SUMMARY OF BEAM INSTRUMENTATION AND BEAM DIAGNOSTICS SESSION

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Abstract

This report is a summary of the beam instrumentation and beam diagnostics session of the eeFACT2016 workshop.

LIST OF PRESENTATIONS

Talks presented in the beam Instrumentation and beam diagnostics session are:

- Beam Instrumentation Needs for a Future e+e- Collider Based on PEP-II Observations, J. Seeman, SLAC,
- Beam Position Measurements at Synchrotron Light Sources, V. Smalyuk, BNL,
- Beam Instrumentation in SuperKEKB, H. Fukuma, KEK,
- Measurement of Beam Polarization and Beam Energy in One Device, N. Muchnoi, BINP.

SUMMARY OF THE PRESENTATIONS

Beam Instrumentation Needs for a Future e+e- Collider Based on PEP-II Observations

J. Seeman presented needs for various beam measurement requirements and techniques for a future e+e- collider using PEP-II observations.

Future e+e- colliders will operate with many bunches, short bunch lengths, small emittances, high currents, and small beta functions at an interaction point (IP). The stability of the colliding beams with these characteristics will depend on detailed, high precision, and continuous measurements. Since beam parameters of a future e+e- collider are not far from B-factories, observations at PEP-II are useful as a starting point of the discussions.

Various measurement techniques for beam position, beam size, bunch length and beam lifetime were used at PEP-II. IP luminous region parameters such as beam sizes and beta functions were measured using data from PEP-II and BaBar together. Beam instabilities were analyzed and suppressed by the sophisticated bunch-by-bunch feedback system.

HOM generated by the beam with high current and short bunch length causes following serious effects:

- Heating of the vacuum elements
  Temperature and vacuum rise
  Chamber deformations and vacuum leaks
  Decreasing the pumping speed
  Out gassing
- Multipacting, sparking and breakdowns
  Vacuum leaks
  Melting thin shielded fingers
  Longitudinal instabilities
  High backgrounds (high radiation level in the detector)
- Electromagnetic waves outside vacuum chamber
  Interaction with sensitive electronics

Many HOM related events such as damage of a cavity tuner and a SiC tile in IR and an overheated vacuum valve occurred at PEP-II. A lot of measurements, for example, an estimation of HOM power from RF power measurements, temperature monitoring and modeling and moderate/fast real-time vacuum pressure monitoring were necessary for identifying damaged parts.

The talk was summarized as:

- Many complicated measurements are needed in a high-power, high-current collider,
- Measure and record versus time as many parameters as possible to diagnose issues,
- Find new innovative measurement techniques,
- Many measurements relate to potential hardware damage to the accelerator,
- Many measurements need to automated and computer monitored to make the accelerator operation safe.

Beam Position Measurements at Synchrotron Light Sources

V. Smalyuk presented beam position measurements at synchrotron light sources mainly based on beam position monitors (BPMs) at NSLS-II.

Modern light sources demand following severe performances for the BPM system:

- Beam stability of 5-10% of the beam size,
- Active interlock system which damps the beam to protect the storage ring and the frontend components from damage by synchrotron radiation if its orbit exceeds the safety limits (e.g. 0.5 mm and 0.25 mrad at insertion devices),
- Fast data transfer and processing for fast orbit feedback systems,
- Flexibility of the system for machine commissioning, lattice optimization and beam studies.

Recent BPM signal processing is mainly based on digital signal processing. A list of BPM signal processing electronics in major light sources shows two third use the Libera digital processor of Instrumentation Technologies, while one third use homemade processors. NSLS-II BPM module is a homemade module whose architecture of analog frontend is based on under-sampling of the signal

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at the 500MHz. An ADC clock is locked to the revolution frequency. Sampling rate of ADC is 310 samplings per turn. Signal processing is "single-bin" DFT calculation at the turn by turn (TbT) rate. BPM resolution reaches about 0.5 μm. Fast orbit feedback is successfully implemented to stabilize orbit oscillation of less than 100Hz. Post mortem data are used to find beam dump sources from, for example, cavity trip, equipment protection system, personnel protection system, power supplies, active interlock and power dips.

Various measurements are possible owing to the TbT digital signal processing. In order to measure the lattice parameters (e.g. betatron tunes, chromaticity, betatron functions and corrector orbit response) so as not to affect the effective beam size enlargement, a small controlled sinusoid disturbance is given to the beam using an actuator such as a strip line and a corrector magnet, and then this frequency component in a data stream (bunch-by-bunch position, turn-by-turn position, fast orbit data) is detected using a digital detector. Data are accumulated over a certain measurement period which determines bandwidth and thus measurement noise.

AC LOCO (Linear Optics from Closed Orbits) is an effective technique of lattice correction. Sine wave excites the beam via fast correctors. Simultaneous excitation of many correctors with different frequencies is possible. Recorded is the fast acquisition (10kHz) data. Synchronous detection is applied to get the beam oscillation amplitude. Standard LOCO technique is applied for fitting the measured orbit response matrix to the model by changing quadrupole strengths, BPM gains and rolls and corrector gains and rolls.

Standard BPM signal processing at NSLS-II looks at the entire turn. Applying a time gate to BPM ADC signals results in resolution improvement by factor of 3 to 4. Unique NSLS-II BPM resolves groups of bunches within a turn by the gated turn-by-turn measurement. TbT data for each train kicked with different amplitude are obtained by a single pulse of a kicker. The single-shot method eliminates possible errors of amplitude dependent tune shift measurements caused by machine drift or jitter.

The reason why the homemade processor instead of commercial processors was adopted at NSLS-II was asked in the discussion session. The answer was that the points choosing the homemade processor were a flexibility to modify the firmware and a cost.

Beam Instrumentation in SuperKEKB

H. Fukuma presented an introduction of instrumentation of SuperKEKB and its performance at phase 1 operation which has just finished in this June.

New narrowband BPM detectors with a detection frequency of 509 MHz have been developed and used together with KEKB detectors. Gain calibration and beam based alignment of BPMs was successfully done using the narrowband system in phase 1 operation.

About 270 gated turn by turn detectors (GTBTs) are to be installed at selected BPMs to measure the optics during collision. A non-colliding pilot bunch is kicked by the bunch-by-bunch feedback system and then the GTBT measures turn by turn position of the pilot bunch using a fast gate to select the signal of the pilot bunch. In phase 1 operation without beam collision, 117 GTBTs were installed and used for injection tuning, measurement of orbit oscillation and measurement of damping of coherent oscillation.

A special wideband detector is to be installed at four BPMs closest to the IP for orbit feedback to maintain stable collision. A prototype model was tested in phase 1 operation.

A bunch-by-bunch feedback system is upgraded using low noise frontend electronics and new 12 bits iGp digital filters which were developed under US-Japan collaboration (KEK-SLAC). The longitudinal feedback system prepared in LER consists of four DAFNE type kickers, with 2-input and 2-output ports in order to get larger capture range. Observed transverse and longitudinal instabilities in phase 1 operation were successfully damped by the feedback system. The measured damping time of the transverse feedback system was about 0.5ms in both rings.

Three kinds of photon monitors, an x-ray beam size monitor (XRM), a visible synchrotron radiation monitor (SRM) and a large angle beamstrahlung monitor (LABM) are installed in SuperKEKB. The XRM uses coded aperture imaging to measure the vertical beam size. Light from an object is modulated by a mask. The resulting image is calculated through mask response including diffraction and spectral width by Kirchhoff integral over mask for various beam sizes to make a template assuming a Gaussian profile. The beam size is determined by a template fit to the measured image. The vertical size measurement by the XRM in LER in phase 1 operation showed good fill-to-fill repeatability and good agreement between different masks.

The LABM detects beamstrahlung radiation which is the radiation of particles of one beam due to the bending force by the electromagnetic field of the other beam. Beamstrahlung polarization at specific azimuthal points provides information about the beam-beam geometry. The LABM in SuperKEKB is being built mainly in US, mostly at Wayne State University.

In the discussion session a possibility to obtain the non-Gaussian beam profile by arrangement of the measurement system such as masks and filters was pointed out.

Measurement of Beam Polarization and Beam Energy in One Device

N. Muchnoi presented a possibility to measure beam polarization and beam energy in one device. Inverse Compton scattering (ICS) of laser radiation is a currently available reliable method for beam polarization measurement and energy determination. The future high energy lepton colliders require polarized beams and polarimetry, especially for application of resonant depolarization technique for precise beam energy calibration at circular machines.

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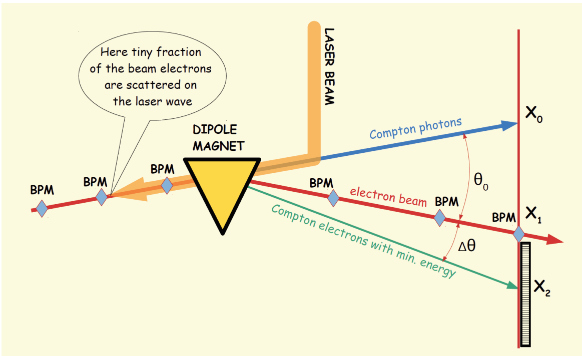

Figure 1: Conceptual layout of the measurement of beam polarization and beam energy.

The proposed method is to measure a 2-dimensional electron distribution of ICS instead of measuring a photon distribution. Compton polarimeters usually deal with scattered photons. At higher electron energies, since the divergence of γ–ray beam is small and high energy synchrotron radiation photons appear, it is reasonable to look at the scattered electrons. One good point is the dimension of the angular distribution of scattered electrons does not depend on the beam energy.

Figure 1 shows a layout of the measurement. Analysis of 2-dimensional distribution of ICS electrons allows to measure beam polarization degree and direction as well as the field integral (Bdl) exactly along a beam trajectory in a conventional magnetic spectrometer. A bending angle of Compton electrons with a minimum energy is proportional to the beam energy. The x-y distribution of scattered electrons is the convolution of the ICS cross section and a transverse distribution of electrons in the beam. The polarization and beam energy are obtained by fitting of the angular distribution of the recoil electrons of ICS.

The proposed approach has no limitations in beam energy. It only requires a small value of vertical emittance of the electron beam.

One comment in the discussion session encouraged a proof-of-principle experiment. Another comment recommended finding an available space to install the detector in the ring.

COMMENTS

Followings are my personal comments.

- Demands for new kind of innovative instrumentations in the rings (FCC and CEPC) did not appear in the workshop as far as I listened. And it was not clear for me what instrumentations are sufficient for the rings. Specifications for the instrumentation will become clear as the design of the machines proceeds.
- Information from existing or past colliders is important to discuss the FCC and CEPC instrumentation. I hope experience at SuperKEKB gives useful information for their design.
- We need to pay attention to the instrumentation in storage ring light sources because its progress is impressive.

ACKNOWLEDGMENTS

I would like to thank all the speakers of the session for giving us interesting and useful information. I would like to also thank the organizers of the workshop for inviting me to the workshop. I learned much in this workshop.

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