PEP-II Alignment*

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1. INTRODUCTION

The PEP-II Asymmetric B-factory consists of two independent storage rings, one located atop the other in the 2200m-circumference PEP tunnel. The high-energy ring, which stores a 9-GeV electron beam, is an upgrade of the existing PEP collider. It re-utilizes all of the PEP magnets and incorporates a state-of-the-art copper vacuum chamber and a new RF system capable of supporting a one-amp stored beam. The low-energy ring, which stores 3.1-GeV positrons, is new construction. Injection is achieved by extracting electrons and positrons at collision energies from the SLC and transporting them each in a dedicated bypass line. The low-emittance SLC beams will be used for the injection process.

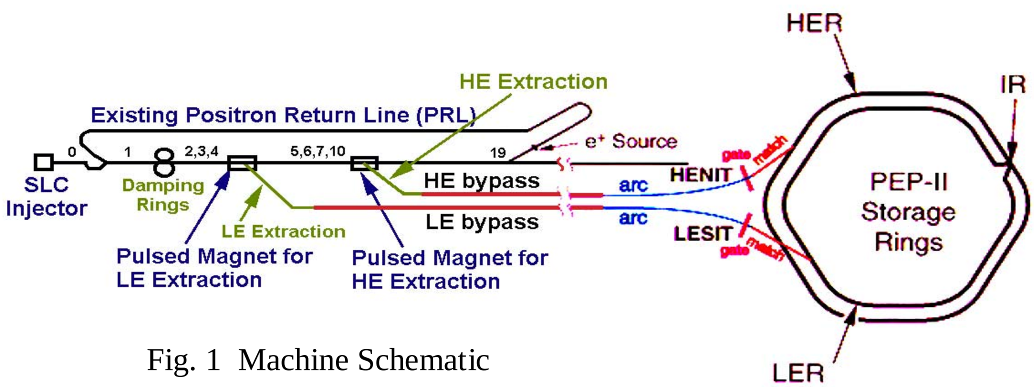

Fig. 1 Machine Schematic

The construction of PEP-II is a collaboration of SLAC, LBL, and LLNL and will be completed in October 1998. The B-Factory facility, PEP-II and BABAR detector, will pursue a broad agenda of physics involving the heavy quark and heavy lepton sector,

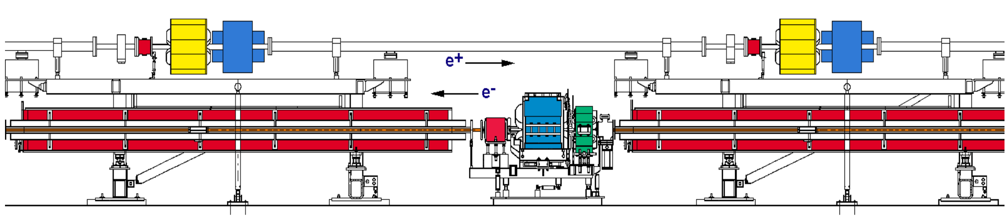

Fig. 2 Rings elevation schematic

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with primary emphasis on the understanding of CP violation. At full luminosity, PEP-II will produce about $1*10^8$ b and c quarks, and roughly the same number of taus per year.[1]

2. TOLERANCES

2.1 Injector

The rms relative alignment tolerances in the extraction, arc, and match areas are +/-0.25mm and in the bypass region +/-1.0mm. While these alignment tolerances did not require heroic alignment measures, the effort was complicated by very tight schedules and the great distance spanned by the system. Since the 30-sector linac will accelerate particles to 50 GeV and only 3.1 and 9 GeV are required, positrons and electrons are extracted at sectors 4 and 10 respectively. Thus, the high and low energy injectors are 2.3 and 3.0 km long.

2.2 Rings

The rms global alignment tolerances for the rings are +/-1.5mm for quadrupole positions and +/-5mm on the circumferences. The quad-to-quad relative alignment tolerances are +/-250μm and 150μm for the HER and LER respectively. Dipole rolls must be set to +/-0.3mrad rms.

3. ALIGNMENT

The first PEP network surveys were the last operations conducted using forced centering. Since then the impressive capabilities of the Leica TC2002 have been used to full advantage. Virtually all survey and alignment activities are now conducted in free stationing mode. Abandoning forced centering has not only saved labor, but improved accuracy by eliminating systematic errors associated with the forced centering system. Also very important is the ability to measure positions in 3D and monitor moves with a single instrument. Figure 4 shows the results of a shoot-out between SLAC's four TC2002s and interferometer. A TC2002 was set up at one end of the bench and the

Fig. 3 TC2002 and accessories

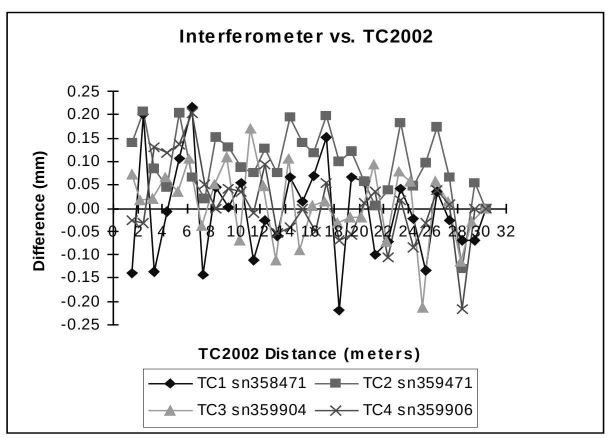


Fig. 4 TC2002 vs. interferometer

interferometer at the other. The reflector trolley was equipped with two reflectors, one facing each instrument. Then distances were observed at one-meter intervals over the 30 meter bench length. Each EDM observation was differenced with the observation to the 30m point to yield distances from one to 30 meters. The same was done with the interferometer values and then the two data sets were compared. The total range of discrepancies is less than +/- 250μm and the standard deviation of a single measurement is less than 70μm.

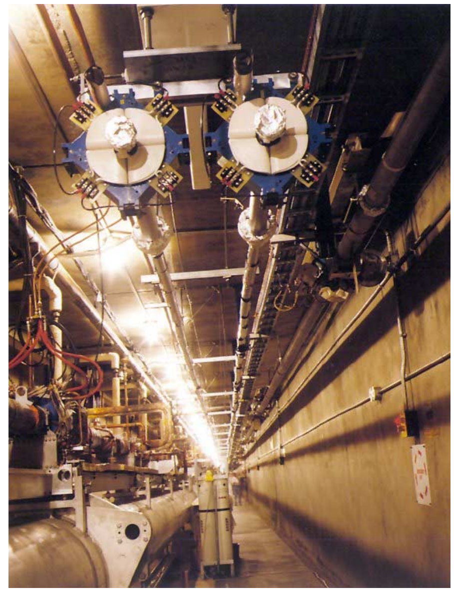


Fig. 5 Bypass quad pair

3.1 Injector

The installation of the injection system was squeezed into two SLC downtime periods. There was no time to measure a network spanning linac sectors 4 to 28 (2.2km) to control the bypass beamlines. Instead, a network was run from sector 4 through 12 to cover the extraction areas and the linac laser alignment system was used to connect that network to the ring network at sector 28. The results of a linac laser survey were used to assign coordinates to external references on the linac. Simple fixtures were built to allow the references to be included in the network surveys.

All injector alignment tasks, save those for the bypass vacuum chambers, were straightforward Leica TC2002 operations. The floors and walls of the extraction, arc, and match areas were populated with 3-D monuments to facilitate this. The bypass area, on the other hand, required different approaches due to its unique configuration. The bypass lines consist of one ceiling-mounted quad-BPM-corrector cluster per sector (100m) and two-inch drift chamber supported every 3 meters. Obviously, magnet alignment was the smaller portion of the task. The magnets were laid out and aligned with the TC2002, using the linac reference fixtures and linac laser survey coordinates to resect the instrument. During layout, reference points were established on the floor to control the chamber alignment. Over these points laser theodolites and targets were set up to establish visible reference lines. The ironworkers first used the visible laser lines with a fixture to rough-in the chamber supports and then the surveyors used a different fixture to align the chambers.

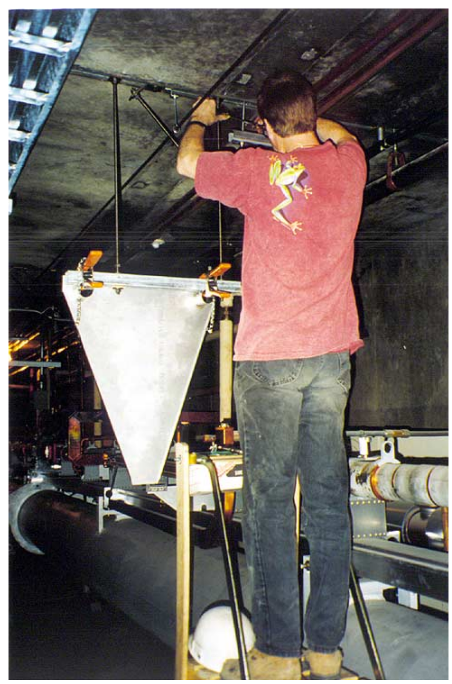


Fig. 6 Bypass chamber support installation

3.2 Rings

Simulations indicated that the global tolerances could be met with tunnel measurements alone by using the old PEP floor monuments as our primary control network. There are 102 floor monuments in the ring and additional monuments extending upstream through the north and south injection tunnels to the linac. The monuments accept 3.5" sphere targeting. The primary network was measured in early 1994 using Kern E2 theodolites, ME5000 distance meter, and our SLC forced centering system. Shortly thereafter 300 additional 3D ring monuments were installed and the NIT/SIT network was extended upstream to sector 27 to form a secondary net. The new monuments accept 1.5" targeting and were measured with the TC2002. All ring layout, stand positioning, and initial HER magnet alignment were performed with TC2002s as well.

3.2.1 HER Quad Fiducialization

The 286 main ring quadrupoles were fiducialized with SLAC's CMS 3000 laser tracker. An area in the magnet warehouse was cleared so that the tracker could be rolled on its stand all the way around the magnets. Monuments were installed in the floor around the perimeter of the cleared space. Six fiducial bushings were welded onto each magnet, four on the top and two on the aisle side, to accept removable magnetic mounts for 1.5 inch sphere targeting. The magnet engineer designed a one-meter-long mandrel that registered on two pole tips, projected through the magnet, and held a magnetic sphere mount on axis at each end.

Fig. 7 Mandrel in quad bore

The magnets were measured six at a time. They were arranged in a line, in three groups of two to facilitate mandrel handling, as shown in Figure 8. The tracker was situated adjacent to the first magnet pair, on the "aisle" side, and measurements were recorded to all floor monuments, the fiducials and exposed lamination edges on the two magnets, and the mandrel in the two magnets in four different positions each. With bungy cords and shims the mandrel was forced into contact with each pair of pole tips for four different positions. In turn, the tracker was moved into position next to the aisle side of each magnet pair for data collection. Then the tracker was rolled to the "wall" side and another data set was recorded next to each

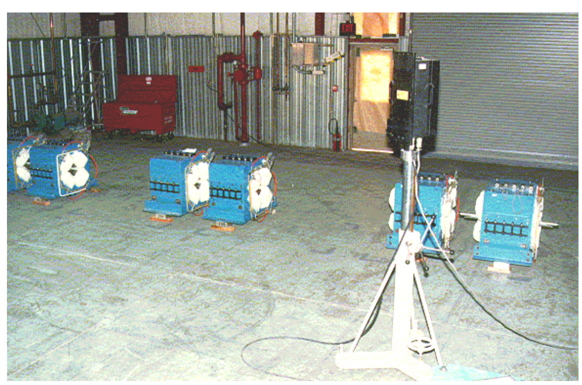


Fig. 8 HER quad fiducialization

magnet pair. One surveyor in one shift measured this large, six-magnet data set. On the swing shift, another six magnets were moved into position to be measured the next day.

The day's measurements were processed in one big adjustment. The resulting coordinates were parsed into individual magnet data sets for further processing. Each magnet data set was used to generate magnet-centered fiducial coordinates. The beamline axis was defined by the axis of a best-fit cylinder through the mandrel coordinates, magnet center by the average of magnet end positions, and roll by a best-fit plane through lamination edge coordinates.

3.2.2 HER Quad Raft Initial Alignment

The HER quad rafts use the LBL six-strut adjustment system concept.[2] The quad is bolted to its raft and the raft connects to a base plate via six struts. Each raft assembly bay was equipped with an alignment scope and bore target. The mechanical technicians used the scope, target, and adjustment struts to position the quad centerline relative to two mating holes in the baseplate. In the tunnel, hole patterns were laid out and drilled, the threaded anchor studs and steel mounting plates were installed, the plates were leveled and then grouted. Next, the mating pin locations were laid out on the mounting plates and the ironworkers followed with a magnetic base drill to make the holes and install mating pins. The mating pins controlled a quad raft's position and orientation upon installation. This installation sequence proved very effective as most quads were found within 1mm of their ideal positions. Initial alignment was performed by measuring and monitoring moves with the TC2002, two magnets per setup. Production averaged 8 rafts per shift. Vacuum, electrical, and water system interconnection followed.

4. RESULTS

After initial alignment, the quadrupoles and the network were mapped with a combination of CMS 3000 laser tracker, TC2002, and NA3000 digital level measurements. The laser tracker was set up next to each quad where measurements were recorded to the quad, its BPM, to the adjacent quads, and to a number of wall and floor monuments. The TC2002 was used to measure only the floor monuments, the primary

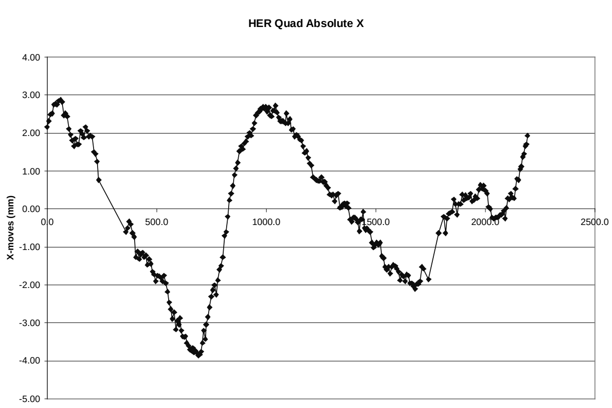
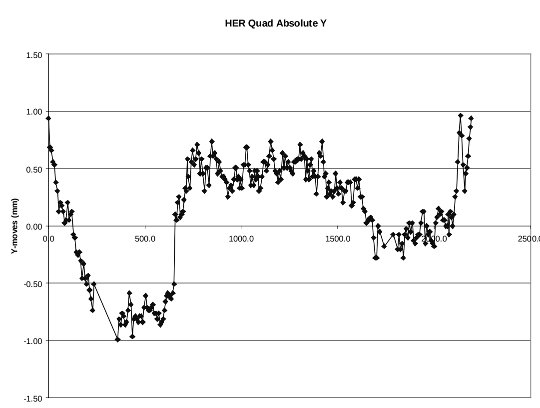


Fig. 9 Quad center X absolute positions



Fig, 10 Quad center Y absolute positions network. The NA3000 was used to level over all monuments and to level from quad to quad hitting just one point per quad. This huge data set was analyzed in a single adjustment. The coordinates were transformed into the ring system by fitting the new primary network values to the old. Figures 9 and 10 show the resulting absolute quadrupole positions. The long-period trends may be due to the end of a multi-year drought and the beginning of an unusually wet time as well as survey epoch. Figures 11 and 12 show a histogram of the distribution of quad center offsets from a smooth curve.[3]

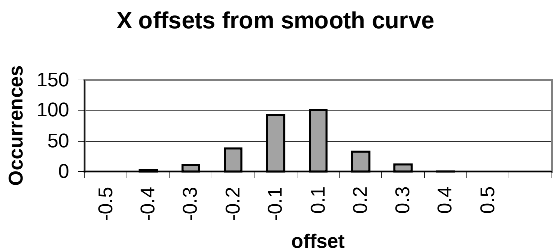


Fig. 11 Histogram of quad center X-offset from smooth curve

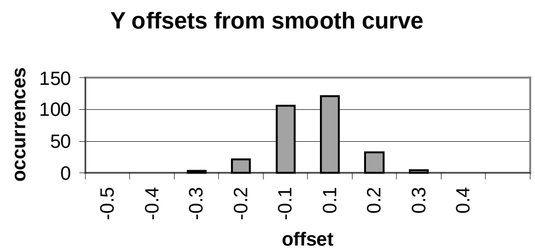


Fig. 12 Histogram of quad center Y-offsets from smooth curve

The standard deviations in X and Y are 20µm and 80µm respectively. To save money, no further HER alignment will happen until the LER is installed.

5. CONCLUSIONS

The high energy ring received its first beam late in May and took a partial turn to a tune-up dump without incident. In June, on the first attempt and without correctors, 10 turns were achieved. Later in June RF capture was achieved and 50 milli amps were stored for several hours. During the July-August installation period the rest of the RF system and the injection septum were installed. In September, 285 milli-amps were stored, the most current ever at this energy.

6. REFERENCES

[1] PEP-II CDR and home page.

[2] W. Thur: 'Rigid, Adjustable Support of Aligned Elements via Six Struts', Proceedings of the Fifth IWAA, ANL, 1997.

[3] H. Friedsam, W.A. Oren: 'The Application of the Principal Curve Analysis Technique to Smooth Beamlines,' Proceedings of the First IWAA, SLAC, 1989.