THE NEXT LINEAR COLLIDER DAMPING RING RF SYSTEM*

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Abstract

We report progress on the design of the RF systems for the Next LinearCollider (NLC) Damping Rings [1]. The 714MHz RF system is a critical component of the damping ring complex, and must provide flexible operation with high-power systems generating 1.5 MV in the main damping rings and 2 MV in the positron pre-damping ring. Average beam currents are approximately 750 mA, and bunch trains are rapidly injected and extracted. A cavity design incorporating higher-order-mode (HOM) damping schemes to minimize beam impedance and maximize current thresholds for coupled-bunch instabilities will be presented. Cavity construction techniques are designed to reduce costs while providing a reliable system with excellent performance. Descriptions of feedback systems requirements will be presented, with particular attention to the klystron bandwidth requirement for feedback against transient beam loading. Flexible low-level controls and feedback loops will be described.

1 OUTLINE OF DAMPING RING RF PARAMETERS

The design of the NLC damping rings is described elsewhere [1], here we present the parameters most relevant to the choices of RF systems designs. Table 1 lists parameters for the pre-damping ring and the main damping rings.

Synchrotron radiation loss in the main rings is dominated by the damping wiggler, and requires approximately 600 kW of RF power, and an additional 125 kW is needed to provide the peak voltage. We have chosen to base our design on a 1 MW klystron to allow adequate overhead for operation of feedback and feedforward systems.

Based on recent experience from PEP-II B-factory RF systems, we propose to use conventional copper cavity design and similar technology for the NLC damping rings. To obtain the required voltage, with a reasonable dissipated power density in the cavity, three cavities will be used in the main damping rings and four in the positron pre-damping ring.

The RF systems design is driven mostly by the large beam current. The beam is arranged in bunch trains with substantial gaps to allow for the rise and fall of injection and extraction kickers. The large current can result in rapid growth of single-bunch and coupled-bunch instabilities, and the RF cavities may be a dominant part of the impedance driving these instabilities. Transients in the RF voltage waveform experienced by bunches along a train may result in phase errors in the extracted beam, which propagate into energy errors in the bunch compressors following the damping rings.

Table 1: NLC Damping Rings Parameters

	Pre-damping ring	Main damping rings
Energy (GeV)	1.9 – 2.1	1.9 – 2.1
Circumference (m)	214	297
Bunch spacing (ns)	2.8	2.8
Fill pattern	2 trains 95 bunches 2 gaps 100 ns	3 trains 95 bunches 3 gaps 68 ns
Damping time (ms)	< 5.21	< 5.21
N_{max}/bunch	1.9×10^{10}	1.6×10^{10}
Current (mA)	800	750
Injected emittance X/Y (m-rad) (normalized)	$< 9 \times 10^{-2}$ (edge)	$< 150 \times 10^{-6}$ (rms)
Extracted emittance X/Y (m-rad) (rms, normalized)	$< 1 \times 10^{-4}$	$< 3 \times 10^{-6}$ / 0.03×10^{-6}
RF voltage (MV)	2	1.5
Momentum compaction	0.0051	0.00066
Energy spread (%)	0.09	0.09
Bunch length (mm)	8.4	3.8

A flexible low-level system including various feedback and feedforward loops, controls, and protection interlocks will be provided. The system will be designed to provide cavity voltage and beam phase control, minimize the effects of transient beam loading, and to provide ease of monitoring of RF systems performance with a minimum of complexity.

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To avoid coupled-bunch instabilities driven by the cavities where possible, and allow control of residual oscillations by coupled-bunch feedback systems, we propose to damp the cavity higher-order-modes (HOM's) using waveguides attached to the cavity in a manner similar to that used in the PEP-II B-factory cavities [2].

Table 2: NLC Main Damping Rings RF Parameters

RF Frequency	714 MHz
Harmonic Number	708
$U_{s.r.}$	750 keV/turn
$U_{HOM's}$	5.6 keV/turn
$U_{parasitic}$	36 keV/turn
V_{RF}	1.5 MV
Cavity Wall Dissipation	42 kW/cavity
Klystron Power	1 MW
Shunt Impedance	3.0 MΩ/cavity
Unloaded Q	25500
Coupling Factor	5.8
Synchronous Phase Angle	32°
Synchrotron Frequency	6.9 kHz
Energy acceptance	± 1.8 %

2 HIGH POWER SYSTEMS

Figure 1 shows a schematic of the RF system layout for the main damping rings, a similar layout is proposed for the positron pre-damping ring but with an additional cavity and modified power split to feed four cavities.

A single klystron, protected from reverse power by a high-power circulator, feeds a 2:1 waveguide hybrid power divider. The greater part of the power is further split in a waveguide magic-T (which provides additional isolation and protection for the klystron), and then feeds two cavities in the ring. The third cavity is fed from the low power arm of the power divider.

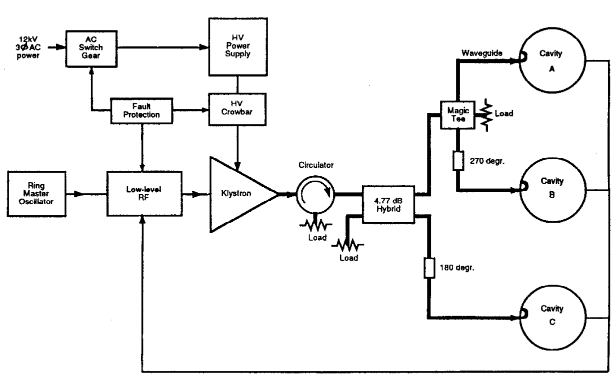

Figure 1: Main damping rings RF systems layout

A 2 MW high-voltage power supply with SCR voltage control and solid-state crowbar based on the successful PEP-II design is proposed. Voltage ripple on the power supply will be filtered to 0.1% or less.

Klystron bandwidth of up to 10 MHz is presently being considered, to allow feedforward control of cavity voltage and phase during the bunch train gap transient. The increase in bandwidth results in a high perveance and reduces the efficiency of the klystron.

A network of WR1500 waveguide connects the high-power components, with the circulator, hybrid, and magic-T splitters terminated in 1 MW waveguide loads. Cavities are placed in the beamline 4.75 wavelengths apart, to direct common mode reflected power into the loads, and fine adjustment of the phase between cavities is obtained with the use of waveguide bellows.

3 LOW-LEVEL SYSTEMS

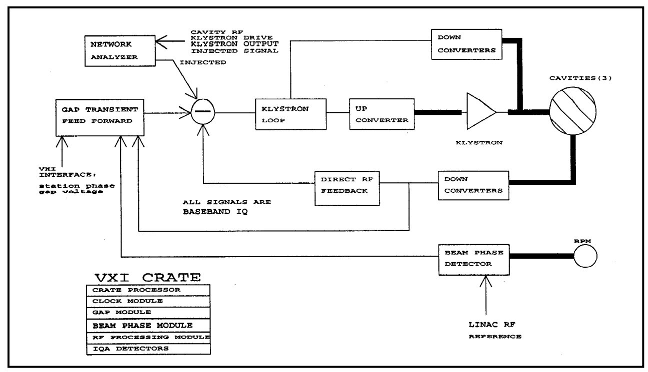

Figure 2: Block diagram of low-level RF systems

A modular LLRF system is planned based in the PEP-II system [3]. The RF hardware will reside in a single VXI crate and interface to a family of commercial programmable logic controller (PLC) modules to handle slow interlocks and tuner stepper motor control. The pulsed aspect of the ring operation will be supported by connecting several machine timing system triggers to VXI interrupts, allowing software to launch any time critical tasks related to injection, store or extraction.

Many RF vectors throughout the system will be monitored with digital IQ detectors. The bandwidth of each channel will need to be sufficient to detect the desired signal in the pulsed environment of the damping ring. Diode based analog detectors will provide hardwired RF interlocks with programmable trip levels and response times.

The system will perform the following functions:

1. Station voltage and phase control with software feedback loops.
2. Interlock functions by a combination of fast RF hardware and PLC protection.
3. Tuner control in the pulsed environment via triggered software loops.

4. Direct RF feedback will be implemented in baseboard electronics.
5. A baseboard network analyzer similar to the PEP-II design will be included.
6. Precise measurement and control of the mean bunch phase for next train to be extracted by a dedicated detection module with a DSP.
7. Feed forward damping of the cavity phase (gap) transient caused by the empty buckets with an adaptive algorithm driving a wideband klystron.

The gap transient is a critical parameter since it effects the energy spread in the main linacs. Early results from simulations show that a 4.5 degree transient can be reduced to +/- 0.05 degrees with a klystron bandwidth of 10 MHz. Other options to deal with the gap transient issue are being investigated. One method is to change the frequency of the RF system such that the bunches will be properly spaced for injection in to the linac. This approach introduces additional constraints to the timing scheme. Another possibility is to reduce beam loading transients by use of a low R/Q cavity or a high stored energy device.

4 RF CAVITY DESIGN

An extensive R&D program has been initiated to develop a high-power spectrally pure cavity for the NLC damping rings. We propose a copper structure, with HOM damping accomplished by three waveguide loads attached to the cavity shell. Lossy dielectric materials in the waveguides absorb the higher-order-mode power. Input power is coupled to the cavity from the WR1500 waveguide through a ridged iris aperture.

To reduce the broadband transverse impedance, the beampipe aperture at the cavity is increased from the nominal 1.6 cm diameter by a factor of approximately two. Tapers connect the larger cavity aperture to the adjacent vacuum chamber at the ends of the RF section; the larger diameter is continued between the cavities. This allows a reduction in transverse loss factor while maintaining a high shunt impedance for the fundamental mode.

Over 200 modes are expected to be trapped below the beampipe cut-off frequency (the highest dipole mode cut-off frequency is 5.9 GHz), and the damping waveguides must de-Q each of these modes by approximately two orders of magnitude to reduce coupled-bunch growth rates below the radiation damping rate. In addition, the strength of any modes trapped between cavities and between a cavity and taper must be ensured to be below a threshold which may induce coupled-bunch motion. So far our studies have not shown trapped modes outside the cavities which are not strongly coupled to fields within the cavities, which are damped by the waveguides on the cavities. We will continue to search for such modes.

We propose to achieve such broadband damping by use of double-ridged waveguides, with absorptive material placed along the length of the guide to provide a good match to the waveguide modes and power density commensurate with the heat flow through tiles brazed to a water cooled copper plate.

The maximum dissipated power density in cavities scaled from PEP-II design is 72 Wcm^{-2}, comparable with the PEP-II operating power density of up to 67 Wcm^{-2}. We have designed ridged waveguide apertures to reduce the associated heating from RF currents crowding at the waveguide coupling apertures in the cavity. The intersecting surfaces are designed with large radii to decrease power density. Figure 3 shows a three-dimensional design drawing for a half-cavity shell with short damping waveguides attached. To reduce manufacturing costs we propose to form the blended radii on the cavity apertures using a plunge electric-discharge method.

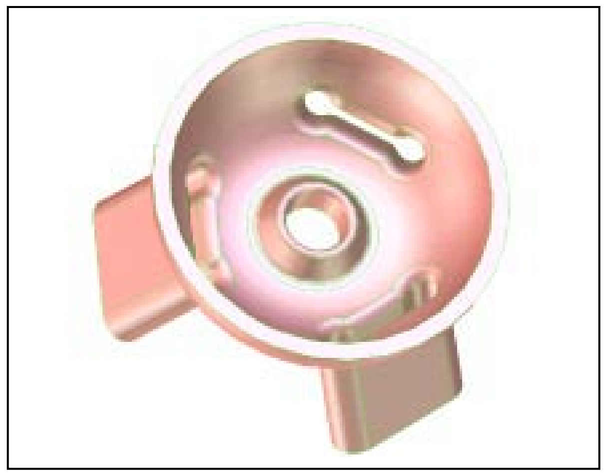

Figure 3: 3-D engineering sketch of half-cavity showing ridged damping waveguides, beampipe, and nose cones.

Cooling of the cavity will be accomplished by water flow through channels cut in the outer wall of the cavity shell and covered with an electroplated copper layer [4].

Other design considerations for the cavity may be found in [5].

5 REFERENCES

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