The Twenty-First KEKB Accelerator Review Committee Report

June 15, 2016

Introduction

The Twenty-First KEKB Accelerator Review Committee meeting was held on June 13-15, 2016. Appendix A shows the present membership of the Committee. Two members of the Committee, In Soo Ko and Matt Poelker, were unable to attend. The meeting followed the standard format, with two days of oral presentations by the KEKB staff members, followed by discussion between the Committee members. The Agenda for the meeting is shown in Appendix B.

The amount of progress that has occurred since the last review is impressive, but the expected budgets may delay the following steps. As always, the high standard of the presentations impressed the Committee, particularly the remarkable evolution of the new hardware that isnow installed in the tunnel, and the excellent results from the phase 1 commissioning. The Committee examined the progress of the project.

The most important recommendations of the Committee were presented to the KEKB staff members before the close of the meeting. The Committee wrote a draft report during the meeting that was then improved and finalized by e-mail among the Committee members. The report is available at **http://www-kekb.kek.jp/MAC/**.

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A) Executive Summary

Since last year's ARC meeting the SuperKEKB project has made spectacular progress. The ARC warmly congratulates the SuperKEKB team for a successful fast beam commissioning. In only a couple of months this commissioning has resulted in storing close to 1 A of beam current in both HER and LER, encouraging vacuum conditioning with more than 500 Ah of stored beam in both rings, accurate optics correction, HER injection using the electron beam from the RF gun, top-up injection, and a characterization and optimization of the Belle II background conditions using the BEAST-II Phase 1 set up and various ring collimators.

It is important that Phase 2 commissioning starts in the fall of 2017 and phase 3 data taking with the complete Belle II in 2018, so as to enable Belle II data to make competitive contributions to frontier flavor physics.

The Belle II construction and integration with the machine are on track, but the schedule is tight. Phase 3 of the accelerator commissioning can begin when the Belle detector is complete. Some data taking with the Belle II outer detector could take place during the accelerator commissioning Phase 2.

The construction of the damping ring is progressing well and should be completed in time for Phase 2. Beam commissioning of the damping ring is now planned to begin in October 2017, just ahead of, and continuing during, the Phase 2 commissioning run.

The vacuum scrubbing is proceeding well. The electron cloud build up has been well controlled for Phase 1 operation, and can be further mitigated, e.g. by extended surface conditioning or by the installation of additional solenoids. The refurbished RF systems are performing well and have supported all the Phase 1 goals.

Finances have had a significant impact on the progress of the SuperKEKB project. The project has been very efficient in using the past available funding to manufacture the absolute basic needed hardware to get to Phase 1 commissioning. Substantial beams have been stored, keeping the project on a solid but delayed path forward. The 2016 budget is again a challenge to get ready for Phase 2 over the next year for the October 2017 commissioning start. The ARC supports the KEKB team's efforts for securing supplemental funding in 2016 and to promote a more satisfactory operation budget in the next fiscal year. This improved funding would help Belle II to be in more effective competition with the LHCb and other similar experiments at the CERN LHC collider and worldwide.

B) Recommendations: The Committee has made recommendations throughout the different sections below. The most significant recommendations are summarized here.

1) The Committee believes that SuperKEKB needs to remain the top priority of the KEK Tsukuba campus in the next few years if the commissioning and operation are to be successful in a timely fashion.

2) Despite the strong support of KEK management to increase staffing, including a few new junior hires and rehiring senior, experienced retired staff, the shortage of qualified staff continues to be a risk to successful completion of the project, the commissioning and operations. The number and skills of the additional staff members going forward should be optimized for the commissioning and operations phases of the project.

3) We encourage transfer of knowledge from more senior to younger staff to ensure continuity of system knowledge over the full lifetime of SuperKEKB.

4) Continue and expand involvement of international and domestic collaborators in the commissioning of all SuperKEKB accelerator systems (linac, damping ring, LER, HER).

5) Develop a complete, detailed commissioning schedule for the guns, linac and rings for the commissioning Phases 2 and 3. Follow the recommendations of the SuperKEKB RF Gun Committee.

6) Study the unexpected HER vertical emittance value. If possible, the question whether the observed large emittance is real should be clarified before the long stop of operation following Phase 1.

7) The SuperKEKB/Belle II interaction region (IR) is extremely complex and, although enormous progress has been made over the past year, the Committee recommends continued attention to the issues of the beam-beam interaction, beam lifetime, superconducting magnets, vacuum pressure, backgrounds, assembly, and machine detector interfaces.

8) Strengthen quality assurance of procedures for installation of magnets in the cryostat.

9) While an optics solution exists for Phase 2, reaching the final luminosity in Phase 3 depends on solving a challenging set of interconnected beam dynamics problems. Despite considerable progress, a complete overall solution has only partially been obtained. The Committee recommends that studies continue to optimize the luminosity.

10) The electric power consumption is the main cost driver for operation. Electricity cost per MWh for SuperKEKB is significantly higher than at the time of KEKB. Strategies should be devised by the KEK management to lower the electricity costs of SuperKEKB operation in the longer term.

11) The Committee recommends that the online version of the SuperKEKB Technical Design Report be regularly updated.

C) Findings and Comments

1. Overview of SuperKEKB, status and plans

The construction of SuperKEKB is well advanced, aiming at 40 times the luminosity of KEKB with a goal of 8×10^{35}/cm^2/s. This new accelerator uses the techniques of a nano-beam scheme with β_y^* of 0.3 mm and doubled beam currents in each of the rings at 4x7 GeV. There will be an 83 mrad crossing angle at the IP with 2500 bunches collided, having beam currents of 2.6 A for electrons and 3.6 A for positrons. Many of the accelerator systems are the same for SuperKEKB as for KEKB but there are also many new systems including LER magnets, LER and HER vacuum chambers, IR layout and magnets, LER and HER wiggler sections, RF configuration, diagnostics, photo-injector-gun, and positron damping ring.

The Phase 1 installation of the two rings was completed in early 2016. Over 1000 new vacuum chambers have been produced. Many pre-running system checks were completed before the beam was turned on. Commissioning for Phase 1 for both beams started in February 2016. As planned, Belle II and the final IR magnets and vacuum chambers were not installed. Beam commissioning has proceeded very well with progress more rapid than the corresponding period with KEKB. Vacuum scrubbing is well under way. Currents of 830 mA of electrons in HER and 910 mA of positrons in LER have been achieved. Initial data on IP backgrounds were taken by the BEAST-II Phase 1 configuration. Many beam parameters have been measured with most being what was predicted. The RF system has been running at about 70% of full specifications. The use of electrical power has to be watched carefully as this cost determines the running time. More commissioning will be done over the next few days before the upcoming 18 month shutdown. The IR will be taken apart in July 2016 to start the final IR and Belle II installation.

Phase 2 commissioning with the full IR and Belle-II (but without the vertex detector) will start in November 2017. Belle II may take a little production data during Phase 2 running if the target luminosity of 1×10^{34}/cm^2/s can be reached.

Phase 3 will have the full accelerator and full Belle II detector installed. It will start around November 2018 after all upgrades are finished.

The proposed schedules for Phases 1 and 2 depend on anticipated yearly funding and any funding supplements allocated to SuperKEKB and Belle II operations.

Recommendations:

R1: Develop a few alternative high-level spending profiles in case the anticipated funding profiles do not arrive as planned.

2. Belle II Physics and Construction Status

A very impressive display of the physics questions Belle II could address was presented. There are several hints that there is something beyond the Standard Model in flavor physics studies. The decay of heavier particles, and especially of the bottom quarks, is sensitive to the existence of new particles, which allows for the probing of New Physics (NP) in high statistics experiments such Belle II or LHCb. We were presented with several decay channels, first studied by the previous B-factories, which hint at the possibility of NP where more data is crucial in settling the issue. It is vital that the detector start collecting data as soon as possible in order to remain competitive.

The status of the detector was also shown and the schedule for finishing the final subsystems (primarily the SVD and PXD vertex systems and the Aerogel RICH (ARICH)) indicated that the timeline was tight but possible. There have been a few difficulties with the ARICH HV and HAPD photo-sensors and an issue of signal cable space between the SVD and PXD was recently uncovered but there are no apparent showstoppers at present.

Recommendation:

R2: Maintain the present schedule for completion of the detector and IR magnets. Try to foresee possible issues and strive to produce mitigating strategies for keeping to the schedule. Further delays will weaken any impact the Belle II data could have on the heavy flavor physics searches for NP.

R3: If Phase 2 commissioning goes well and is successful, we suggest that the Belle II and SuperKEKB teams discuss the possibility of including an early physics run during the Phase 2 time.

3. Overview of Phase 1 Commissioning

An overview of the Phase 1 commissioning of SuperKEKB was presented. The goals included basic machine tuning, vacuum scrubbing with 360 – 720 Ah and optics tuning for low emittance. Total beam currents of above 0.8 A were reached both in the HER and the LER. The beam lifetimes reached 600 min (HER) and 75 min (LER) with the difference explained by the vacuum pressure. Significant progress in zero current LER emittance was achieved, approaching near design values. The X-Ray monitor in the HER has some issues and is being investigated. The commissioning progress was faster than in KEKB, illustrating the excellent preparation and learning experience. Several important issues were encountered and addressed:

(1) Strongly nonlinear vacuum pressure rise and a vertical beam size blowup as a function of beam current were found in the LER. As a countermeasure solenoids were installed at the Al bellows in the LER. The solenoidal fields strongly improved the vacuum behavior and were also effective in raising the blowup threshold by a factor 1.5.

(2) Frequent beam aborts associated with vacuum bursts were observed in the LER. The beam current where the bursts occurred has gradually increased. Possible causes are the discharge at poor electrical contacts by the wall current and the collision of dust (small particles) with the circulating beam. Dust particles were provoked by hammering the vacuum chambers and could reproduce the signature of the observed vacuum burst events.

(3) Longitudinal coupled bunch instabilities were observed in LER. Studies are ongoing.

(4) A few hardware problems were induced with the high beam currents, in particular a vacuum leak and damage to the feed-through of the transverse FB kicker.

(5) Coupling and dispersion correction are important for achieving a low vertical emittance and were indeed studied in the context of emittance tuning. While the HER corrections went well, a difficulty was encountered for the LER corrections. A leakage magnetic field from the Lambertson septum magnet with a skew quadrupole main component was identified as cause. Skew quadrupole magnets (ferrites) were installed for canceling the leakage field from the Lambertson, allowing much improved optics and almost nominal zero current emittance.

The committee congratulates the team for the excellent achievements. Rapid progress was demonstrated, major milestones were achieved, a few issues identified and problems addressed in a highly professional attitude.

Recommendations:

R4: Options for local shielding and correction of the Lambertson leakage field should be further investigated and, if possible, implemented.

R5: Try to reach beam currents above 1 Ampere in the last days of operation.

R6: Study whether the unexpected HER vertical emittance increase with current is due to beam-gas fast-ion effects on the beam size.

R7: The consistency of the measured vacuum pressure and the observed beam lifetimes should be shown in an analytical or numerical analysis.

R8: A survey of any other suspicious places for electron cloud in addition to the aluminum bellows should be performed.

R9: The longitudinal and transverse impedance measurements should be compared with the impedance model of the machine. This can allow early identification of limiting hardware for higher current operation.

R10: The tune spread along the bunch train should be measured, analyzed and compared to expectations.

R11: The current-dependent vertical emittance blow-up should be further analyzed and countermeasures developed.

R12: The residual coupling problem in the LER should be studied further.

4. Overview of Lattice

Upgrade of the KEKB Main Rings optics aimed at implementation of the novel NanoBeam collision concept with the expected 40-fold luminosity gain will proceed in 3 phases. Phase 1 is devoted to single-beam problems, without final focus QSC's and detector solenoid.

Two main tasks of Phase 1 commissioning are i) beam scrubbing of the vacuum components to achieve an acceptable background level for the Belle II detector before its installation; ii) tuning the lattice to the minimum vertical emittance (of the order of 10 pm), that is essential for the NanoBeam collision regime. The latter is only possible with a good understanding of the optics model, including betas, dispersions, x-y coupling, sextupole families etc.

The staged strategy of the optics tuning includes the wiggler-off optics tuning by local bumps, obtaining the gain map, adjusting and equalizing the ring circumference with the wigglers-on the, and finally, a fine tuning of the beta-beat and of the betatron phase advance plus minimizing the x-y coupling.

The arc lattice includes non-interleaved pairs of sextupoles equipped with skew-quadrupole correction coils. These pairs are connected by a "–I" transformation, in order to preserve the dynamic aperture of on-momentum particles, while the skew-quad coils are used to locally correct the vertical dispersion and the coupling.

An important step in LER optics studies was identifying the leakage field of the Lambertson septum magnet in the beam abort line as a source of strong coupling. After installing the in-situ correctors to cancel the skew-quadrupole component of the leakage field, this problem was greatly mitigated.

The local coupling correction was supported by the vertical beam size monitoring using the new X-ray imaging monitor with coded aperture (XRM). From these measurements, the vertical emittance of LER is successfully minimized down to 10 pm (5 pm target), that is roughly consistent with the optics measurement data. From the latter an emittance of 7.2 pm is expected.

However, in HER the XRM data indicate a vertical emittance of 120 pm (corresponding to the x-y coupling ratio of 2.8%!), in contradiction to the HER optics data predicting some 9.1 pm. Further study of XRM data adequacy is recommended to find the reason for this discrepancy. Of equally high priority is the planned measurement of the Touschek lifetime in HER, in order to obtain an independent estimate of the vertical emittance.

The Committee is impressed by the rapid progress of the Phase 1 Main Ring optics during the relatively short commissioning period. As for the vacuum scrubbing task the target dose of ~700 A hrs can be reached by the end of Phase-1, with currents of about 1 A each beam, but there are some concerns about many installations scheduled in sequence and requiring vacuum venting: new BPMs, collimators, low-beta quadrupoles and eventually the final detector setup. All these operations will have a negative impact on the achievement of the optimal vacuum conditions, slowing down the overall machine optimization.

Recommendations:

R13: During the remaining period of the Phase 1 commissioning concentrate on the improvement and understanding of the X-ray beam size monitor accuracy.

R14: For the Phase 2 optics, the Committee recommends preparing robust optics tuning procedures for curing the effects of the final focus system on the dynamic aperture. A series of IR optics should be prepared for the step-by-step beta* squeeze, with understanding of how the dynamic apertures can be recovered at each step.

5. Optics correction and low emittance tuning

The optics commissioning during Phase 1 has been carried out very efficiently in a rather short time. SuperKEKB features a new lattice, new magnets and new instrumentation. All the required tools had been well prepared before the commissioning.

These allowed the identification of a large skew quadrupolar error source at the LER Lambertson magnet, which was quickly corrected by powering selected coils in nearby sextupoles and by inserting a new skew quadrupole permanent magnet next to the source.

The fast reaction time and the suitability of the mitigation techniques demonstrate the outstanding capabilities of the SuperKEKB commissioning team.

Both LER and HER optics measurements imply a vertical emittance at the level of 10 pm. This is seen as satisfactory for the phase 1.

The LER vertical emittance has been confirmed with beam size measurements.

However, and only very recently, the HER X-ray monitor has shown a vertical beam size measurement an order of magnitude larger than expected. This could be due to limitations in the measurement device or to actual optics issues. Another traditional figure of merit for the vertical emittance is the Touschek lifetime.

Current measurements might support a larger vertical emittance than expected but with a large uncertainty.

Investigations are ongoing to clarify the situation. This is of crucial importance for the performance of the collider.

HER measured horizontal and vertical chromaticities are in agreement with model predictions, while offsets of 2 and -4 are found for LER. This could be explained by sextupolar components in the new dipoles, however first estimates from magnetic measurements suggest too weak an effect.

Recommendations:

R15: Compare the HER optics measurements using different techniques. Coupling from turn-by-turn data might be less sensitive to BPM errors such as incorrect calibrations or tilts.

R16: Develop a correction strategy for the residual Lambertson leakage field.

R17: Measuring LER natural chromaticity, resonance driving terms and amplitude detuning might help understanding the source of the chromaticity offset. Also, some optics measurements could be repeated after switching off all sextupoles and associated correction coils.

R18: Measure dispersion in the LER after switching off the closest magnets of the HER, in order to clarify a possible interference in the Tsukuba section, which might be responsible for the anomalous dispersion in the LER.

R19: Repeat Touschek lifetime measurements for both rings after a reasonable dynamical vacuum level has been achieved. HER Touschek lifetime might provide an independent measure of the vertical emittance.

R20: Critically revise the calibration procedure of the HER X-ray monitor.

There are two recommendations from the 20th review committee that still remain valid and are even more important now, having the IR magnetic measurements, and in view of the opposite sign of the leak compensation magnet tilt angle:

R21: Identify all relevant IR non-linear optics errors affecting the dynamic aperture (DA) and develop a suitable correction scheme.

R22: On the basis of realistic LER/HER optics model simulations with and without beam-beam interactions, develop correction procedures aimed at the DA control, suitable for the control-room implementation.

6. Vacuum system, beam scrubbing

As expected, the vacuum system was ready to take beams from February 2016 onward. The NEG activation performed at the end of the last year was the conclusive step of five years of production and installation.

Beams approaching currents of 1 A are now (10th of June) circulating in both rings. The lifetime are 600 and 75 minutes for HER and LER, respectively; the smaller value for the latter is due to an average pressure one order of magnitude higher: 2×10^{-6} against 2×10^{-7} Pa at 500 Ah. The difference is essentially due to the fact that in the LER most of the beam pipes are newly manufactured and were never exposed to beams before; on the contrary, most of the HER vacuum chambers were fully conditioned during the KEKB operation.

The conditioning of the vacuum walls is progressing faster in the electron ring: photo-desorption yields as low as 10^{-7} have been recorded (500 Ah). In the positron ring, the attenuation of the pressure rise (Pa/A) is delayed because electron clouds develop in the uncoated Al bellows (5% of the ring length) and electron stimulated desorption is consequently generated. The gas release was localized and eradicated by the installation of solenoids and permanent magnets in all uncoated Al bellows.

The combination of antechamber and TiN coating has shown to be very effective in the mitigation of electron cloud at low current. However, a non-linear pressure increase is measured at higher beam current (i.e. at $I>0.5$ A in present operational conditions, or already at I>0.2 A in tests with the design bunch spacing of 2 buckets). This could be the result of an incomplete conditioning of the coating; higher beam doses are necessary to better evaluate such a behavior.

As it was recommended last year by this committee, the effect of venting and long storage on the secondary electron yield of TiN, after months of operation, has to be measured to better understand the need of possible re-conditioning of the coating.

Results obtained by clearing electrodes seem to indicate that photoelectrons are the dominant source of electron clouds and that the different bunch filling pattern used until now do not generate significantly different electron density, at least in the wigglers. This result and its interpretation – which may be in conflict with the clearly pattern-dependent threshold for the vertical blowup – need to be probed with higher beam currents.

In LER, unexpected and frequent positron beam losses (“bursts”), and consequent beam aborts, with concomitant pressure spikes have been experienced. Such events are mostly localized in D1 and D2 around Tsukuba straight section. They seemed to initially increase in frequency and to spread to the nearby dipoles with increasing beam current; a conditioning effect has been observed. A possible explanation is dust particles intercepted by the beam. Grooves could be one of the sources of such particles. The effect is seen mostly, or entirely, for vacuum chambers from one manufacturer.

A vacuum leak appeared in a flange of a tapered beam pipe. The explanation given is electron beam collision on the vacuum wall of the flange due to beam instabilities. A possible mitigation is an optimization of the collimator positioning or a local beam mask. Photons reflected from the tapered area should also be considered.

Other issues appeared during the commissioning, but most of them are already solved or do not seem to be showstoppers for the following phases of operation.

In conclusion, the recommended conditioning phase is almost completed with encouraging results. The only potential obstacles to proceed to the next operational phases are the non-linear electron-cloud effect at currents above about 200-700 mA, depending on the filling scheme, and the sudden vacuum-pressure bursts – both in the LER. No problem with the collimation system has been found. All issues encountered have been isolated, studied and solved or highlighted for further analysis.

Recommendations:

R23: The experimental study of SEY degradation after venting or long storage is an important subject that should be tackled as soon as possible to understand the need of reconditioning between operational phases.

R24: The origin of the dust particles that generate beam losses and beam aborts should be identified. The venting-pumping cycles from the coating to the final installation should be analyzed to find any anomalous event that can be correlated with the incriminated dust particles.

R25: We recommend that, for Phase 2, permanent or solenoid magnets are deployed on the most critical beam pipes, as planned, so that no showstoppers correlated to electron cloud hinder the achievement of nominal operational parameters. A factor of five higher positron current is still needed.

7. Instabilities: simulation and observation

The Committee is positively impressed by the effective and successful effort aimed at understanding the behaviour of the instabilities as well as their impact on the transverse beam sizes in both rings, with special attention to the LER.

In the first stage of the commissioning beam dynamics in the LER has been clearly dominated by the electron-cloud related phenomena, regardless of the many precautions adopted in the design to cope with these effects: grooves in the dipole vacuum chambers, TiN coating, solenoidal windings and electron clearing electrodes in the wiggler magnets. Experimental evidence for electron clouds has been clearly and quickly recognized. The most harmful consequences were mitigated already during the commissioning, e.g. by installing permanent magnet solenoids around the Al bellows of the vacuum chamber, which were identified as a major source of electron cloud. These solenoids have increased the threshold for vertical blow-up by about 50%.

Extensive simulations concerning the vertical beam size threshold evolution along with measurements of the electron cloud intensity have helped guide the progress and helped keep under control the vertical beam size growth with beam current. The work done allowed, already after a short scrubbing period, operations with 1 A positron beam current in a 4 bucket separation pattern.

A transverse coupled bunch instability induced by the electron cloud was identified experimentally and its growth rate measured; both aspects are consistent with expectation.

Tune shift measurements indicate that the two rings have transverse impedances comparable to those measured in the old KEKB rings.

A longitudinal coupled bunch instability of still unknown origin has been observed in the LER. This instability was suppressed by the longitudinal feedback system.

Longitudinal impedance has been investigated by measuring bunch length as a function of single bunch current and for several collimator setups. Data are not yet much revealing. At first glance the microwave threshold behavior which had been observed at a single bunch current of the order of 0.4 mA in the KEKB LER has disappeared. On the other hand the measured bunch lengthening with bunch current (about 25-50% for a bunch current of 1.4 mA) appears to be significantly larger than what had been expected from the impedance model.

Simulations can predict the threshold in the electron density where vertical beam size growth occurs. Achieving a sufficiently low electron density is a challenge for the vacuum system.

The Committee believes that the work done is well founded and represents a solid prerequisite for guaranteeing stable vertical emittance values of the order of 10 pm, as required to reach high luminosity in the NanoBeam collision scheme.

Recommendations:

R26: Validate simulation results against measurements in every way possible, with the aim of estimating high current challenges. The simulations can be very valuable in estimating limits, thresholds and high-current dynamics if they are carefully validated against real physical data from the machine.

R27: Coordinate with feedback studies, measure bunch tune vs. position along the train, e.g. by analyzing the grow-damp data shown in the presentation. This diagnostic can help distinguishing HOM driven motion from ion or electron cloud driven motion.

R28: What is the source of the unexpected longitudinal instability? A study with various filling patterns, and observation of the unstable modal patterns can help sort out possible HOM frequencies related to impedance-driven instabilities.

8. Beam instrumentation and bunch feedback systems

In Phase 1 several BPM systems are available. The old KEKB narrowband 1 GHz detectors are being used in the HER. For the LER with a new vacuum chamber (lower cutoff), new 509 MHz narrowband detectors are employed. All VXI main frames were replaced by new ones. Wrong cable connections were found and corrected for 25 BPMs. BPM offsets have been determined by beam-based alignment. The measured position resolution has been measured to be better than 3 micron in LER and better than 5 micron in HER. The stability of the relative gain was inferred using the “consistency” method (comparing the 3 against 1 BPM button). While these consistencies are stable for the new BPMs in the LER, some BPMs in the HER show drifts or sudden jumps (possibly due to old feedthroughs and/or old cables). A larger noise level was found in the 1 GHz detectors located in site building D7, where RF equipment is located. The BPM resolution in the Oho and Nikko straight sections is probably affected by the same cause. A mitigation measure would be to replace the 1 GHz detectors with the new 509 MHz detectors, which appears to be better shielded against such noise. Some minor problems were found and corrected for five of the new 509 MHz BPMs.

A gated turn-by-turn (GTBT) monitor is based on a fast switch (with 6 ns gate width). In total 117 units of these gated BPMs are installed, i.e. more than 50 such detectors per ring. The commissioning of the GTBT included timing adjustment with the injection beam, and a fine timing adjustment using a pilot bunch during scrubbing run. The system is ready to use.

The IP orbit feedback is not needed during Phase 1. However, the BPMs of this feedback can be tested with beam. The specifications foresee a resolution of better than 1 micron (and a feedback bandwidth below 100 Hz). With increasing beam current, for the LER the relative quality of the y signal is seen to degrade compared with the x signal. One possible explanation is a vertical vibration of the BPM head. The size of the effect is a few micron rms.

Beam loss monitors are used to trigger a fast beam abort in case of unexpected sudden losses. The SuperKEKB beam loss monitor systems include 32 ion chambers and 114 PIN detectors. A few examples of beam aborts triggered by beam losses illustrate that the actual aborts occur typically a few 100 microseconds after the start of the loss.

Obtaining the betatron tune with a global tune measurement for multiple bunches works well at low beam current. However, at higher current the beam response is strongly damped by the feedback. Here a gated tune measurement is available for a pilot (or selected) bunch, excited by a PLL using the digital filter iGp12. The iGp12 is the successor of the iGp digital filter developed under US-Japan collaboration with SLAC.

The SuperKEKB transverse feedback systems have been developed in SLAC-Japan and INFN-KEK collaborations. The longitudinal feedback uses a kicker made from Al-alloy. The feedback systems support a variety of applications/functions. The injection kicker can be adjusted using the transverse feedback system as detector. The bunch current information from the current monitor is sent through reflective memory (real time) to the bucket selection system at the linac during the injection period (<20 ms).

At a very early stage of the commissioning, strong transverse coupled-bunch instabilities were observed in both rings and both planes even for fairly low stored current. In the LER the vertical instability was much stronger than the horizontal one; in the HER the instability strength was about the same in both planes. All these instabilities were fully suppressed by the feedback systems, which thereby enabled vacuum scrubbing with high beam current, as well as studies of coupled-bunch instabilities (e.g. ones driven by electron cloud or ions). Instabilities have been characterized by growth-damp experiments. The LER vertical instability shows the fastest growth rate. In operation with 3-bucket spacing above the threshold current of 660 mA a longitudinal coupled-bunch instability is seen, with an instability mode number around 500. Such a longitudinal instability was never observed during KEKB operation.

The water-cooled dummy loads for LER of the longitudinal feedback systems burned out due to a stopped water chiller. Now an automatic abort is triggered when a chiller stops.

The new transverse feedback kicker for LER seems to be broken. A complete short-circuit appeared after a short maintenance period. There had been no indicator of any trouble prior to this event, i.e. no abnormal temperature rise, no reflection, and no vacuum burst.

The BPMs and the feedback kickers exhibit only a very slight increase of temperature with beam current, of order 1-2 degree at 1 A, which suggests that any HOM heating will remain acceptably small even as beam currents are raised further.

Most of the beam instrumentation prepared for the SuperKEKB rings (Phase 1) is working well, including the BPM system (narrowband position monitors, gated turn-by-turn monitors, and IP position monitors), the beam current and bunch current monitors, the loss monitors, and the bunch-by-bunch feedback systems (tune monitors, transverse FB (HER and LER), longitudinal FB (LER)).

The LER transverse kicker needs to be repaired. The root cause of its breakage needs to be investigated. In preparation for Phase 2 operation, also a few damaged BPM heads will be replaced. An advanced kicker is being developed with collaboration of SLAC. Simulations of the IP feedback performance (with dithering) and an implementation of IP feedback algorithms are foreseen.

The impressive commissioning experience profited from the investments made in the past years and validates the design choices. The BPM consistency checks (“3 bpm method”) are extremely helpful for assessing the performance of thee hundreds of monitors and processors. Possibly, these could be made to run in the background as a diagnostics for the system operational state.

New systems, such as gated turn by turn monitors, IP position detectors, and loss monitors are just starting their commissioning. Manpower is tight, but initial results suggest these systems are ready to be tested with beams. When they are fully understood, they can be further commissioned and used as part of operations.

The transverse and longitudinal feedback systems are building on KEKB expertise. The benefits of a flexible architecture and multiple kickers are evident from the smooth operation even with one damaged kicker unit.

Recommendations:

R29: Check interlocks and instrumentation in light of future high operational currents.

R30: Use diagnostic information from feedback studies. Try to understand modal growth rates, and compare them with estimates (tie to simulations and models).

R31: Develop a plan for obsolescence of the HER BPM processors – if they are to be run for many decades, spares and a test jig plan are needed.

R32: IP feedback commissioning and system development will also be manpower limited. We encourage collaboration with sister labs and the use of passive measurements as a means to begin to understand this critical system.

R33: Measure the mechanical vibration of the IP feedback BPMs and/or adjacent beam pipe; where available compare the modal spectrum with ANSYS simulations and with presently observed (and future) IP BPM noise spectra.

9. Photon monitors

Since the last review meeting great progress has been made for the photon monitors, including X-ray monitor (XRM), synchrotron radiation monitor (SRM) and large angle beamstrahlung monitor (LABM). The committee enjoyed the very detailed talk, with an abundance of results ranging from installation and calibration to the measurements on the beam blow-up due to electron cloud during the Phase 1 commissioning. All the basic functionalities were well demonstrated.

Transverse bunch sizes were measured by different monitors, as well as the emittances and coupling coefficients. The XRM calibrations yielded excellent results on the geometric magnification factors, which agree well with the beam-based measurements at both rings. An emittance knob calibration was applied. The overall performance is reasonable for LER, and results consistent with expectations based on the measured optics. The XRM in LER was used to study the electron-cloud blow-up, which provided an opportunity for further checks of the instrument.

For the HER, a light-level dependence was seen, with some possible sources analyzed. Also a possible x-y tilt at the source point was observed, which is different from the LER. The analyses of this problem are reasonable, and more efforts will be made in the near future.

The following will be done next: examining masks after exposure to the beam, improving vacuum pumping ability around the optics box and getting faster pixel readout.

Interferometers and streak camera are set up for measuring transverse beam sizes using synchrotron radiation light in both LER and HER. Diamond mirrors for visible light monitors were installed in the extraction chambers, and well aligned. The measurement results are displayed in the control room, which is of great help in the commissioning.

In the calibration of SRM, the ratio of slit separations between interferometer slit plane and extraction mirror plane is about a factor of two larger than expected. Analysis is ongoing and more measurements are needed to understand this discrepancy. Bunch lengthening was measured in both LER and HER, but the measurement errors are large for all bunch currents. Raising the light intensity will be a way to lower these errors. A shift of the optical axis is observed in the HER, but not in the LER. All the problems found during the system setup and calibration are now being investigated.

The LABM system was installed at the IR, with the DAQ and EPICS records developed for the Phase 1 commissioning. Some measurements were performed using the synchrotron light from far side of the IP. Work for the LABM transition from Phase 1 to Phase 2 is being carried out.

Recommendations:

R34: In view of a possible coupled bunch instability, using a large bunch spacing for the measurement of bunch sizes in the HER with the XRM might minimize the beam current dependence.

R35: Continue to study the problems encountered in the calibration of the SRM and LABM, and be ready for the Phase 2 commissioning.

10. Operation Status of RF System

The refurbished and reconfigured RF systems are working well and supported all the Phase 1 goals. Some nine stations are using the new uTCA based digital LLRF system. This is also working well and includes built in diagnostics such as fault logs etc. that will make troubleshooting and analysis of trips much easier. The old analog LLRF systems are still working well but it is planned to phase them out as the new LLRF system is implemented.

New analysis and simulations of the gap transients suggest that partial filling of the gap and possibly altering the overlap of the gaps between the two rings might reduce the residual error in the collision point to less than 0.5 degrees. The ringing of the transient caused by the three-cavity ARES system is reproduced in the simulation. The mix of NCRF and SCRF cavities in the HER results in a different shape of the transient compared to the LER. This is one reason for the residual error. It is not clear if this small residual error will cause significant loss in luminosity, but the new collision scheme will be more sensitive than the old KEK-B. The bunch top off scheme should be able to keep the fill pattern stable even if some bunches on either side of the gap experience shorter lifetimes. In addition it may be possible to adaptively modify the fill profile in order to learn and minimize the residual transient by controlling individual bunch intensities. It may also be possible to correct the residual error with RF feed-forward if there is sufficient headroom available in the systems.

Recommendations:

R36: Continue the transient analysis, quantify the effect on luminosity from the residual mismatch between the rings. Continue to study the influence of fill pattern shaping or adaptive feed-forward on the residual error.

R37: During beam tests in Phase 1, inject a bunch train with the largest number of bunches at the correct spacing and full design bunch charge.

11. Normal-Conducting RF Cavities for SuperKEKB / MR & DR

The reconfigured NCRF ARES cavities have performed well during the Phase 1 run. Some issues have been found including one ARES cavity that had a crack near the coupler flange. This was sealed with an O-ring and continued operation. It will be repaired or replaced before Phase 2 operation. There have been several coupler arcs and the couplers are being monitored by cameras in addition to the normal arc detectors.

At the last review it was reported that 13 couplers were conditioned off line to 850 kW. This is still the same number today, while there are 5 more waiting to be conditioned. The installed couplers have not seen maximum power in Phase 1 because of the low beam current during scrubbing. It may be possible to push individual cavities by phasing, to increase the demand while reducing others. This could be a good test to demonstrate robust coupler operation before full current is available and test the couplers for any weaknesses. With care this could be done parasitically during scrubbing.

The chillers for the NCRF systems have been replaced but there is an issue with the anti-corrosion additive in the new systems precipitating out. This has caused down time due to clogged filters. One possibility is low pH caused by exposure to the tunnel environment affecting the chemistry of the water system. Similar problems in PEP-II were solved by introducing a nitrogen blanket over the water system to exclude oxygen.

Two cavities are parked in LER to save electricity, another two are off due to faults. Detuning of these parked cavities is important because they can drive low-order coupled-bunch modes. The -1 and -2 modes have already been seen during commissioning. Balancing pairs of cavities detuned in opposite directions may be one way of minimizing this problem. Other coupled-bunch instabilities have been observed, possibly due to the additional impedance in the LER due to cavity relocation, but have been well controlled by the bunch to bunch feedback system.

Most of the scrubbing has been performed in the every third bucked filled pattern. As vacuum conditions improve it would be good to attempt high current running in the design fill pattern.

Recommendations:

R38: Consider gradually pushing individual RF systems up to high beam loading power to test for robustness. This could be done parasitically during scrubbing or as a dedicated experiment at the end of Phase 1. If there is enough voltage headroom some additional stations could be turned off. This could increase power in the remaining stations and may improve klystron efficiency, saving electricity costs.

R39: Optimize the detuning of parked cavities to minimize excitation of low mode coupled bunch instabilities. Consider parking cavities in pairs, detuned in opposite directions.

R40: As opportunities allow, continue conditioning the remainder of the couplers to full power.

12. Integrated vacuum control system for RF and Operation status of SCC

The new integrated vacuum control for the LLRF system is operational in the D4 and D5 areas and performs as expected. It is based on PLC embedded with ladder-CPU and EPICS-IOC and its purpose is the protection of the RF cavities against excessive pressure increase. The PLC based system is flexible and can be extended to other cavities and vacuum components. The pressure-rise alarm is sent to the beam abort and vacuum control systems. No issue is identified.

In general the RF characteristics of the SCC modules have been preserved after the long shut-down. The operation of the SCC modules is stable and fulfils the requirement for Phase 1. Eight superconducting cavities, inherited from KEKB, are installed in the HER. Despite the higher beam power required for SuperKEKB, by the help of the ARES cavities, the beam loading is kept similar to the one of the previous accelerator.

Two issues have been identified and addressed:

- New high power SiC beamline absorbers are needed in between the cavities for the expected higher HOM power at full current. These have not yet been installed but can be added outside of the gate valves, so that there is no need for venting and the cavity conditioning should not be affected. The implementation will be carried out either for Phase 2 or Phase 3. The cleanliness of this installation will be very important to avoid introducing new sources of particulates close to the cavities.

- Two cavities have shown a degraded performance (i.e. a reduced *Q* at the operational field or a reduced gradient). This is attributed to particulate contamination. One cavity is known to have suffered a vacuum leak. This cavity was recovered by horizontal high pressure rinsing (HPR) without any need for module disassembly except for coupler and HOM dampers. The second cavity may be exchanged against the spare prior to Phase 2. More conditioning time may help. In case the spare cavity will eventually be installed the cavity that is taken out should be refurbished as a usable spare.

Beam aborts due to RF trips have been reported 7 times during the last 4 months (quenches in cavities and discharges in couplers). Intriguingly, it was observed that the cavity trip rate increased after experiments with vacuum bumps were performed elsewhere in the ring (to study backgrounds in the BEAST II detector). Pressure at the cavities was not seen to rise, so that the exact cause is unclear.

Problems have been experienced with some piezoelectric tuners (failure due to electrical breakdown). The Piezo manufacturer suspects that rapid voltage fluctuations as seen in this application may be harmful to the piezo actuators. Filtering with a decreased voltage-change rate will be tried to mitigate this effect. In the medium term, an alternative supplier could be selected.

New vacuum interlocks have been developed to monitor and protect the SCRF cavities. These have been installed and can quickly turn off the RF in case of vacuum transients close to the cavities. Such vacuum transients always are a concern for the RF couplers. The protection of the latter will be even more important at the new high power level.

Recommendations:

R41: We recommend that the planning for the Q recovery of the affected SC RF cavities is detailed and integrated into the global planning of Phase 2 or Phase 3. Consider trying to improve the performance of degraded cavities by horizontal HPR (as already demonstrated) or by further in-situ conditioning.

R42: It would be useful to study if the availability of additional spare modules is necessary and the actions to tackle in the short term for achieving a good availability in Phase 3.

R43: The increase of the trip rate after the pressure bumps needed for the BEAST study is puzzling. We recommend that this correlation is studied in details so that possible issues are identified (dust generation?).

R44: If the spare cavity is installed then consider timely refurbishment of the extracted cavity to be returned as a usable operational spare.

R45: Develop an installation procedure for the new beamline HOM loads so as to minimize the risk of introducing new sources of particulates.

13. Beast II (Phase 1), beam background

The aim of the BEAST II detectors is to measure the background signals from the beam during scrubbing and to compare these readings with expectations from simulations. This is in order to validate the simulation model of the IR and the installed detectors. In addition, the team is attempting to separate out various background sources and see if installed collimators are effective in controlling some of these backgrounds. The BEAST team has negotiated special running times for specific running conditions with the accelerator team. The organization has been impressive and the coordination with the accelerator team is very well planned. Some excellent measurements have been made and the team has some very interesting data to analyze. This effort should be adequate to validate the simulation as was hoped. The BEAST team has acquired significant experience in collecting data from various detectors and this expertise will be very important when the Phase 2 part of BEAST II is installed in the detector and the real machine will start up. It will become important for the team to quickly collect and analyze new data in order to make sure there are no unexpected background surprises. The time interval between Phase 2 and Phase 3 is not very long and there will be very little time to respond to surprises.

Recommendations:

R46: Suggest the BEAST team to use the experience it gains from Phase 1 running to improve their efficiency in analyzing new data so that they will get information about background sources from the Phase 2 data promptly.

R47: Additional data could be obtained by inducing aperture limits with closed orbit bumps or collimators around the IP, anticipating reduced apertures with the low beta optics for data taking.

R48: The loss calculations should include deteriorating effects from linear errors (orbit, beta beat) and reduced available aperture.

14. Ring magnet system

As the most important system in Super KEKB, main magnet installation during last year was successful, and there have been great achievements on magnet survey and alignment in anticipation of the Phase 1 commissioning. All this was very clearly expressed in the presentation, with many detailed results from magnet installation, survey and alignment, as well as magnetic field measurements. A lot of work is still waiting for the team in preparation of Phase 2, in particular the installation and alignment of QCS in the IR.

Quite big changes have been made to the main magnet system in SuperKEKB compared with the one of KEKB. In order to get lower beam emittances, new long bends replaced the original KEKB bends in the LER, and 280 new wigglers have been installed in the LER. A total of 36 new wigglers were added to the HER. About 220 new vertical steering magnets, together with ~300 modified horizontal steering magnets were installed in both rings. All this installation work was successfully finished by May 2015, with vacuum chambers installed in the North tunnel. Checks of magnets and related power converters plus cables were carefully done.

A survey of the main magnets along both LER and HER has been performed, with the results cross-checked by 3 teams. A deformation of the rings has caused its Northern and Western parts to expand towards the outside by up to about 10 mm, yielding a smooth, low order perturbation. Data analysis of the tunnel motion reveals a correlation with earthquake activity. A continual tunnel sinking is observed, enhanced after the big earthquake in 2011. The rings are larger than the design. The expected 16.4 mm difference between the LERs of SuperKEKB and KEKB was confirmed after the beam injection in February 2016. The motion of the tunnel is also monitored by a hydrostatic leveling sensor (HLS) system.

Crosstalk between adjacent steering magnet and quadrupole was measured. The results could be used to improve the magnet models.

The magnet power supplies for SuperKEKB are a mix of refurbished converters from KEKB, and a smaller number of newly fabricated supplies. One important item of this last group is a new type of QCS supply.

The successful machine start up is a result of the care and careful work of the power-converter group. The smooth machine start up is built on the careful testing and characterization of the many power supplies, cables, sensors, software codes, etc. A few technical issues were encountered during the testing and checkout. The presentation included some test data. The histograms of the measured output currents demonstrate that the ripple and resolution of the main ring supplies is at the several PPM level. This impressive result testifies to the care in design and fabrication.

The new QCS supplies were designed and a prototype system fabricated plus tested. The design has implemented a hybrid analog-digital regulator, where an analog PWM system runs closed loop with a setpoint that is adjusted via a digital feedback from an 8 1/2 digit DVM. Results from this prototype reveal the action of the digital feedback to reduce current drifts and ripple to the 2 PPM level over 8 hours. This is a significant result.

One question that was not clear from the presentation is what physics requirements set the specifications for the power supply noise and ripple? Is there a specification for each class of supply for long-term stability, harmonic content or broadband noise in some bandwidth? Each class of supply has been tested. Our question is how well the power supplies meet the necessary specifications.

Recommendations:

R49: Simulation of beam orbit distortions due to the misalignments determined by the survey could be compared with the orbit measurements from Phase 1 commissioning.

R50: The differences between the magnetic field measurement results made in the experimental hall and in the IR (Tsukuba) should be considered.

R51: Close cooperation with the accelerator physics group will help to understand the results of the survey and the magnetic field measurement as well as their implications.

R52: Analyse the failure causes for the various power supplies to determine any common factors that can be addressed before run 2 to reduce the impact on running time.

R53: Compare the achieved power-converter performance with the specifications.

15. Beam Transport and Injection

The beam transport (BT) system connects the end of the linac to the LER, the HER as well as to the PF-AR. The beam line system for injection into the LER/HER consists of a total of 6 arcs. Half of the BT lines have a double-story structure (for the electron and positron beams). Prior to the last arc, sections with a significant download slope transport the two beams, separately, to the KEKB collider tunnel, which is located 11 m underground. The BR comprises about 60 dipoles and 50 quadrupole magnets each, for the electron and positron beams. In addition 3+3 kickers and 4 (or 2) septa are used for injecting the electrons (or positrons). Two sextupole magnets for each beam will be used in phase 2 to correct the higher order dispersion.in addition to 60 BPMs each, the beam lines are equipped with 20 screen monitors, as well as several wire scanners and collimators.

Upgrades for SuperKEKB included (1) an increase of the positron magnet strengths required by the higher beam energy, and (2) new septa. The change of beam energy also necessitated a change of the layout of the beam switchyard 3. Some dipoles for the positron required new power supplies for the higher beam energy. Another solution was applied in arcs 2 and 3: here, the gaps of the dipoles were narrowed, which avoided upgrading their power supplies or water cooling. The beam switchyard is directly connected to an energy compression system for the positrons. The latter is also being modified for the higher beam energy, with construction still ongoing. To reduce the injection error, the effective septum thickness was lowered from 5 to 3.5 mm (only for HER in Phase-1, and for LER in Phase-2).

A large part of the new BT has been commissioned. The positron beam has a huge emittance, since the damping ring is not yet in operation, and the positron beam comes directly from the flux concentrator. A large part of the positrons is lost at collimators (used for cavity protection) and in the linac. Some 10% of electrons and (remaining) positrons may be lost in the BT, but the decrease in charge may be within the large error bars of the measurement. The injection efficiency is close to 100%, for the positrons, and fluctuates, with an average perhaps around 50% for the electrons. The electron injection efficiency is affected by a large vertical orbit jitter at the end of the BT, of a few mm peak-to-peak. Groups of 4 wire scanners are installed at several locations in the linac and the BT. These wire scanners are used for emittance measurements and optics matching. Wire scan measurements in the BT indicate a spurious horizontal dispersion and also a vertical jitter coming from the linac. Measurements were performed for the beam from the thermionic gun and from the RF gun. The latter produces a smaller emittance. The vertical jitter was found to be about the same, i.e. independent of the electron of the gun. The jitter corresponds to about 1 sigma of the beam size from the RF gun. The measured electron-beam emittance is about 100-200 μm, and therefore 5-10 times above the design value (20 μm). The measured emittance increases in the BT compared with the upstream linac (by about a factor of 2), which is attributed to spurious dispersion.

Some technical issues were encountered during the commissioning. A water interlock trips the dipole magnets 2-3 times per week, due to filter clogging by CuO dissolved from the cooling water pipes. Also the water interlock is triggered for some of the dipoles whose gap was narrowed, due to the increased leakage magnetic field (20~30 Gauss) and/or due to aging of the switches.

An abnormal x-y coupling and occurrence of unexpected vertical dispersion is observed in the positron line, between arcs 2 and 3. Possible explanations like quadrupole rolls and sextupole components in the dipoles have been suggested, but none of them appears realistic.

On the whole, the first results of the BT commissioning satisfy the demands of Phase 1.

Recommendations:

R54: The origin of the abnormal x-y coupling and vertical dispersion in the e+ BT line should be understood.

R55: The water interlock problems need to be addressed (perhaps involving shielding of the leakage field and replacement of the switches).

R56: The leakage dispersion seen at the BT wire scanners should be corrected.

R57: Accurate monitoring of charge transmission in the BT lines should be made available.

16. Beam Abort System

The SuperKEKB beam abort system is challenged by the increased beam power and the shortening of the abort gap. A thorough upgrade of the system has been put in place to cope with the new requirements. Previous damage tests have been used to define the allowed current density in the extraction window, which determines the kicker sweep parameters. The ceramic chamber could not be coated with vapor and, instead, the sputtering technique has been used.

The abort system has been equipped with appropriate diagnostics to ensure it is correctly functioning. In particular, the extracted beam orbit and beam size have been experimentally verified as expected. The temperature increase due to image currents has been verified to be within tolerances. The most critical system failure modes have been identified to be the vertical kicker discharge and circuit fault. The probability of these failure modes are suppressed by duplicating the electrical circuit.

Recommendations:

R58: Revisit the horizontal capacitor breakdown (discharge) failure mode to, hopefully, discard the possibility of damage.

R59: Investigate the source of the losses towards the end of the train.

17. Controls

The SuperKEKB Control systems are mature systems based on well-developed and well-functioning KEKB systems. The rapid machine commissioning of the last year was an example of the excellent technology base in the machine controls and experienced highly-skilled staff. The use of commercial networks, commercial computer systems and extensive standard software platforms means that the transition of the KEKB system to the SuperKEKB era can be incremental and allows the existing expertise to be brought to new accelerator systems.

The upgrades center on higher-performance networks, host computers and new IOCs. Many of the original KEKB sub-system interfaces, such as for power supplies and the VME sub-systems are carried over. In future years there can be upgrades to some hardware backplanes. The reviewers do not think there is urgency in replacing the operating I/O subsystems. As the new IOCs and backplanes are implemented the EPICS structure facilitates integration and testing of new hardware as incremental upgrades.

The Fault files and data logging features have been expanded, and upgraded. The Alarm and monitoring system has also been upgraded using EPICS functions.

The new abort trigger system with new modules is partially commissioned. The new functionality is very helpful and will be fully implemented in later machine phases.

Recommendations:

R60: Develop in situ test methods for the beam abort modules, and have a robust automated way to be sure the system is properly configured and ready to function when it is really needed. In addition, there should be redundant triggers to the abort system.

R61: Can physicist staff write python scripts for new diagnostics or machine measurements? Does this help with commissioning?

18. Beam Injection Controls

The presentation showed the timing system and LINAC injection had excellent operational readiness and these critical systems were stable in the first commissioning – a great job.

The group can be proud that they were ready to accommodate the first commissioning needs, including the beam scrubbing top-up tools.

The Event timing system is complex and uses new modules. We stress the importance of good tools to write timing programs, to efficiently operate and understand the timing system, and to allow for rapid integration with many accelerator sub-systems.

The presentation highlighted some of the tricky issues in synchronizing the various oscillators. Some functions were not completely integrated between LINAC and Ring timing needs. A new system configuration used during the Phase 1 commissioning was shown, but the future integration of the damping rings, including techniques to efficiently inject and extract, and to synchronize to the main ring, etc. still need to be developed.

Regarding diagnostics, timing programs using TDC functions have been tested. Can these be run in the background? Maintenance issues with cables, etc., need to be considered. Some members of the committee were concerned that the module fibers, cables etc. might get misconnected in some late-night diagnostic or maintenance situation. Any real time changes should be documented.

Recommendation:

R62: It is critical to check the timing programs, and to use the TDC as operationaldiagnostics.

R63: Begin coordination process with damping ring needs; plan now for later integrated operational phases.

19. RF Gun Report

The RF guns, cathodes and lasers have been followed by a separate Review Committee, the SuperKEKB RF Gun Committee, which has been meeting every six months. The reports from the most recent three meetings were presented to the Accelerator Review Committee. The Gun Committee established a “Philosophy:”

- Any component integrated into the accelerator must be reliable, maintainable, and reproducible.
- Start with a simple, robust system. Improve it and add features step by step afterwards.
- Cost is not irrelevant.

The Gun Committee has consistently recommended to reduce the number of options being pursued in parallel, and this advice has not always been followed. At this time, there are two RF guns (one of which, the Quasi-Traveling-Wave RF Gun, has now delivered beam successfully through the linac to the SuperKEKB rings), at least three lasers and several cathodes. The Accelerator Review Committee is also concerned with the proliferation of options. We would like to see better prioritization of the upcoming tasks that includes all items required to meet the parameters of Phase 2 and Phase 3. This should also include diagnostics for determining that the gun is delivering the required performance as well as software and screens for the operators to ensure that the gun is working correctly with the required stability.

Recommendations:

R64: Follow the recommendations of the SuperKEKB RF Gun Committee.

R65: Provide a detailed prioritized list of tasks required for Phase 2 and a second prioritized list of tasks required for Phase 3.

20. Injector Linac Overview

The overall progress on the injector system for SuperKEKB has been good. Upgrades on photo-guns, positron source, linac controls, linac stability, emittance wire scanners, and utilities have already been made. More improvements are coming including a new damping ring, RF gun and positron target upgrades. During Phase 1 beams were successfully injected into SuperKEKB from both the thermionic and the RF gun.

Ultimately, the injector must keep the SuperKEKB beam currents constant with ring lifetimes of about 6 minutes. Twice the beam currents are needed compared to KEKB. For the new collider, the injected beams have to be more stable, of higher charge, and of smaller emittances. In a few years, beam injection into five rings on site will be needed, varying pulse by pulse.

An event generator for the linac is needed to control the generation of bunches to be injected into specific SuperKEKB buckets. The control of the bunch timing for injection into the right buckets of the SuperKEKB rings will need more work on the low level RF LLRF system for the linac, especially to help with synchronization delays longer than 2 milliseconds. A report on the status and improvements of the LLRF should be given at the next meeting.

After the Damping Ring is on-line, bunch trigger timing changes from 490 to 2000 microseconds are needed. There should be simulations to determine which timing requirements are needed and what errors can be tolerated.

The tolerances for beam pulse to pulse jitter in position, angle, emittance, and charge that can be accepted into SuperKEKB and the photon factories should be tabulated. Indications from recent measurements are that the beam position jitter and pulse-by-pulse charge jitter certainly need work in the linac.

The KEK light sources will need top up injection over the next few years. Though this task should be significantly easier than the injection needed for SuperKEKB, plans are needed for the light sources that are compatible with SuperKEKB injection.

Recommendations:

R66: Identify the solution for the Low-Level RF (LLRF) system upgrades required and formulate the specifications.

R67: Determine if the longitudinal location of the positron bunches in the Damping Ring can be shifted during the storage damping time to facilitate the bunch timing for injection into SuperKEKB. (This was done successfully and easily in the SLAC damping rings.)

R68: Continue the work on reducing linac beam jitter sources to bring them to the needed specifications.

R69: The project should continue to monitor the linac upgrade schedules as there is much to do and the time to perform the work is short while complicated by required injection during the photon factory operating periods.

21. RF Gun and Electron Beam

Great progress has been made since the last review. The QTW RF gun has been installed and commissioned and delivered beam to the HER for extended periods during Phase 1 running. There is some evidence that the emittance from the RF gun is significantly smaller than the thermionic gun as expected but there is a large residual jitter in the horizontal plane. This is possibly coming from laser pointing jitter since the laser comes in at a wide angle in the horizontal plane, but this is not well understood and is currently still under investigation. The simplified drive laser has worked well in operation, running for long periods without intervention. R&D on pulse shaping has been deferred until later to concentrate on making the basic system robust for operations.

The new Ir5Ce cathode has performed well and a new press-fit cathode holder has eliminated the breakdown problems experienced with the previous design. A new Ir7Ce2 cathode, possibly a single crystal, may improve the quantum efficiency and provide better uniformity.

In parallel another new RF gun has been developed. The cut disk RF gun has a simpler geometry and a large enough aperture for normal illumination of the cathode. This may reduce the jitter if it is indeed coming from the laser transverse fluctuations. This gun will be installed off to the side on the 45° line during the summer shutdown to allow further testing.

The RF gun has not yet produced high enough bunch charge to be used for the positron production. The thermionic gun has performed this task well during Phase 1 and will remain in place until one or other of the RF guns has proven capability.

Recommendations:

R70: Maintain focus on stable operation of the RF gun and laser system to support the Phase 2 run. Work with whole injector and linac team to understand and mitigate the sources of jitter.

22. Laser and RF Gun

The present laser system of the RF gun was discussed, along with planned upgrades for obtaining the higher charge and repetition rates required for Phases 2 and 3. All laser systems are original developments from KEK. The final SuperKEKB laser should deliver a pulse energy of 50 or 500 microJoule depending on the cathode material (Ce2Te or Ir5Ce, respectively). It must produce two bunches, spaced by 96 ns, at 50 Hz, allow for temporal pulse shaping and for continuous operation.

The laser employed for the Phase 1 operation.is a Yb doped solid state laser, realized as a hybrid system which combines fiber-based amplifiers and Yb:YAG thin-disk multi-pass amplifiers at a wavelength of 1030 nm. The development of this underground laser is complete. The stability of the laser is acceptable. A spectral range adjustment allows temporal pulse shaping. The pulse shape was optimized with the help of a streak camera.

The temperature increase of the thin-disk amplifier is limiting the repetition rate of the present laser to 25 Hz, where the pulse energy at the fundamental frequency and at the wanted 4^{th} harmonic (generated by a nonlinear crystal) reaches a maximum value of 10 mJ and 230 microJoule, respectively.

Monitoring the stability of the laser pulse energy reveals a power variation at the level of 10% on short time scales, along with a smaller long-time drift. The effect of regular elevator maintenance can also be noticed in the history.

It is difficult to meet the 50 Hz double bunch repetition rate with the existing system. A new, upgraded laser is being developed for the future higher power operation. Here, after the fiber amplifier, the light is split into two paths, towards a fiber + Yb:YAG thin-disk and a fiber + Nd:YAG rod regenerative amplifier, at wavelengths of 1030 and 1064 nm, respectively. The Menlo system commercial oscillator is available only for the 1030 nm of the Yb:YAG laser. Chirp pulse amplification is used to compress the Yb:YAG pulse to a length of 30 ps. Lowering the temperature of the Yb:YAG thin disk laser to a few tens of centigrade below zero increases the amplifier gain, reduces the noise level, and yields a more stable signal. A 50 Hz test operation at low temperature has already been done. A plan A and a simpler plan B have been prepared for the future evolution of the laser system.

The reported laser technology is complex, with several systems being developed in parallel, and multiple reviews in the past year. With one short presentation, we cannot try to advise or pretend to have the expert knowledge from the system reviews. Instead, we wish to highlight the need to begin to integrate this system as part of the operational SuperKEKB facility.

The diagnostics need to be integrated with the operational needs. A photo-diode and a scope is not a path to robust operations. What technical specifications for pulse temporal shape, energy, jitter and controlled parameters drive the operational needs? What diagnostics are needed while the system is in development? And in commissioning? And in operation? How much can be automated? Can one write log files?

As an example, if the system incorporates feedback regulators, a logging system that samples the feedback actuator/correction signals over time, and allows correlations of disturbances against other machine states, might be very useful. Similarly, knowing the typical range of the feedback actuators may be insightful when in operation they are about to exceed their limits because of some unexpected disturbance. It is good to know something is amiss before it becomes a loss of the injector.

Recommendations:

R71: One person should develop the user control strategy and interface that will be needed by operations now – and start to understand necessary functions for operations as well as system experts. The system and technology will need to transition away from a 10 person R&D project towards a day to day operational system, critical for daily use.

R72: Visit a lab with an operational laser injector, see how it is operated and what experts do, what operators do. Start to develop procedures for commissioning and operation with this laser gun system.

R73: Specify the operational diagnostics and a commissioning plan. What instruments or test equipment is needed to become part of an operational injector? Clarify the specifications for the SuperKEKB injector (e.g. charge stability).

23. Positron Generation and Beam

For the Phase 1 commissioning, the Positron Source is used without the Positron Damping Ring (DR). Hence the full potential of its upgrade is not yet available. On the other hand, the period of 2015 till 2017 can be used for step-by-step testing of key components of the positron production chain.

Last year the operation started with limited performance: the Flux Concentrator (FC) used for collecting the positrons worked at 50% of its design current (6 kA instead of 12 kA) with a temporary pulse modulator, the DC solenoid current was 370 A (instead of 650 A), the accelerating voltage in the capture section was 10 MV/m (design target 14 MV/m). As a result, a positron yield of only 20% was obtained at beam switchyard 2, at the entrance of the DR injection line. The first positron charge available for SuperKEKB was only 0.12 nC per bunch.

A number of technical problems were encountered and resolved, resulting in implementing the FC tri-plate feeder line, new coaxial cables, the snubber circuit, and a full-scale 12 kA pulse modulator. These enabled the successful test run of the spare FC head #4 at the full specification of 12 kA (but without the bridge coils) for continuous 200 hours.

By the end of last summer these new components were installed for beam operation in the linac tunnel, together with the FC assembly #1 (head #3), bridge coils, DC solenoids and capture accelerating structure already in place. The FC processing, with a bridge coil current of 750 A, was interrupted, last September, by an FC breakdown resulting in an unrecoverable damage. The FC current was only 9.8 kA. However, in previous tests without the bridge coils, the FC was stable even at 11.5 kA.

The solution suggested by SLAC positron experts was to apply "work hardening" to the OFC copper block of the FC. The multi-cycle repeated plastic deformation of copper would result in stability of the spiral gap, and its spacing is expected to recover after breakdown. The crucial tests are planned for this summer (1) with the FC head #4, not "work hardened", trying to reproduce the breakdown conditions, and (2) with the newly made FC head #5 to be tested for operability after the "work hardening" at full current and with the bridge coils at their nominal current.

After the beam tuning at the end of last year, with an FC current of only 6 kA, the positron yield was raised up to 30%, and the positron charge was 1.9 nC at the beam switch yard 2. The yield enhancement from the FC was only 1.8.

A complete simulation of the positron yield including all operational conditions is being prepared. At present the expected loss in the positron yield caused by the limited performance of almost all components of the Positron Source is not yet known.

The positron injection conditions now are as follows: 7 nC electrons at the target; 2 nC positrons at the DR injection line entrance (actually, 1.3 nC due to collimators), 0.75 nC at the linac end, and 0.3 nC at the Beam Transport line end, the latter two intensity drops are caused by beam acceptance limitations when the direct injection is performed without the DR. Since February 2016 stable injection into the LER was achieved with a positron charge 0.3 nC in each of 2 bunches.

According to the plan, after testing, the new FC assembly with "work-hardened" copper head will be installed in the beam line by the end of 2016. DR commissioning and LER injection for Phase 2 will start in November 2017.

The Committee is satisfied with the efforts of the Positron Source team to overcome some serious problems and yet to supply the LER with enough positrons for the Phase 1 commissioning. A few comments in conclusion: i) restoring the old linac injector called the "double deck' is a good addition and helps with operational flexibility; ii) the work on increasing the Flux Concentrator current is very good and has shown promising progress for enhancement of the positron yield; iii) the new effort to implement the "work-hardening" of the Flux Concentrator should help a lot.

Recommendations:

R74: A simulation of all the effects influencing the positron yield should be finished to estimate the expected beam losses and their distribution after the target.

R75: The linac group should estimate the losses of positrons after the target while being transported to and injected into the positron Damping Ring.

24. Injector Alignment

Achievements and status of the injector alignment were presented. The alignment of the injector linac is important for delivering a high quality beam into SuperKEKB. The target emittance of 20 mm-mrad requires the local rms alignment to be better than 0.1 mm, and the global rms alignment to be better than 0.3 mm.

The alignment methods rely on a 500 m long straight laser reference line, laser trackers and targets on walls, girders and machine elements. In January 2015 a complete injector alignment was done to an accuracy of better than 0.1 mm. The hardware alignment on the girders has remained within 0.1 mm and a standard deviation of about 0.05 mm. Some minor problems were found on the girders but the overall stability is as required.

Radiation damage to the alignment system has been observed in the collimation sections. The team is looking for alternative equipment with better radiation hardness.

Alignment surveys for the linac have been performed regularly since 2015. It was found that the linac alignment has deteriorated since 2015 with deviations reaching up to 1 mm. The worst drifts occur at the expansion joints, where changes of up to 0.5 mm per year were observed, influenced by weather, temperature in the tunnel, flow of underground water, etc. There also seems to be a yearly cycle. Simulations are being performed to better understand the actual alignment requirements.

The Phase 1 studies will be continued during Phase 2 commissioning and will be complemented by studies on beam effects of misalignments, beam-based cures and studies on the feasibility of magnet movers. For Phase 3 commissioning it is envisaged to have either active or passive alignment systems in place, to steer to a golden orbit that minimizes emittance growth, and to develop compensation methods like offset injection.

The committee notes the very good work done on monitoring the injector alignment and on identifying critical issues.

Recommendations:

R76: Perform a detailed analysis of measured and simulated emittance growth, taking into account alignment errors. Review alignment tolerances in view of the observed emittance growth.

R77: Study methods of beam-based alignment and the required hardware for achieving and maintaining the alignment within tolerances. Closely couple these studies to the work on the injector commissioning and the team pursuing this.

R78: Continue the studies on radiation hardness for alignment equipment.

25. Injector Commissioning (Phase 1 &2)

The results from the injector commissioning were presented. The 600 m long injector must provide beams of electrons and positrons for four (or five) different storage rings. The transverse emittance for SuperKEKB must be a factor 15–70 reduced with respect to KEKB. Precise trajectory measurements and control as well as simultaneous top up operation are required. After the positron target and up to the end of sector 2 the electron and positron beams must be transported through quadrupoles with the same DC fields. Pulsed correctors are available for independent e+/e- trajectory correction.

The main ring injection both into HER and LER started in this February with the thermionic e-gun. The RF gun was used on May 31, 2016 with success at the first attempt. The overall injection efficiency is 10–20% without bunch compression and increases to 70–100% with bunch compression. The normalized emittances with the thermionic gun at the end of the linac are 160/300 mm-mrad (x/y e-) and 1000/1200 mm-mrad (x/y e+). With the RF gun early measurements indicate linac emittances at sector 5 of 107/77 mm-mrad (x/y e-). This would mean an emittance growth by 500-1000% for beam from the RF gun. Further studies are needed.

The bunch charge fluctuation from the RF gun is about 4–5%, down from 20% in 2014. This must be compared to 1%~2% stability with the thermionic e- gun. Fluctuations in beam position with the thermionic gun vary from 0.1 mm to 1 mm, the horizontal fluctuations being larger than the vertical.

The Committee congratulates the team for successful injection into SuperKEKB, enabling the successful Phase 1 commissioning. The beam quality is being assessed in a professional and careful way. Several limitations have been identified and are being properly addressed.

Recommendations:

R79: Commission the common electron/positron optics between the positron target and end of sector 2.

R80: Perform a detailed analysis of normalized jitter, taking also into account the dispersion and effects of energy jitter.

R81: Perform a detailed analysis of emittance growth and its sources. Develop correction and optimization strategies for optics, energy, RF phase and trajectory.

26. Positron Damping Ring

All the design concepts of the Damping Ring have been defined and assessed since long time and the construction is progressing at the right pace. We congratulate the team on the impressive installation work that we had the opportunity to visit during the meeting.

All magnets in the transfer lines from (LTR) and to the linac (RTL) have been installed as well as those in the DR. Power supplies and the related cabling are already in place and connected. Vacuum chambers are already installed in the DR arcs and the ones of the straight session will follow soon. RF systems have already been assembled in the tunnel for subsequent in-situ checks; the installation will be complete in December. The presented planning foresees the beginning of the beam vacuum pumping in one year’s time, and the beginning of the beam commissioning four months later. The planning is tight and ambitious considering the lack of manpower, which has affected the DR construction since the beginning of the project.

Still we notice how a detailed study aimed at integrating the RF systems and the injection-extraction kickers of the DR in the general timing has never been presented.

Two cavities have been conditioned off line and have recently been moved into the tunnel to begin assembly of the RF station. Electropolishing was very beneficial in permitting rapid conditioning. A few light emitting events were seen early in conditioning but the cavities quickly attained full gradient. The off-line tests met all performance goals. The klystron and power supply for the damping ring RF are in place. The RF system is expected to be fully ready to support commissioning later this year. The third damping ring cavity has been postponed since two cavities should be capable of providing all the voltage and power needed. It would be good to have the third cavity as a spare when the machine is in full operation.

Recommendations:

R82: It is important that the DR is ready for Phase 2. We recommend to prepare a plan addressing a subset of activities essential to start the commissioning and at the same time compatible and consistent with the assigned resources, in terms of funds and manpower. Maintain schedule to support damping ring commissioning ahead of Phase 2.

R83: In order to let the DR accomplish its duty efficiently, a timing system properly integrated with the corresponding devices of the linac and of the rings is required. We recommend to prepare in time such DR timing developments.

27. IR Construction

A very good presentation was made concerning the IR construction. The work accomplished has been remarkable. A plan has been made and the steps are well thought out on how to assemble the two final focus cryostats, the final vertex detector assembly and the main detector. According to the schedule, the detector will roll on line this coming December. Then the general assembly of the cryostats inside the main detector can begin. The team is waiting for the second cryostat to arrive and, once here, will proceed to characterize and then prepare it for assembly. Phase 2, which will start in the fall of 2017, will not yet have the vertex assembly but will have a suite of temporary detectors in the same volume to study detector backgrounds prior to installing the vertex subsystems. The innermost vertex tracker (the PXD) is assembled directly onto the central beam pipe and, hence, needs to have the final beam pipe early in order to start a long, complicated and delicate assembly. This precludes any possible modifications to the central beam pipe if some issues arise after Phase 2 background data is collected. The connecting bellows sections between the cryostats and the central chamber still need to be made and these are crucial elements of the assembly. It was also pointed out that because of the tight space constraints there will be no vacuum pumping near the collision point which will result in a pressure bump at the central interaction point. This is not uncommon in this region near the collision point where space is at a premium.

Recommendations:

R84: Try to ensure the second cryostat arrives on time. This will assist in getting the complete assembly sequence thoroughly understood and tested.

R85: Try to get the connecting bellows sections fabricated promptly so they can be tested and certified.

28. Overview of IR Magnets and Construction Status

The 8 main quadrupole magnets, the 8 leak field coils, and the 36 corrector coils are made, as are 3 of the 4 compensation solenoids. The 4th solenoid is due to be delivered in July. The electrical insulation problems encountered last year with the assembly of the magnets into the QCSL cryostat were resolved and the complete unit was delivered to KEK in December 2015. Since then the system cooled down using helium from a 1000 liter dewar. Now testing of the complete system is well advanced. All the magnets and correction windings have been powered up to full current without problems (one magnet required 3 training quenches). The fields have been measured with harmonic coils and using stretched wires in order to verify the load lines and to locate the alignment targets on the cryostat body. It was discovered that while the leak field cancelling magnets took out the normal components, the skew components appear to be in the wrong direction. The reason for this, due to an apparent inversion of the coil is being investigated. Uncorrected, this could lead to a halving of the Touschek lifetime, but according to the beam optics group it should be possible to correct the global effect using devices outside the IR region. The measurement campaign continues, and is now addressing the solenoids.

The QCSR cryostat is presently being equipped with its magnets, and should be delivered to KEK in November this year.

Following the problems last year, it is reassuring to see the progress made with the QCSL assembly. It is however regrettable that the cancel coil was installed reversed and every effort should be made to find the cause so as to avoid a repetition of this, or a similar error on the QCSR assembly.

There remains an immense amount of work to do on this system, and this will have to be done with the utmost care at every step, given the difficulty in making repairs. The functioning of the complete system cannot be fully verified until installation in the field of the BELLE solenoid in phase 2 of the programme. The team is therefore encouraged to continue simulation work, exploring all working (and failure) conditions.

Recommendations:

R86: Determine as to why the cancel coil was installed reversed, so as to avoid future occurrence.

R87: Strengthen quality assurance of procedures for installation of magnets in the cryostat.

R88: Ensure redundancy of signal wiring.

R89: Compare measured quench behavior with that predicted by simulations.

29. Measurements of field quality for quadrupole magnets using harmonic coils

The array of superconducting quadrupoles which form the final focus system in the SuperKEKB has high gradients (70 T/m) and tight tolerances on the higher-harmonic content (0.05%). A careful magnetic measurement has been performed in order to assure the target field quality.

Rotating coil technique is used, with three types of different radius (12, 25 and 33 mm) coils fitting different quadrupole sections. Each coil has a long winding to measure the field integral and a short winding to scan the field profile longitudinally.

The QCSL magnets, including the leak-field compensator, are assembled and installed in their final cryostats in the lab. The assembly is mounted on the moving stage, with appropriate position monitor and inclinometer to control the magnet roll. Rotation is done by a motor with a rotary encoder.

The field integral measurement revealed deviations from the design by +0.08% for QC2LP and –2.69% for QC2LE. Each excitation curve was obtained, including the hysteresis (which, actually, is very small in the operation current range). The harmonic amplitudes are all below 0.05% with a reported measurement accuracy of 0.01%.

The measured field profiles are in reasonable agreement with those calculated. Measurements also revealed some skew and "forbidden" normal harmonics, whose effects on the beam dynamics should be checked in simulations.

Recommendations:

R90: Clarify the sources of systematic errors affecting the harmonic content measurement, e.g. the effect of the rotation axis offset or inclination with respect to the magnet axis.

R19: Consider calibration of the coils in a reference uniform-field magnet in order to avoid the systematics.

R92: In the next stage of measurements, on the beam line together with the solenoid fields, check the repeatability of the measured data, especially after a quench-recovery and complete warm-up–cool-down cycles.

30. Measurement of the magnet center with single stretched wire system

The stretched wire system enables the precise (± 0.1 mm) determination of the magnetic center and angular orientations of a quadrupole. The method was pioneered and has been extensively developed by Fermilab. A system was delivered to KEK in May and a Fermilab expert (Joe di Marco) came to help with is use. Initial results show the centers of QC2LP and QC2LE to have horizontal offsets of about 1 mm and vertical offsets of 0.1 to 0.6 mm with respect of the design values, and roll-angle errors of about 2 mrad. Measurement results will be compared with those coming from the harmonic coils. This work is ongoing. It is important to realize that the apparatus itself is subject to harboring systematic errors and should be checked.

Recommendations:

R93: Verify the apparatus with a warm (resistive) quadrupole that can be measured physically.

31. Cryostat Performance

The final focus cryostats are extremely complicated and critical assemblies combining tight alignment tolerances, heavy shielding elements, large magnetic forces and over 50 separate current connections. Enormous progress has been made since the last review. The QCS-L has been tested off-line at KEK and has performed very well. Extensive magnetic field mapping is under way. However, since the magnet is not connected to the final helium refrigerator, it has to be tested in batch mode, with daily filling from a 1000 liter dewar. The LN2 shield was initially configured with the flow in the opposite direction to the planned final installation. The shield temperature was significantly higher than expected, which probably contributes to an overall higher static load than design, although this is still within operating margin. The shield flow will be put back to the design configuration in the near future to see if this improves the temperature. The current leads are cooled by return gas. The temperature of the intercepting shield and those of the cold mass mechanical supports were higher than expected. This could affect the static load to the cold mass significantly. The current lead gas flows were set to achieve stable operation but there has not been sufficient time to optimize them. Once the shield temperature is reduced they may be fine-tuned to reduce overall helium consumption and to extend the batch running time.

Very recent measurements have shown discrepancies in the electrical center of the magnets between the stretched wire measurements, the rotating coil and the mechanical data. Further investigation is ongoing. The QCS-R will be delivered in November and will only have warm checks off-line before being installed and fully measured in the tunnel.

Recommendations:

R94: Continue measurements and optimization of the static loads to try to get closer to design values.

R95: Continue magnetic field mapping measurements to understand the discrepancies in the electrical center.

R96: Start to measure and evaluate the mechanical response with resonant modes in order to compare with simulations.

32. Quench protection system for superconducting solenoids

The integrated field of the Belle II solenoid on the beams is cancelled by solenoids installed in the cryostats housing the magnets of the low-beta insertion, and surrounding those magnets. While for the solenoids ESR2 and 3 which have low inductance andwork at about 10% of current carrying capacity, protection is trivial, that required for solenoids ESL and ESR1, which provide the main compensating field and have inductances of 2.5 H and 8.8 H respectively, requires careful attention. It is proposed to use the classical approach of detecting the quench by monitoring the voltage across a coil, upon which a (solid state) circuit breaker opens so as to allow a significant fraction of the stored energy to be extracted into an external resistor. The value of the resistance is calculated to ensure that the voltage to ground does not exceed an acceptable limit for the coil, in this case 200 V. Each of the solenoids is divided into 2 circuits, powered by 2 power supplies, via 3 leads. The temperature of the quenched coil should not exceed 200 K. Calculations show that this scheme works for ESL, but that for ESR1 cold diode stacks must be installed across the coils to ensure that the temperature does not rise above a value of 200 K.

Recommendations:

R97: Check that expected radiation level at the location of the cold diodes can be tolerated.

R98: Test the diodes in cryogenic conditions before installation.

R99: Foresee the possibility of replacing diodes in case of failure.

33. Tour (KEKB control room, MR tunnel, Linac, Damping ring, QCS)

The Committee was treated to a tour of the Main Control Room, the SuperKEKB tunnel, the Injector, the Damping Ring and the superconducting quadrupole. The careful engineering and the quality of the installation were really impressive. The tour made it easier for the Committee to visualize the topics that had been discussed during the presentations.

The Committee would like to thank the many members of the SuperKEKB team for taking the time to show us the facilities.

Recommendations:

None.

Appendix A

KEKB Accelerator Review Committee Members

Frank Zimmermann, Chair	CERN
Ralph Assmann	DESY
Paolo Chiggiato	CERN
John Fox	SLAC
Andrew Hutton	JLab
In Soo Ko	POSTECH (unable to attend)
Catia Milardi	INFN-LNF
Evgeny Perevedentsev	BINP
Matt Poelker	JLab (unable to attend)
Qing Qin	IHEP
Bob Rimmer	JLab
John Seeman	SLAC
Michael Sullivan	SLAC
Tom Taylor	CERN (ret.)
Rogelio Tomas	CERN
Seiya Yamaguchi	KEK, Director of Acc. Laboratory, Ex Officio Member
Katsunobu Oide	KEK, Former Director of Acc. Lab, Ex Officio Member
Kazunori Akai	KEK, Head of Acc. Division III, Ex Officio Member
Kazuro Furukawa	KEK, Head of Acc. Division V, Ex Officio Member
Haruyo Koiso	KEK, Head of Acc. Division IV, Ex Officio Member

Appendix B Agenda of the 21st KEKB Accelerator Review Committee

June 13 (Monday)		
08:30 - 09:00	Executive Session	
09:00 - 09:05	Welcome	S. Yamaguchi
09:05 - 09:45	Overview of SuperKEKB, Status and Plans	K. Akai
09:45 - 10:15	Belle II Physics and Construction Status	T. Browder
10:35 - 11:05	Overview of Phase I Commissioning	Y. Funakoshi
11:05 - 11:20	Overview of Lattice	Y. Ohnishi
11:20 - 11:45	Optics Correction and Low Emittance Tuning	H. Sugimoto
11:45 - 12:25	Vacuum system, beam scrubbing	Y. Suetsugu
13:25 - 13:45	Instabilities: simulation and observation	K. Ohmi
13:45 - 14:10	Beam instrumentation and bunch feedback systems	M. Tobiyama
14:10 - 14:25	Photon monitors	J. Flanagan
14:25 - 14:45	Operation Status of RF System	T. Kobayashi
14:45 - 15:05	Normal-Conducting RF Cavities for SuperKEKB / MR & DR	T. Abe
15:05 - 15:20	Integrated vacuum control system for RF and Operation status of SCC	M. Nishiwaki
15:40 - 16:10	Beast II, beam background	H. Nakayama
16:10 - 16:50	Ring magnet system	M. Masuzawa, T. Oki
16:50 - 17:05	Beam transport and injection	N. Iida
17:05 - 17:20	Beam abort system	T. Mimashi
17:20 - 17:35	Control	T. Nakamura
17:35 - 17:50	Beam Injection Control	H. Kaji
June 14 (Tuesday)		
08:30 - 09:00	Executive session	
09:00 - 09:15	RF Gun Report	Y. Honda
09:15 - 09:25	Injector Linac Overview	K. Furukawa
09:25 - 09:45	RF gun and electron beam	M. Yoshida
09:45 - 10:05	Laser and RF Gun	X. Zhou
10:25 - 10:45	Positron generation and beam	T. Kamitani
10:45 - 11:05	Injector alignment	T. Higo
11:05 - 11:25	Injector commissioning (phase 1&2)	M. Satoh
11:25 - 11:55	Positron Damping Ring	M. Kikuchi
13:00 - 13:20	IR construction	K. Kanazawa
13:20 - 13:40	Overview of IR magnets and construction status	N. Ohuchi
13:40 - 13:55	Measurements of field quality for quadrupole magnets using harmonic coils	Y. Arimoto

13:55 - 14:10	Measurement of the magnet center with single stretched wire system	H. Iinuma
14:10 - 14:25	Cryostat performance	Z. Zong
14:25 - 14:40	Quench protection system for superconducting solenoids	X. Wang
15:00 - 17:30	Tour (KEKB control room, MR tunnel, Linac, Damping ring, QCS)	
18:30 - 19:00	Report Writing / Executive Session	
June 15 (Wednesday)		
08:30 - 11:00	Executive Session / Report Writing	
11:00 - 12:00	Close-out	