particles per bunch was measured. Three possible upgrades using IQ demodulation and digital signal processing techniques are presented at the end. The goal is to improve dynamic range, increase resolution and provide for feedback on a single bunch when two bunches are present.
DAMPING RING
S - BAND BEAM PHASE LOCK SYSTEM
J.G. JUDKINS 4/7/98
DAMPING RING 2000 WORKSHOP
SLAC

I. PURPOSE/FUNCTION

II. DESCRIPTION

III. MEASUREMENTS

IV. IMPROVEMENTS
I. FUNCTION: 2 MAIN CORRECTIONS PERFORMED

1. PARASITIC MODE LOSS:
SYNCHRONOUS PHASE ANGLE $\Phi_s$
INCREASES WITH INCREASING CURRENT $5^\circ \Phi/1\ E10$ charge.

THESE ARE WALL LOSSES FROM THE BEAM AND ARE
COMPENSATED BY THE BEAM INCREASING $\Phi_s$ TO A HIGHER RF
VOLTAGE.

VARYING BEAM INTENSITY AND MAINTAIN SECTOR 2
INJECTION PHASE.

2. PHASE RAMP:
PATH LENGTH CORRECTION FOR LTR-RING-RTL.

ADJUSTS INJECTION PHASE INTO SECTOR 2.

PAPERS:

PHASE DETECTOR AND PHASE FEEDBACK FOR A SINGLE BUNCH IN A TWO-
BUNCH DAMPING RING FOR THE SLAC LINEAR COLLIDER, IEEE TRANSACTIONS
ON NUCLEAR SCIENCE, . SCHWARZ, JUDKINS

ACCELERATOR PHYSICS MEASUREMENTS AT THE DAMPING RING, MAY 95,
SLAC - PUB - 3690
II. DESCRIPTION:

REPEITITIVE IMPULSE TRAIN FROM BPM SIGNAL TRANSFORMS INTO A REPETITIVE IMPULSE TRAIN IN FREQUENCY DOMAIN.

118 nsec $\Rightarrow 8.5$ MHz

59 nsec $\Rightarrow 17$ MHz

2856 MHz FREQUENCY COMPONENT IS FILTERED (STRETCHED IN TIME) AND PHASE LOCKED TO A SECTOR 2 2856 MHz REFERENCE.
IF FREQUENCY OF 57.5 MHz WAS CHOSEN TO UTILIZE LOW PHASE SHIFT LIMITER AMPLIFIERS: 4 STAGE, 46 dB GAIN < 1° PHASE SHIFT.

IF FILTER BANDWIDTH OF 2 MHz RINGS FOR = 1/π BW = 160 nsec.
FOR ONE BUNCH; 118 nsec SPACING = 1.5 X INCREASE IN SIGNAL DUE TO IF FILTER CHARGING OR 3.5 dB.

FOR TWO BUNCH; 59 nsec SPACING = 3 X INCREASE IN SIGNAL OR 10 dB.

THE DIFFERENCE RESULTS IN 6 dB LOSS IN DYNAMIC RANGE FROM ONE TO TWO BUNCH OPERATION = 40 dB DYNAMIC RANGE (100 Δ I).
III. MEASUREMENTS

IF PHASE DETECTOR OUTPUT IS 5mV = 0.35° AT MINIMUM SIGNAL
REDUCES TO 1mV (0.04°) WHEN INTO HARD LIMITING

NDR INTENSITY TEST VS. DYNAMIC RANGE (ONE BUNCH ?)

<table>
<thead>
<tr>
<th>Charge/Bunch</th>
<th>Orbit in RTL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 E10 to 1 E9</td>
<td>&lt; 1° PHASE FEEDBACK (32 dB)</td>
</tr>
<tr>
<td>2.5 E10 to 0.5 E10</td>
<td>0.4 mm</td>
</tr>
</tbody>
</table>

RTL Δ COMPRESSOR LOADING 0.4°/1 E10 (200 keV/1 E10)

0.8° ATTRIBUTED TO COMPRESSOR LOADING
0.2° ATTRIBUTED TO S-BAND BEAM PHASE
IV. IMPROVEMENTS

A. IMPROVE RESOLUTION: CURRENTLY 1/4° TO 1/2°

REDUCE NOISE LEVEL: BETTER IF AMPS
IF PHASE DETECTOR

B. IMPROVE RESOLUTION AND DYNAMIC RANGE:

USE I Q DETECTION OR ADC SAMPLING TECHNIQUES.
SINGLE BUNCH SAMPLING.
Fig. 5. Phase detector block diagram.
1. **S-BAND I/O DETECTOR TO BASEBAND**

**BPF OR SERIES OF S-BAND COUPLERS FOR**

- TONE BURST > 10 S-BAND CYCLES; 3 nsec PHASE PULSE

**2856 REF.**

- 8 BITS
- 3 nsec TRANSIENT RESPONSE
- 50 - 100 KHZ SAMPLE RATE

---

2. **DIGITAL DEMODULATION: SINGLE ARM- SYNTHESIZER REFERENCE LOCKED**

**BPF OR TONE BURST > 10 S-BAND CYCLES; 3 nsec PHASE PULSE**

**2737 LO SYNTHESIZER**

---

3. **DIGITAL I/Q SAMPLING DETECTION**

**I/Q SAMPLING +90° IF FREQUENCY**

**IF BANDWIDTH:** 17 MHz REP RATE * 5 = 100 MHz

**IF FREQUENCY:** 100 MHz * 5 = 500 MHz
This page intentionally left blank.
The Damping Ring Window is currently .3 " thick and 10" in diameter. There is some empirical evidence that the window is too thin for its diameter, and will have a tendency to puncture, rather than arc on the air-side without puncturing as evidenced with the PEP-II window design. Modeling of the current window was done in HFSS and a thickness increase to .6" is possible with slight changes in the rectangular WG stub length. We recommend this increase in thickness, which, if the arcing/puncture model is accurate, will not puncture, but arc on the air-side first, thus increasing the reliability of the Damping Ring Window design.
DR2000 Window Design

• HFSS model
  • existing window in a WG model
  • various window thicknesses
  • comparison of .6" and .3" thick window

• Charging/breakdown model
  • Advantage of .6" window
VSWR vrs Window Thickness

VSWR vrs Window Thickness of damping ring window at 715 MHz (modeled into 1x9.75 w/g)

M. Neubauer 4/7/98
Window diameter to prevent charging puncture (assuming 30 kV/cm breakdown in air)

Dielectric strength values published by WESGO

region of charging puncture through ceramic

DAMPING RING

region of air-side arc preventing charge build-up

M. Neubauer 4/7/98
Conclusions

.6" window will present a different impedance to cavity

Impedance can be adjusted by WR975 stub length

.6" window will not puncture, due to charging, but will likely breakdown on air side first.
Damping Ring Tuner Upgrade

Heinz Schwarz

SUMMARY

The existing tuners for the SLC damping rings are based on the design of the PEP-I tuners with carbon contact brushes and have experienced difficulties at high stored beam currents. It is suspected that the vacuum bursts when the tuner is moved may be caused by contact problems in the carbon brush area. The brushes are pressed against the tuner stem by spring pressure and that contact should be good. The area around the brush in its guide hole does not have a positive contact mechanism and could keep on arcing when the tuner is exercised while conducting higher order mode currents. The brush design worked well for PEP-I tuners but tests for the use of the carbon brush design for PEP-II at 476 MHz showed relatively high impedance and expected heating and/or arcing in the brush area. Consequently a spring finger contact design was developed and successfully used for PEP-II cavities. Another source of possible outgassing is higher order mode resonances in the tuner gap.

The design of a tuner with spring finger contact is described based on the PEP-II tuner design:

The mechanical difficulties with spring finger contacts are abrasion and cold welding under ultra-high vacuum conditions. These are reduced by hardening the surface of the tuner plunger with a thin layer of Rhodium and silver coating the surface of the finger tips. Mechanical tests under vacuum show that contacts could survive 100,000 cycles, equal to 10 years of operation of PEP-II.

The gap size around the plunger was made 4 mm to avoid arcing, but multipacting could exist at this gap size and was observed at low power (1 kW into cavity) and posed no problem.

To calculate wall current in the tuner gap where fingers might be placed a MAFIA model was made of the cavity with a tuner and gap (calculated wall power loss: 2 W/cm² 8.5 cm back from cavity wall). The distance of 8.5 cm was optimized based on calculated resonances of the tuner gap at higher order mode (HOM) frequencies and a relatively HOM free region of damped cavity resonances between 750 and 1295 MHz. At 8.5 cm gap length the fundamental frequency power dissipation is high but fingers made of GLIDCOP (Dispersion Strengthened Copper) can handle the heating without softening.

The PEP-II tuner design with spring fingers should be adapted to the damping ring tuners and is expected to prevent resonances and arcing and the related outgassing. The damping ring cavities with a tuner should be modeled to determine resonances and wall power dissipation in the tuner gap. The same basic plunger dimensions would be used but with a relatively long tuner port in the cavity the exact placement of the finger contacts will be a challenge. The existing drive mechanism could be retained. It should also be evaluated whether the amount of tuner cycling expected in the damping rings is compatible with the finger wear.
DAMPING RING TUNER UPGRADE

• Problems:

  • Vacuum activity -- Vacuum bursts when the tuner is moved may be caused by contact problems in the carbon brush area. The brushes are pressed against the tuner stem by spring pressure and the contact should be good. The area around the brush in its guide hole does not have a positive contact mechanism and could keep on arcing when the tuner is exercised.

  • Heating due to beam induced HOMs -- It is very likely for HOM frequencies to find resonance conditions in the variable spaces in the tuner gap and volume behind the tuner plunger. To my knowledge this has not been simulated.

• Proposed solution:

  • The carbon brushes should be replaced by spring finger contacts as developed for PEP-II. This provides a positive contact point and a defined path for all RF currents. Outgassing after initial processing will diminish. The gap can also be designed such that it does not present any resonant conditions.
Introduction to PEP-II tuner design

- Tuner movement: 20 mm outside to 30 mm inside cavity for 1 MHz tuning range

- Challenge: Prevent RF power from reaching and heating bellows in a movable tuner

- Carbon brush design of PEP-I rejected because of heating and lack of contact around carbon brush; also carbon dust a potential problem

- Spring finger contacts chosen because of their successful use at LEP/CERN and APS/Argonne

Issues with spring fingers:

- Mechanical abrasion and cold welding of fingers at ultra-high vacuum

- Gap size to prevent arcing and/or multipactor

- Distance to spring fingers to prevent heating from HOMs

- Distance to spring fingers to prevent excessive heating from fundamental frequency
PEP II TUNER
PEP-II B-Factory

Tunner Plunger with Rhodium

Gildcop Fingers

Assembly

PEP-II
RF Cavity Tuner
Mechanical issues

- Mechanical abrasion and cold welding of fingers at ultra-high vacuum resolved by choosing a hard surface - RHODIUM - to rub against a soft surface - SILVER

- The tuner plunger will be partially coated with rhodium 0.3 mils thick; this is a hard layer with resistivity 3 times that of copper; heat transmitted to plunger cooling water

- Spring fingers coated with silver 3 mils thick

Gap size

- To prevent multipactor choose gapsize <1 mm

- Problem with arcing in fixed tuner with gap <1 mm in high power test cavity; in PEP-I the tuner gap was increased to 4 mm to prevent arcing; APS recently experienced arcing in tuner gaps <1 mm associated with steps and sharp corners

- Simulation of field strength in 2 mm and 4 mm gap of a tuner in the HOM loaded cavity indicate best size 4 mm

<table>
<thead>
<tr>
<th>gap size</th>
<th>2 mm</th>
<th>4 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak field @ 150 kW</td>
<td>1.4 MV/m</td>
<td>1.3 MV/m</td>
</tr>
<tr>
<td>Peak volts</td>
<td>2.8 kV</td>
<td>5.2 kV</td>
</tr>
<tr>
<td>Power @ 10 cm short in Cu</td>
<td>1.3 W/cm²</td>
<td>0.8 W/cm²</td>
</tr>
</tbody>
</table>

- Deal with multipactor by titanium nitride coating of copper plunger
Power loss on tuner wall

Short position at 8.5 cm
4 mm gap; 1 cm insertion
HOM resonances

- Goal is to avoid 1/4 wavelength or 3/4 wavelength resonances at fundamental frequency and lowest HOMs.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Freq.</th>
<th>Q</th>
<th>λ/4</th>
<th>3λ/4</th>
</tr>
</thead>
<tbody>
<tr>
<td>fund. freq. TM010</td>
<td>476</td>
<td>6000</td>
<td>15.8 cm</td>
<td></td>
</tr>
<tr>
<td>TM011</td>
<td>750</td>
<td>28</td>
<td>10 cm</td>
<td></td>
</tr>
<tr>
<td>TM021</td>
<td>1295</td>
<td>907</td>
<td>5.8 cm</td>
<td>17.4 cm</td>
</tr>
<tr>
<td>ME-4</td>
<td>1435</td>
<td>3955</td>
<td>5.23 cm</td>
<td>15.7 cm</td>
</tr>
<tr>
<td>EE-6</td>
<td>1670</td>
<td>2134</td>
<td>4.5 cm</td>
<td>13.5 cm</td>
</tr>
</tbody>
</table>

- Simulation of tuner gap at different tuner positions indicate nominal distance from cavity to spring fingers of 8.5 cm is optimum.

Heating due to fundamental RF

- Simulation of fundamental mode RF penetrating into gap in TEM mode and evanescent higher modes using HOM loaded cavity model indicate that fundamental mode heating can be handled.
Fig. 5-98. Effective longitudinal impedance of the cavity modes before (solid line) and after (dashed line) damping. Also shown for reference are the radiation damping (RD) threshold and a tolerance from the longitudinal feedback system (FB) for a gain corresponding to 3 kV for a 5-mrad phase amplitude.

Fig. 5-99. Effective transverse impedance of the cavity modes before (solid line) and after (dashed line) damping. Also shown for reference are the radiation damping (RD) threshold and a tolerance from the transverse feedback system (FB) for a gain corresponding to 5 kV for a 0.5-mm transverse amplitude.
Resonance frequency of tuner gap vs. tuner position

Spring fingers 8.5cm back

Average of 15cm and 25cm Cavity radius

Tuner Range

Relative Tuner Position (cm)

withdrawn
Application to the damping ring

- The spring finger contact scheme can be applied to the damping ring tuner, keeping approximately the same tuner diameter and the same drive mechanism. New tuner vacuum envelop would have to be built.

- A potential difficulty is the length of the existing tuner ports on the cavities.

- The placement of the fingers has to be optimized for the damping ring cavity. Required is a model of the cavity and tuner in MAFIA to calculate higher order modes and also the wall dissipation in the tuner gap.
Conclusion

A spring finger contact system for the PEP-II tuners has been designed, mechanically tested for 100k cycles in vacuum and has worked successfully for several month operation in 20 cavities and up to 750 mA of stored beam.

The damping ring tuners could be similarly upgraded which is expected to improve their operation with stored beam significantly.
This page intentionally left blank.
Mechanical Considerations For Existing Tuners, Windows, And Pumps

Bobby McKee

We have implemented 3 major improvements to the damping ring RF-cavities. We have designed, fabricated, and installed in two locations a new tuner assembly that uses wire-scanner ball-screws for improved reliability. This assembly is pre-aligned for ease of installation. We have also designed and released for procurement the thicker RF-cavity windows. The ceramic is now .600 inches thick. This is twice as thick as the present windows installed on the cavities. We hope to install one of these on RFC-590 this downtime. Finally, we installed RF screens that double as flange gaskets in all the HIPs on all the cavities. Data is showing significant improvement of the RF-cavity vacuum.
<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>REQUIREMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance</td>
<td>Inspect and remove brushes</td>
</tr>
<tr>
<td>Alignment of tuner</td>
<td>Pre-aligned slide</td>
</tr>
<tr>
<td>Minimize radiation damage</td>
<td>Locate sensitive components away from high radiation</td>
</tr>
<tr>
<td>Travel</td>
<td>3.00 inches</td>
</tr>
<tr>
<td>Pitch</td>
<td>Less than or equal to present screw</td>
</tr>
<tr>
<td>Vacuum loads</td>
<td>Loads less than or equal to present loads</td>
</tr>
<tr>
<td>Tuner plug design</td>
<td>Use present design</td>
</tr>
<tr>
<td>Operating cycles for screw</td>
<td>500,000 cycles minimum</td>
</tr>
<tr>
<td>Lubrication</td>
<td>Radiation resistant</td>
</tr>
</tbody>
</table>
NOTES:
1. THE USE OF ANY PROCEDURES INCOMPATIBLE WITH SEALING PRACTICE IS PROHIBITED. FURTHER INFORMATION REFER TO SLAC DOE, NO. FP-202-222-14.
2. CHEMICAL CLEAN SEPARATE, 6TH CLEAN ENSURE, CLEAN SURFACES, ETC., SHALL BE CLEAN AND PACKAGED PER SLAC Doc. NO. FP-202-632-14. CLEAN ROOM GLOVES ONLY SHALL BE USED IN SUBSEQUENT HANDLING OF COMPONENTS.
3. DRY STICKY MATERIALS PRIOR TO MOUNTING TO CHECK FIT.
4. VISUALLY INSPECT PARTS FOR ALLOY METING, NO SAMS PERMITTED.
8. WRAP IN DRY-TREE TISSUE A UV ALUM FOIL, BAG AND TAG WITH PART NUMBER.
9. APPLY UNSTABLES POISON TO NOT OPEN LABELS TO ALL SIMULATING CONDUCTIVE.
10. TO BE PROCESSED AT SLAC.
11. PARTS WHICH HAVE BEEN CLEANED SURFACE ARE SHOWN WITH TITANIUM BON.

DETAIL A
SCALE 2:1

OUTLINE

SLC RF CAVITY
RF WINDOW, 0°
FINAL BRAZE ASSEMBLY
SA-446-566-27 E0 U
Adjustable Stub-line Tuner

Heinz Schwarz

SUMMARY

The question has been raised if tuning of a cavity can be accomplished by multiple adjustable stubs in the drive waveguide outside the cavity and its vacuum window. The answer is "yes" with some restrictions.

Based on an equivalent RLC resonant circuit it is shown how an added capacitance can change the resonant frequency but is also required to handle a portion of the large reactive power circulating in the resonant circuit. The added capacitance can be transformed to an equivalent capacitance in the drive line to the resonant circuit and will handle the same reactive power for the same frequency change. As an example with parameters of the damping ring cavities a 100 kHz frequency change would translate into 90 kW of reactive power traveling between cavity and external tuning stub. This power is much larger than the power traveling to the cavity for wall loss and beam power. It would stress vacuum window and coupling iris into the cavity. Small amounts of frequency adjustments or changes to the input coupling factor can be done with movable stubs in the drive waveguide and would have to be evaluated.
ADJUSTABLE STUB-LINE TUNER

• Question:
   Can the cavity tuner be moved from the cavity to the waveguide outside the vacuum vessel?

• Answer: Yes............But!

• The following issues are involved:
Resonant Circuit:

\[ \Delta C = \eta^2 \Delta \tilde{C} \]

\[ \omega = 2\pi f = \frac{1}{\sqrt{LC}} \]

\[ \frac{\Delta f}{f} = -\frac{1}{2} \frac{\Delta C}{C} \]

\[ Q = \frac{\text{Reactive Power}}{\text{Wall Power}} = \frac{I_{\text{Imag.}}}{I_{\text{Real}}} \]

\[ \frac{\Delta f}{f} \Rightarrow \frac{1}{2} \frac{\Delta \text{Reactive Power}}{\text{Reactive Power}} \]

For damping ring:

\[ Q = 24000 \quad \text{Wall Power} = 14.5\, \text{kW} \]

\[ \text{Reactive Power} = 320\, \text{MVA} \]

For \( \Delta f = 100\, \text{kHz} \) \( f = 714\, \text{MHz} \)

\[ \Delta \text{Reactive Power} = 90\, \text{kVA} \]
Conclusion

Yes - the frequency of the damping ring cavities can be changed by ADJUSTABLE STUB-LINE TUNERS in the waveguide.

But - the reactive power to be transmitted through the coupling slot and window easily gets significantly large. The reactances also may be difficult to produce repeatedly dependent on the coupling factor of the cavity.

For small adjustments of frequency or coupling value it is feasible and details could be worked out.