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PEP-II Status Report*

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Abstract

The main design features of the PEP-II asymmetric two-ring electron-positron B Factory collider, built at the Stanford Linear Accelerator Center, are described. This facility will complete construction in June 1998. The high energy ring, completed in May 1997, has had 3 months of commissioning and successfully stored 0.75 A of electrons. The success of the high energy ring testing validates not only its ring components, but also the injection system, the RF system and the control system all of which are common to the two rings.

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ABSTRACT

The main design features of the PEP-II asymmetric two-ring electron-positron B Factory collider, built at the Stanford Linear Accelerator Center, are described. This facility will complete construction in June 1998. The high energy ring, completed in May 1997, has had 3 months of commissioning and successfully stored 0.75 A of electrons. The success of the high energy ring testing validates not only its ring components, but also the injection system, the RF system and the control system all of which are common to the two rings.

1 INTRODUCTION

PEP-II is a two-ring, asymmetric electron positron collider constructed in the PEP tunnel at the Stanford Linear Accelerator Center (SLAC). The design[1] calls for the high energy ring (HER) to store 0.75 A of electrons at 9.0 GeV and for the low energy ring (LER) to store 2.1 A of positrons at 3.1 GeV, providing a peak luminosity of $3 \bullet 10^{33}$ cm^{-2} sec^{-1}. The beams will collide head-on in a single interaction region (IR), where the BaBar detector will be placed. Each ring will store 1658 bunches. The very large stored currents stress the vacuum design in the areas of thermal management, broad-band impedance and desorption. The closely spaced bunches stress the design in the area of narrow-band impedance and high order mode coupling. The magnetic separation scheme in the IR region generates very large synchrotron radiation thermal loads. Background amelioration must deal with this large photon flux and requires excellent vacuum to reduce background from lost beam particles. The main machine parameters are given in Table I.

The project, which is a collaboration of SLAC, Lawrence Berkeley National Laboratory (LBNL) and Lawrence Livermore National Laboratory (LLNL), began construction in January 1994 and will be complete in June 1998. The HER was completed in May 1997 and has undergone about 3 months of dedicated commissioning. First LER commissioning and low-current collisions are anticipated in a short commissioning run in July 1998. Further commissioning will occur in October through December 1998 after which the BaBar detector will be installed in the accelerator. First collisions with BaBar in place are anticipated in April 1999. Figure 1 shows an arc section of PEP-II.

Parameter	**Units**	**HER**	**LER**
Circumference	m	2199.32	2199.32
Energy	GeV	9.0	3.1
Luminosity	$cm^{-2}s^{-1}$	$3x10^{33}$	$3x10^{33}$
Bunch spacing	nsec	4.2	4.2
Crossing angle	mrad	0	0
Bunch Lenth	cm	1.1	1.0
σ_x	μm	155	155
σ_y	μm	6.2	6.2
β_x*	cm	50	37.5
β_y*	cm	1.5	1.5
Tune shift		0.03	0.03
x tune		24.57	36.57
y tune		23.64	34.64
τ beam	hours	4.2	5.3
ε_x	nm-rad	48.	64.
ε_y	nm-rad	1.9	2.6
Bunches		1658	1658
Current	A	0.75	2.14
RF Frequency	Mhz	476	476
RF Voltage	MV	14.	5.5
ν_s		0.045	0.035
Filling time	min	3	3
Injection rate	Hz	60	60

Table I. Primary PEP-II Parameters

Figure 1. Arc region showing the LER stacked vertically above the HER

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2 INJECTION

The SLC damped electron and positron beams are used for injection. The two beams are extracted from the linac at their respective beam energies (on-energy injection) and transported in dedicated transport and match lines to the rings. Each beamline has a keep-alive dump close to the injection septum, which permits constant surveillance and maintenance of beam quality during collisions. Electron injection is possible at rates up to 120 Hz in the energy range of 7 to 12 GeV. Positron injection is possible at rates up to 60 Hz in the energy range of 2.5 to 4 GeV. Intensities in the range of $l0^8 - 4\bullet 10^{10}$ e^+ per pulse are possible. Expected fill times for the rings are 3 minutes, top-off times about one minute. Both systems are complete and operational; status of the commissioning of these systems is covered in section 9.

3 LATTICE DESIGN

The lattices for the rings differ significantly. The HER has a 60 degree per cell lattice in the arcs and a standard interleaved sextupole chromatic correction scheme. The LER has a 90 degree per cell lattice in the arcs with a non-interleaved sextupole correction scheme. In the interaction region, the LER chromaticity has a semi-local character, with the x correction done in the IR region and the y correction done in the nearby arcs. For the HER, the IR chromatic correction employs large x and y beta functions in the nearby arc sextupoles (“beta beats”). The dynamic aperture of the HER is large, about 15 $\sigma_{x,y}$ for a l0σ energy offset, but tighter in the LER at 10 $\sigma_{x,y}$ for a l0σ energy offset. (β_y* is 1.5 cm for both rings. A wiggler section in the LER provides additional damping and emittance control.

4 RF and FEEDBACK

The RF system must provide short bunches (1 cm), good lifetimes, handle the heavy beam loading while at the same time possessing low enough impedance to reduce deadly multi-bunch coupling. Both rings employ a room temperature single cell, copper cavity system, incorporating high order mode (HOM) on-cavity damping. To further ameliorate multi-bunch coupling, active, bunch-by-bunch longitudinal and transverse damping systems are used. RF components for both rings are identical (5 stations in the HER, 3 in the LER); the HER has four cavities per klystron (station) while the LER has two cavities per klystron.

Figure 2 shows a PEP-II cavity assembly incorporating the cavity body, three on-cavity HOM dampers, tuner, and window. The HOM absorbers use tiles of AlN+40%SiC. The high power windows are TiN-coated ceramic held in compression by a stainless steel ring, and have been tested up to transmitted power levels of 500 KW.[2] The tuner is a copper plunger with rhodium plated glidcop fingers.

The 476 MHz, 1.2 MW klystrons are provided by Philips. The sophisticated low-level control system[3], which comprises three feedback loops, is crucial for stable operation. Bunch-by-bunch feedback is provided to damp both transverse and longitudinal oscillations.[4] The transverse system uses a pair of BPM’s to derive an x and y error signal for each bunch which is fed back on each turn via a pair of kickers. The longitudinal system, shown in block diagram form in figure 3, incorporates a form of digital signal processors. The processors provide turn-by-turn data for each bunch, which allow for in-depth, offline study of coupled-bunch motion. They also provide for a programmable error signal derivable from the weighted information of sequential bunches. The full, five-station HER system has been successfully operated with feedback systems as described in section 9.

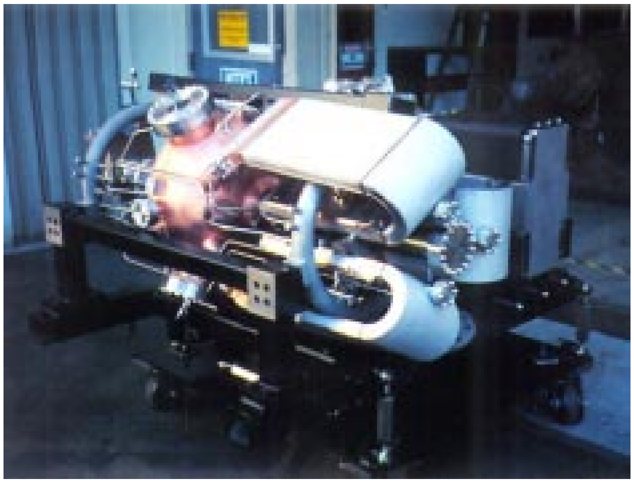

Figure 2. PEP-II Cavity. The three HOM dampers arc clearly visible.

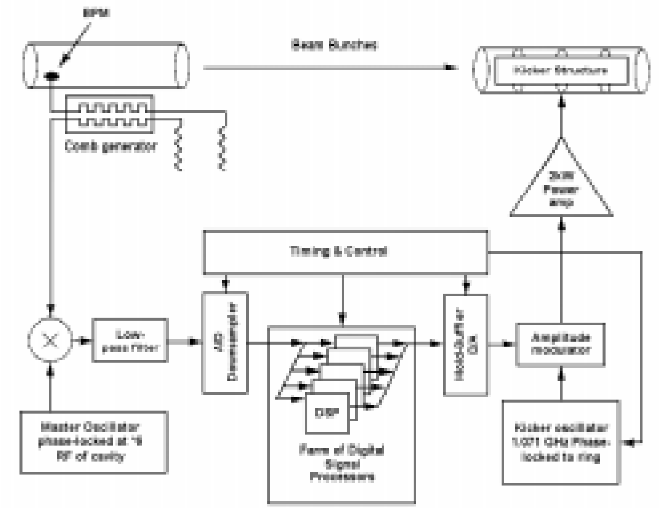

Figure 3. A block diagram of the Longitudinal Feedback System.

5 VACUUM

The main challenge for the vacuum systems are dealing with the large synchrotron radiation load which presents significant thermal loading and potentially very large gas desorption loads. In meeting these challenges, the vacuum system must be “smooth” and avoid trapping HOM.

In the HER arcs,[5] the dipoles are rather long (5m) and therefore distribute the radiation load over a large circumferential distance. The use of copper chambers (see figure 4) provides good thermal management and almost total absorption of the synchrotron photons. But most importantly, copper which photo-desorbs molecules at a rate about 50 times less than aluminum, permits the use of a conventional pumping scheme of distributed ion pumps within the dipoles and lumped ion pumps at the quadrupoles. The LER dipoles are short (0.45m) and lend themselves to an ante-chamber approach.[6] The synchrotron radiation photons leave through a horizontal aperture in the beam chamber, and are transported about 5 m in an ante-chamber to a water-cooled, glidcop photon absorber (see figure 5).

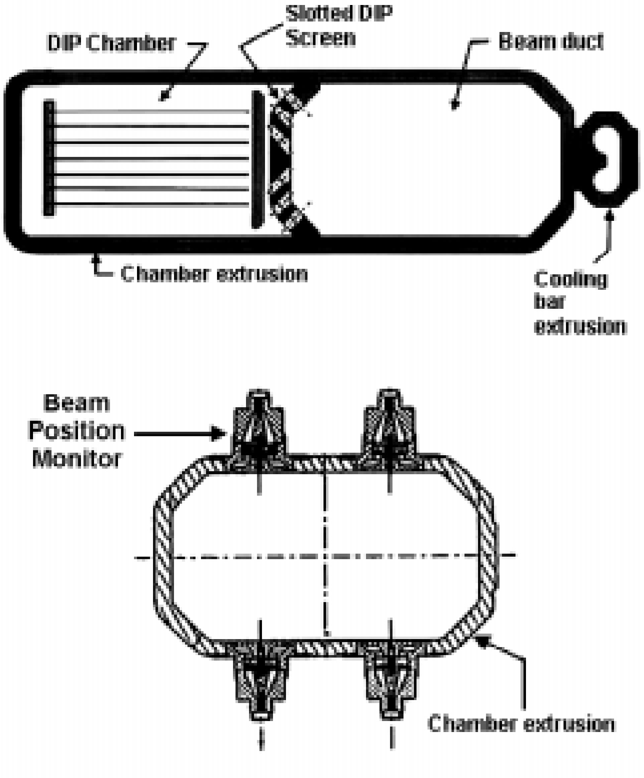

Figure 4. HER Arc dipole (upper) and quadrupole vacuum chamber profile.

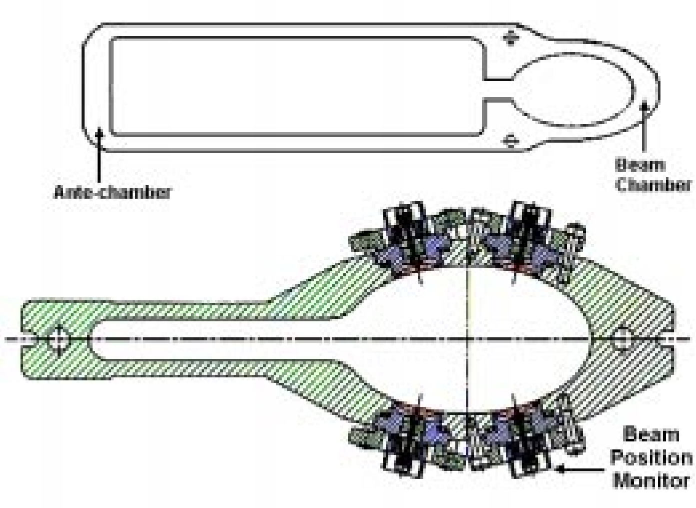

Figure 5. The LER Arc Magnet Chamber (lower) and pumping chamber. The Magnet Chamber is captured by the dipole and quadrupole. The Pumping Chambers, which house the photon absorber, is downstream of each Magnet Chamber.

A high-rate TSP pump is located immediately below the photon absorber. To reduce the secondary electron-induced electron emission, the beam channel of all LER chambers are coated with TiN. Lumped ion pumps provide additional pumping. In the wiggler and IR regions, special copper and /or glidcop chambers with high-speed NEG pumping are used. For both rings, the straight section vacuum chambers are double-walled, water-cooled stainless steel pipes. The HER and LER straight section chambers use Conflat seals; the LER arcs uses Helicoflex and tin seals. The bellows modules use silver-plated fingers riding on a rhodium plated stub. Low impedance is achieved by careful design of all vacuum system elements and a systematic program of calculation and measurement of pre-production prototypes.

6 IR

A plan view of the IR region is shown in figure 6, and the implemented beamline components from the upbeam Q1 through B1, the IP to the downbeam Q1 in figure 7. The LER beam is brought down into the plane of the HER beam and the beams are brought into head-on, horizontal collision. Separation is affected by a pair of dipoles (B1) and traversal off-axis in the focusing quadrupoles. B1 and Ql are permanent magnets. Q2, which with Q1 forms the low energy beam focusing doublet, and Q4/Q5 which form the high energy beam focusing doublet, are iron septum electro-magnets. Magnet tolerances for field harmonies are all in the 10^{-4} range. The vacuum chamber between the B1 magnets is a 25 mm radius, double-walled, water-cooled beryllium pipe. Outboard of this chamber, the vacuum chambers are copper or glidcop and are sculpted with high Z masks designed to handle several kilowatts of synchrotron radiation.

The primary synchrotron radiation load is absorbed on a mask 17m downstream of the IR. Vacuum pressure in the near-IR region is expected to be about 1 ntorr. Avoidance of parasitic beam-beam interactions is achieved by filling every other RF bucket.

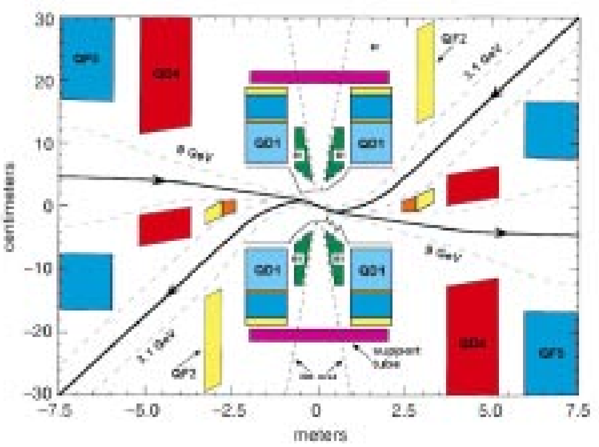

Figure 6. Plan view of the IR showing the seperation bends (B1) and the HER (Q4, Q5) and LER (Q1, Q2 focusing doublets.)

Figure 7. Assembled beamline from Q1 to Q1 before being inserted into the support tube.

7 DIAGNOSTICS[7]

Conventional 15 mm, ceramic, four-button beam position monitors are used in both rings, placed in close proximity to each quadrupole. There are about 300 such monitors per ring. Low threshold readout electronics permit single-pass measurement with 100 micron single-turn precision. This feature makes initial injection easier. It also provides for the storage, for later analysis, of the individual BPM measurements of 1024 successive turns.

A distributed beam loss system incorporating 100 discrete monitors serves both rings simultaneously. The detector comprises a 1 cm-long fused-silica Cherenkov radiator read out with a 16 mm phototube.

The total current in each ring is measured by a commercial DC current transformer. A second system provides a charge measurement for each of the 1658 bunches using the summed signals from a dedicated set of BPM buttons. This system, with a precision of 0.5%, updates the individual bunch current data for each ring at 60 Hz. This information is saved in a dual port memory and is available to the injection system which is required to fill the bunches with a uniformity of 2%.

Synchrotron radiation from an arc bend magnet in the 200-600 nm range is used to measure the transverse beam profiles for each ring. Special care has been taken in designing the mirrors to handle the large beam power.

The machine tune is measured using a spectrum analyzer processing signals from dedicated BPM-style pickups.

8 CONTROLS

The control system of PEP-II is an extension of the very successful SLC system. By maintaining this system, high-level applications and sophisticated analysis packages come with modest effort. The SLC VAX system has been upgraded for the PEP-II era. In addition, the CAMAC-based system has been augmented to incorporate VXI control which is used by the bunch-by-bunch feedback and the EPICS-based RF and feedback controls.

9 COMMISSIONING RESULTS

By June 1997, the HER, the electron injection system, the control system and three of the five HER RF stations were complete. Two commissioning runs were done in this configuration; a one-month run in June 1997 and a five-week run commencing in September 1997. A one-month run with the full complement of RF followed in January 1998.

During the first run, beam was captured and successfully stored within the first week. By the end of the month, as much as 60 mamps had been stored and lifetimes in excess of 3 hours had been achieved. During the second run, stored currents up to 0.3 A were achieved in up to 1700 bunches. Single bunch currents of 12 mamps had been achieved (nominal is 0.6 mamps) indicating low broadband impedance. Lifetimes as long as 10 hours were seen at low currents. During the third run, with the full RF system in place and with all three low level feedbacks operational, up to 0.75 A was stored with lifetimes in the 2-3 hour range. With the feedback systems on (but not the longitudinal kicker), beams were very stable up to about 0.6 A; above these currents the onset of longitudinal instabilities were observed using the digital feedback system, the light monitor and a streak camera. Transverse, coupled bunch motion is seen to set in at currents of ~50 mamps, much below the expected threshold of ~250 mamps. The transverse system has enough gain to provide stable operation up to the highest stored currents of 750 mamps, but the cause of the low threshold is not yet understood. By contrast, longitudinal coupled bunch motion is seen to set in not at the expected ~300 mamps, but at ~600 mamps. The frequency spectrum of the oscillating modes corresponds closely to the simulated expectations, the surprize is the high threshold. There is some early indication from the data that a Landau-like damping effect is being seen in the bunch train, the damping being initiated by variations of the synchronous phase which result from the presence of the ~5% ion-clearing gap. Electron injection is clean, highly efficient and fast. Using 10 Hz of linac pulses, the ring was filled to 0.75 A in 5 minutes, which translates to under a minute at the nominal fill rate of 60 Hz, well within the specification of 3 minutes.

The HER has been fairly well characterized at this time. Table II summarizes some of the achieved parameters. The lattice performs very close to model predictions. X/Y coupling is small, measured chromaticity is nominal. The bunch length is measured with a streak camera to be nominal. The relatively quick success is in large measure due to the robustness of the hardware, the power and sophistication of the control system and the investment in good diagnostics. In addition, the success is a validation of the novel, single-cell damped cavity RF system. The low level feedbacks and the bunch-by-bunch feedbacks were critical to storing large currents. Thermal management is well within specifications and there are no indications which preclude taking the HER well above 1 A. Average pressure around the ring is as expected for the accumulated dose of 50 A-hours.

Positron injection has been commissioned through the extraction, transport and match lines, through the injection straight and into the first LER arc.

Parameter	Units	Design	1st Feb. 1998
Energy	GeV	9.0	9.0, ramp to 9.1
Single bunch current	mA	0.6	12
Number of bunches		1658	1700
Total current	A	0.75	0.75
y/x coupling	%	3.0	down to 0.8
Damping Time	msec	37	32
RF voltage/cavity	MV	0.70	0.79
Synchrotron freq.		0.045	0.0447
Bunch separation	m	1.26	0.63<--->2200
Chromaticity		-43, -54 (natural)	-41, -48 (natural)
Beam Lifetime	hours	4	12 @ 50mA 2.5 @ 725mA

Table II. HER Commissioning Performance as compared with the design parameter.

ACKNOWLEDGMENTS

PEP-II is the result of the labors of hundreds of very talented people at SLAC, LBNL and LLNL. Without their very hard work and dedication, this facility could not have been realized so quickly. In addition, the Project enjoyed excellent support from all levels of the DOE.

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