Minutes of the CBETA EPS Review (for stage 1)

March 1

Time: 10:00 to 11:30, March 1, 2019

CBETA project personnel present: Nilanjan Banerjee, Adam Bartnik, John Dobbins, Colwyn Gulliford, Georg Hoffstaetter, Rob Michnoff, Steve Peggs, Dejan Trbojevic

Off-project personnel present: Jerry Codner, David Rubin, Sergei Seletskiy

Purpose of meeting:
To review the CBETA equipment protection system (EPS) for stage 1 of commissioning to ensure that the system will adequately protect the machine for the stage 1 beam, which includes limiting the average beam current in the FFA loop to 200 pA to prevent permanent magnet damage.

Related documentation:
CBETA Equipment Protection System Description:
https://docs.google.com/document/d/1zoNZtdD_3E4BWoLt0BdfqcTbcgH6WGTuwgNiMugJASU

Meeting Agenda:
10:00 - 10:15 Overview of CBETA and its Loss Mechanisms (Georg Hoffstaetter)
10:15 - 10:30 Equipment Protection System Overview (Nilanjan Banerjee)
10:30 - 10:45 Beam Modes for low current operations (Adam Bartnik with demonstrations by Colwyn Gulliford)
10:45 - 11:00 Radiation Monitors for low current operations (John Dobbins)
11:00 - 11:30 Discussion (lead by Georg)

Presentations are available in the box at: https://app.box.com/folder/68719414014

The following comments were made or questions asked during the meeting:

1. Question (Sergei): What is the response time of the existing fast shutdown system? Answer (Adam): under 10 microsecond.
2. Question (Sergei): What is expected safe current in terms of heat damage? Answer (Adam, John): about 1 uA.
3. Question (Sergei): Is synchrotron radiation expected to cause issues? Answer (Adam): No
4. Question (Sergei): For automatic changing of beam mode parameters, is the dipole magnet setting or current measurement used? Answer (Adam): The setting is presently used. All agreed that this should be changed to use the measurement.
5. Question (Sergei): How is the beam current known? Adam explained that a combination of the BPM sum signal and laser trigger rate will be used. Adam also explained that a faraday cup at the end of the diagnostic line can be used to measure the charge per bunch and calibrate the BPM sum signal. (Something not discussed at the meeting but important to

note is that using BPMs for beam current measurements is not precise and will likely vary as the beam position changes.)

6. Sergei cautioned that if there is a valve between the gun and a BPM that is being used for beam current detection, the state of that valve must be known to prevent a “no beam” detection at the BPM when in fact the beam is continuously hitting the valve.

7. Sergei explained that the LEReC laser system has incorporated a mechanical shutter to help decrease the extinction ratio. He suggested speaking with Patrick Inacker at BNL for more details.

8. Question (Dejan): Will the CsI loss monitor detectors be affected by the magnetic field of the permanent magnets? Answer (John): A test has not yet been performed to check this, but will be.

9. Sergei commented that attenuation of the loss monitor signal has been noted when losses are detected at the end of the fiber optic cable. John stated that he is aware of this and that the sensitivity varies by a factor of 2 throughout the length of the fiber.

10. Dave Rubin indicated that at CESR radiation damage to permanent magnets was worse than predicted by simulations. Discussion ensued about how to best determine the actual affects. A plan for testing permanent magnet degradation with know induced radiation levels should be developed and executed. Such tests have previously been discussed and are known to be important.

11. Sergei recommends that all machine protection system equipment be hardware based, not software based at the control system level. John explained that the CBETA fast shutdown system, which includes the fiber/PMT loss monitors will be hardware based. However, the slow loss monitor system using the CsI detectors is planned to be control system software based.

12. Sergei suggests making sure that no ambient light hits the photo cathode in the gun. This could result in DC beam that has the potential of being accelerated. How to measure if this is occurring is not clear but requires additional consideration.

13. Sergei commented that the complete machine protection system including shutting down the laser should be fail-safe. He recommends that as part of the system testing, each cable be disconnected to confirm fail-safe operation.

14. Sergei suggested that one or two people be designated as responsible for the machine protection system parameter settings to ensure that the machine is adequately protected against damage. He also suggested that these responsibilities be assigned to people outside of the scientific group.

The following comments were provided after the meeting by Sergei Seletskiy:

General failure scenarios

- The main concern is an accumulated radiation damage to the permanent magnets. The EPS requirements from such a failure are the most restrictive ones.
- The heat damage to in-vacuum components from missteered high energy nigh current beam was considered.
- The long-term heat load on in-vacuum components from synchrotron radiation was found to be negligible.

EPS parameters

- Reaction time – 10 us. CBETA team measured the end-to-end time of inhibiting the beam and found it to be within the specifications.
- Safe current – 100 pA. Beam current limiter will be employed to guarantee that during the first phase of operation the current does not exceed 100 pA.
- Tolerable routine loss – 100 pA.
- The accumulated dose experienced by the magnets will be monitored with dedicated dosimeter.

Interlocking mechanism

- The beam is inhibited by closing the fast (EOM) and slow (mechanical) laser shutters.

Modes of machine operation

- Modes are switched automatically based on the machine setup observed by the EPS.
- Modes switching is based on measured beam current and on dipoles settings.
- The beam current is measured with the BPMs calibrated versus Faraday Cup. BPM sensitivity is sub-pC/bunch. There are no insertable devices between the gun exit and the first BPM.
- The bends currents are determined from their setpoints.

EPS Diagnostics

- Fast devices include PMTs retrofitted with 2 m long scintillating fiber, BPMs, LLRF. All fast devices have an adequate reaction time.
- Slow devices include dosimeters, vacuum gauges, cryogenic temperature monitors etc.

EPS structure

- There is a dedicated EPS controller.
- All the fast diagnostics is hardwired to the controller.
- Some of the slow signals are monitored through control system software.

EPS Procedures

- Fail-safe procedure is in place and has been exercised successfully.
- Commissioning procedures are in place. The commissioning routine has been automated.
- The procedures for the EPS administration do not exist so far.

Recommendations

- For dipole settings, instead of setpoints, utilize the return current measured with dedicated DCCTs.
- Hardwire all diagnostic signals to the EPS controller. Avoid using software to communicate any diagnostic readings to the EPS.
- Assign one or two persons who will be responsible for setting and adjusting the EPS parameters. Eventually the task of the EPS administration must be assigned to a person from outside of the scientific team.

- Make sure that no ambient light reaches the cathode.
- In addition to the work on improving the laser extinction ratio make sure that there are no laser failure modes, which might result in low current CW beam undetectable by the BPMs.

The following comments were provided after the meeting by Jerry Codner:

- The EPS document defined the radiation dose that can be absorbed by a magnet before performance of the machine is adversely affected. Other components were considered but the permanent magnets are the most vulnerable to radiation. It was agreed that dosimeter placement will be important and may have to be changed based on experience. Meticulous tracking of estimated dosages need to be kept for each magnet. Radiation is considered to be somewhat randomly distributed, but this might not be the case. Some method will need to be determined for when a magnet has suffered enough damage that it must be replaced. The CsI detectors and survey badges will give some measure of this dose.
- The EPS is highly advised to be hardware based and not dependent on software or firmware. If the slower EPS components are software or firmware dependent, then a deadman or watchdog hardware component must be included to indicate that a process is no longer running. Furthermore, the EPS needs some independent method of integrity check regardless of its type.
- Dark current emission from the gun was addressed but seems not to be resolved. This was an important lesson learned by BNL.
- Deviations in magnet power supplies were stated to be detected within 1 millisecond. How is this done?

The following comments provided after the meeting by David Rubin

The review was focused on protection of the permanent magnets that are the guide field from radiation damage. Effect of radiation on magnet field quality is determined largely by simulation (GEANT4,MCNP6). Tolerance, characterized as integrated dose is 100pA at 150MeV for 1 hour, beyond which point altered field cannot be compensated with correctors.

- The EPS document states that one region of a permanent magnet is demagnetized with a 100pA beam at 150MeV in 1 hour
- The whole magnet is damaged in 100 hours

Is replacement required if one region is damaged?

Or does the magnet continue to perform as required until it is entirely damaged?

Commissioning

The fast beam loss detectors system is required to shut off the laser within 10 micro-seconds to minimize radiation damage, even at the lowest measurable beam current of 100pA. That allows precious little time to measure and correct orbit, energy, phase, etc. Indeed, it would seem to allow no more than 10 micro-seconds to make a measurement.

Another way of thinking about it is that you have 1 hour’s worth of tuning to steer the beam past an aperture. Having spent many hours tuning injection into CESR that does not seem like a lot of time. Good use of the limited time available will depend on commissioning beam instrumentation with very little beam.

Beam loss is detected by CsI beam loss monitors, scintillating fiber and beam position monitors. BPMs probably have inadequate resolution to be useful to detect beam loss at 100 pA.

Beam position monitors nominally require 100pA in 11 bunches to achieve 1mm position resolution. Is that the optimal configuration. It might make more sense to accelerate single bunches in the FFA tuning mode with sufficient charge (10pC) to get precision position measurement that can be used to correct trajectory.

What are the minimum beam requirements to commission the beam position monitors, establish timing triggers, preliminary calibration, etc?