

# The Eighteenth KEKB Accelerator Review Committee Report

March 6, 2013

## Introduction

The Eighteenth KEKB Accelerator Review committee meeting was held on March 4-7, 2013. The following members of the committee were unable to attend: Stuart Henderson Miguel Jimenez, and Frank Zimmerman. Nadine Kurita (SLAC) attended as an expert in lieu of Miguel Jimenez. Appendix A shows the present membership of the committee. 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 committee was impressed by the enormous progress in the construction of SuperKEKB and, as always, by the high standard of the presentations. It was particularly pleasing to have such excellent presenters including many junior staff members. The committee evaluated the present status of the project and prepared recommendations, which 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**

The SuperKEKB Project has made exceptional progress since last year. The development, fabrication and installation of SuperKEKB Main Ring components have progressed well, including beam pipes, magnets, wigglers, magnets power supplies, RF cavities, klystrons, LLRF system, diagnostics and controls. The Damping Ring is also progressing smoothly; the design and fabrication of its components, magnets, RF cavity, vacuum system, injection system, instrumentation and controls are well advanced. Injector upgrades are proceeding on schedule with a notable accomplishment on the RF gun.

Solid progress has been made in the design and fabrication of the Interaction Region and its associated components such as the superconducting QCS magnets and vacuum chambers. However, the construction of the Interaction Region, including the installation of all the components, still remains on the critical path for SuperKEKB to start commissioning with Belle II.

The design and construction of the Belle II detector has also made considerable progress. The most important outstanding item is the TOP detector, which could delay the move-in of the detector.

There still remain some discrepancy between the linac alignment methodologies, and the ring alignment is seeking the best strategy to mitigate the slow, but inevitable, settling of part of the ring (~2mm per year).

The Main Ring commissioning plan was presented and the detailed three-phase plan is credible and takes account of all of the constraints. Two options were presented: the first assumes that the detector and interaction region components are ready on the present schedule. The second changes the commissioning order to enable progress in case either the detector or the interaction region components are delayed. The linac commissioning plans are being developed and will be presented at the next Review.

Overall, the committee considers the technical cost for the entire Project to be on track, but there are still concerns about timely funding. The technical and schedule risks are considered low for the Injector chain, facilities and the ring components, but the committee considers the technical and schedule risk high for the Interaction Region. The committee is pleased that a mitigation strategy has been developed, which has been included in the commissioning plan. The alternate plan also enables the project to initiate beam commissioning in JFY14, as required by the funding agency.

**B) Recommendations: The committee has made recommendations throughout the different sections below. Highlights of these recommendations are summarized here.**

- 1) Despite the strong support of KEK management to increase staffing, including a few new junior hires and rehiring senior, experienced retired staff, shortage of qualified staff

continues to be a major risk to successful completion of the project, the commissioning and operations.

- 2) Develop and track to a clear set of milestones for the production of the IR SC magnets, cryostats and the other IR components so that progress can be carefully monitored and the high schedule risk, which concerns the committee, can be mitigated.
- 3) Continue the ongoing work aimed at the development of necessary simulation tools, with benchmarking, to study various critical path beam dynamics effects impacting SuperKEKB performance. These simulations should include at least the 3D IR modeling, error effects, dynamic aperture, beam-beam interaction, space charge, intrabeam scattering, and the outcome figures of merit including the achieved luminosity, detector background, and Touschek lifetime. International collaboration should be enhanced to use the experience accumulated in the sister laboratories.
- 4) Continue the detailed evaluation of all sources of beam-induced background to identify and mitigate the major loss terms in the detector to prepare for shielding; this includes the impact of the additional weight on the QCS support system.
- 5) Continue to aggressively pursue the timely completion of the components of the injector chain while maintaining the ability to simultaneously inject into the PF and AR. Complete hardware demonstrations of key components and simulations with the goal of a self-consistent start-to-end description of the injection system that meets all of the requirements.

## **C) Findings and Comments**

### **1) Overview of Ring Construction Status and Schedule**

The KEKB team has made extremely good progress in the ring construction since the last review. The design of the main ring has been improved based on an optimization of the Interaction Region. The development, fabrication and installation of SuperKEKB Main Ring components has progressed well under consistent project planning, including beam pipes, magnets, wigglers, magnets power supplies, RF cavities, klystrons and LLRF system. The Damping Ring is also progressing smoothly, the design and fabrication of the components, magnets, RF cavity, vacuum system, injection system, instrumentation and control system, are also well advanced.

Although the project schedule is aggressive, the master schedule of the SuperKEKB is based on realizable and feasible plans. The schedule optimization of fabrication, installation and integration for the all of the SuperKEKB accelerators has been done in a very efficient way leading to the planned completion of the target project milestone of commencing the commissioning by the end of JFY2014. The construction and commissioning schedule of the Damping Ring is arranged in parallel with KEKB to be ready to complete the Phase I and Phase II commissioning requirements.

The SuperKEKB Commissioning Scenario is clearly defined and well developed in three phases, which greatly optimized resource utilization for fabrication, installation and commissioning in the project schedule and ensures achievable performance.

Tremendous and impressive progress has been made in the design and fabrication of the Interaction Region and its associated components such as the superconducting QCS magnets and vacuum chambers. However, the construction of the Interaction Region, including the installation of all the components, still remains on the critical path for SuperKEKB to start commissioning with Belle II.

The project team shows very complementary capabilities with hard work of the staff and strong support of KEK management to increase the staffing, including rehiring senior, experienced retired staff. However manpower resources is still a limiting factor for SuperKEKB to be completed on its aggressive schedule. The committee supports the continuing efforts to ensure that sufficient staff is made available for the SuperKEKB construction and operation needs.

#### **Recommendation**

There are number of components which must be systematically checked for their impact on the impedance budget. It is recommended that a single person be assigned as the “impedance police” responsible for checking and controlling every component which has an impedance contribution to MR.

### **2) Belle II Construction and Schedule**

The construction of Belle II is going well. The design phase is approaching the end. The detector had to be rotated about a vertical axis to match the new geometry of the accelerator. The rotation process is nearly complete. The PXD detectors have been successfully modified to accommodate the timing changes of the accelerator bunches to minimize dead time from noise. The SVD detector is in the final mockup phase. The CDC is in production.

The critical path of the the project now goes though the TOP modules being contributed by the US contingent. Several reviews have taken place and new modifications of the

modules are being tested. The production of the quartz bars is under review. A US-DOE CD review of these modules will be held in August. The lifetime of the TOP photomultiplier cathodes from radiation is being studied and a method of replacing the tubes quickly is being investigated.

The luminosity monitor used by both the detector and the accelerator is being produced by the Belle II collaboration. The final details of this monitor needs to be agreed on by the accelerator group so that the SuperKEKB Accelerator Group can complete the interaction point and luminosity feedbacks.

**Recommendation:**

The Belle II TOP detector is on the critical path. Constant attention should be paid to this detector component. Other possible mitigations for the TOP issues should be investigated.

**3) Beam Dynamics Issues in SuperKEKB**

In line with recommendations of the previous ARC, beam dynamic effects of critical importance for the SuperKEKB performance were investigated in greater detail.

Coherent Synchrotron Radiation (CSR) simulation was performed for both DR and main rings. The KEK-SLAC collaboration resulted in benchmarking 5 available codes for evaluation of CSR impedance, wake and Microwave Instability (MWI). Comparison of alternative approaches helped to rule out computational artifacts and produce more reliable results.

In DR, the optics has been optimized for CSR, yet the MWI threshold is likely to be reached, resulting in sizable bunch lengthening. In LER the MWI threshold is predicted to be exactly at the maximum design bunch intensity, while in HER a safety factor of 3 is reported.

In the weak-strong beam-beam simulations, machine nonlinearities of the current optics model are included. The tune scans revealed enhancement of synchro-betatron resonances and more stringent limitations on the working point choice. The current-dependent roll-off of the specific luminosity becomes stronger, accompanied by strengthening of the high-order resonances in the tune map. Optimizing the nonlinear lattice for a larger dynamic aperture leads to a better luminosity performance. This observation leaves a hope that the specific luminosity can be recovered in operation by tuning the real lattice for a better lifetime.

Importance of the chromatic coupling compensation was re-confirmed and the machine parameter tolerance table (relevant to a prior-year optics model) was updated for residual chromatic coupling at the 10% luminosity loss.

In the NanoBeam scheme the space-charge effect turned out to be a **new** serious problem; its interplay with the beam-beam effect became a novel simulation subject. Preliminary results show the vertical beam-beam and space-charge tune-shifts in LER of the same order with no additional degradation of the specific luminosity.

The committee puts an emphasis on studying the space charge effect on the beam-beam interaction in the SuperKEKB LER to see if the effects are as strong as early simulation indicates. Possible mitigation techniques should be investigated.

The committee recommends that a comprehensive table be compiled, where the effects on the beam-beam interaction and resulting luminosity are calculated for accelerator operational errors such as a vertical offset at the IR, a vertical angle error at the IP, a horizontal offset at the IP, a beam roll error, residual dispersion, coupling or chromatic

coupling, all within the same optics model. Possible errors in the detector solenoid fields should be studied for their effect on the beam-beam interaction. The most critical weak-strong simulation results should be checked in the strong-strong simulation.

The committee strongly supports the ongoing work aimed at the development of necessary simulation tools, with benchmarking, to study various critical path beam dynamics effects impacting SuperKEKB performance. These simulations should include at least the 3D IR modeling, error effects, dynamic aperture, beam-beam interaction, intrabeam scattering, and the outcome figures of merit including the achieved luminosity, detector background, and Touschek lifetime. International collaboration should be enhanced to use the experience accumulated in the sister laboratories.

#### **4) Optics Issues**

The design studies of the LER and HER magnetic lattices are very advanced. There have been many optics configurations created and studied for their respective advantages. The arc optics seems to have settled down, being slightly updated with to minor modifications to the detailed hardware design. The Beast optics is prepared for Phase 1 commissioning. The overall ring and the IR optics have been studied mostly independently. The IR optics is still in evolution following the improvements in the technical design of the final focus magnets. Using the 3D IR model, the IR magnet error correction procedure is developed by simulation of the dynamic aperture capable of recovering the Touschek lifetime to ~600 seconds. The right hand side of the final focus is still not fixed, where they are trying to optimize the nonlinear corrector set. The two optics are now being merged into a combined study to allow relative tolerance considerations. Maximizing the Touschek lifetime and the dynamic apertures have been major goals of these studies.

The 20-mm vertical settling over half of the ring tunnel circumference and its impact on alignment is an important issue. Consequently, the machine effectively tilts as half of it sinks by about 2 mm per year. A decision by the magnet group has been made to keep the rings aligned to this existing overall subsidence (trajectory). This removes the need to vertically move the RF cavity systems and reduce the risk of vacuum seal failure. Any magnets with a large discontinuity in misalignment relative to its neighbors will be adjusted locally. One option discussed by the committee that SuperKEKB may wish to consider is biasing the overall magnet and vacuum chamber alignment upward a few mms so that the HER and LER rings will have several years of movement before the settling of the ring tunnels seriously degrade the machine's flatness.

The overall interaction region IR will have 40 correction elements including dipoles, and normal and skew moment correctors from quadrupole, sextupoles, skew octupole, and other higher order fields. All of these correctors will need to be adjusted to maximize the luminosity. The beam measurements and software controls to make decisions and calculations how to adjust these variables are now just being investigated. It would be ideal to develop an orthogonal set of adjusting variables using these 40 correctors to optimize the luminosity as rapidly as possible. However, more likely the less attractive possibility of combinations of non-orthogonal adjustments will be the outcome. This would significantly increase the luminosity tuning time.

R1: The committee recommends concentrating on developing very detailed and robust procedures for correcting the closed orbit and linear optics distortions caused by realistic field errors, especially in difficult places like the local chromaticity correction section. For the IR optics, an algorithm should be developed for the control-room operational usage, aimed at improving the beam lifetime (and the dynamic aperture) by numerous

nonlinear corrections, in addition to the blind downhill-simplex optimization.

R2: The Optics Group should continue to merge the IR and ring lattices with the intent to study optimized luminosity tuning with full IR fields, full error tolerances, all correctors, and the needed small vertical emittances.

## 5) Magnet Overview

It is the middle of the busy period for the magnet program. Installation and survey have been progressing smoothly. More than 100 arc dipole magnets and 140 vertical correctors were installed and aligned. In some areas, the lattice is designed to be very compact, which caused some difficulties in installation, which was resolved with proper equipment. Some of the delivered magnets were mishandled or manufactured with defects by the vendors, which incurred extra manpower to clean up the flaws.

The LER wigglers, 112 half-pole wigglers and 56 single-pole wigglers, were newly installed in the Oho and Nikko sections and aligned. Some of these wigglers were packed near the SC cavities in a straight section without much space for installation. The issue of field leakage in this section was stated to be similar to the previous KEKB installation.

Two teams carried out the alignment of the survey monuments in the Tsukuba IP area from different directions. The measured alignment error between the two groups when they met at the center was within 0.1 mm, which is an excellent crosscheck of the alignment procedures. From the long-term alignment history, the floor in Fuji is sinking 2mm/year with some extra glitches due to the earthquake. It is suggest that the measurement data of 2012 be used as an alignment reference to smooth out the ring, including an allowance for future ground movement. The alignment information should be discussed further with the Optics group to find best solution.

Tilting supports will be introduced to allow 30-degree tilts on 24 sextupole magnets, necessitating the modification of existing KEKB sextupole magnets. More magnets will be fabricated and installed in 2013. Major work in fabrication, field measurements, installation, alignment, connecting cooling water and power supplies should be completed this year. One expects that the magnet program will be continued in 2014.

The committee congratulates the magnet group for the huge amount of work accomplished with extreme precision.

## Recommendations

1. The skew quadrupole components will be built within the existing saturated sextupole magnets using strip coils wrapped around the ion poles. Additional excitation current will further saturate the magnets. Analyzing the non-linear components with full excitation current of the skew quadrupole will be necessary to enable the effect on beam optics to be evaluated.
2. The spaces between some of magnets or wigglers are very tight. The field leakage, edge effect of dipole magnets and the cross coupling between the tight spaced magnets should be double-checked.
3. A similar situation occurred near the SC cavities area. It might be worth to re-measure the leakage field around the SC cavities area, comparing it to the field leakage during KEKB operation.
4. It might be worthwhile for the optics group to evaluate the magnets measurement results to see if sorting the magnets would reduce the strength of the correctors.

## 6) Magnet fabrication and field measurement

There are now 138 arc dipole magnets, 168 wigglers, and 220 vertical correctors installed in the LER tunnel. The rest of magnets are either in mass production or in procurement. The dipole field was measured by a 6-meter long flip-coil, which was calibrated by a reference magnet after each measurement. The normalized field error distribution for the 109 dipoles is  $1.1 \times 10^{-5}$ . Damping wigglers are used in the main rings to reduce emittance. These wigglers are measured by harmonic coils. The normalized standard deviations are  $1.49 \times 10^{-5}$  and  $2.45 \times 10^{-5}$  for half pole and single pole wigglers, respectively. All these tolerances are acceptable.

The committee has some unanswered questions on the effects of cross and leakage fields for these tightly packed wigglers and magnets. The measured results on these delivered magnets should be provided to the optics group to include in the correction algorithms.

## 7) Magnet Power Supplies

The KEKB team continues to show progress in addressing the magnet power supply needs for SuperKEKB. There are a total of 308 power supplies to be used for SuperKEKB. Of these 285 require a 20-bit resolution with corresponding stability of <20 ppm/day and a ripple of less than 10 ppm. The balance of 23 power supplies require 24-bit resolution with a corresponding 10 times smaller stability (<2 ppm/day) and ripple (<1 ppm). To achieve this 24-bit resolution, the KEKB team has come up with a system of adding 16 20-bit DACs fed by a FPGA. It is not clear to the review committee how successful this approach will be if the errors of the 20-bit DACs are not completely uncorrelated. Similarly, the review committee does not fully appreciate the value of having a resolution significantly less than the stability of power supplies (24-bit corresponds to 0.12 ppm). Consequently, as was indicated in the 17<sup>th</sup> review report the committee remains cautious.

### Recommendation

The temperature of the environment might also have considerable effect to the high performance power supplies. The committee suggests that the team checks the correlation between the long-term drift of output current and temperature near control unit.

## 8) IR Magnet

Work continues on all aspects of the complex magnet systems of the Interaction Region (IR) and considerable progress has been made since the 17<sup>th</sup> KEKB Accelerator Review committee meeting. In the area of IR Magnets and their associated cryostats there has been an improvement in the cross sectional designs of all of the magnets since the previous review, and very good results from the prototype magnets. Vanadium permendur has been selected to be the yoke material for two magnets, QC1E and QC2P. Three-dimensional design analysis has also been started in collaboration with BNL and adaptations have been made to the cryostats to lessen the coupling to vibration.

The QC1P and QC1E prototype magnets have been constructed and cold tested and magnetically measured. The QC1E was powered up to 2.157 kA without a quench well above the nominal operating point of 1.559 kA. The measured load lines have adequate margin for both the nominal operating point and 12 GeV operating point. The measured quadrupole field was 1% below the design. The QC1P was operated at 2.1 kA without a quench well about the nominal operating current of 1.625 kA, again with adequate load line margins for both nominal and 12 GeV operation. Both prototypes produced within

~±1% of the design value for the integrated quadrupole. Sextupole error moments were present in both prototypes. Subsequent analysis of the source of these errors has resulted in a number of areas with design refinements.

The choice of vanadium permendur for the yokes of two magnets to reduce the leakage field is understandable. The size and shape of the yoke pieces are such that production in vanadium permendur should not present too much additional difficulty. Analysis of the full implications of the use of vanadium permendur is just beginning. The mechanical properties of vanadium permendur are significantly different from those of steel and iron. Care must be exercised to not exceed the material properties in the design or to stress the material during fabrication or assembly. This is particularly important after the full magnetic anneal required to obtain the desired magnetic characteristics when the mechanical properties are considerably changed.

The cryogenic system for the QCSL has been installed and cold tested. Nevertheless, the challenges associated with the construction and installation schedule for the QCSL is extremely aggressive and acknowledged as being difficult to achieve. Although not presented as such, the critical path of the SuperKEKB construction and installation appears to run through the production, installation integration of the IR Magnets. No remediation of the schedule risk was discussed in detail.

As stated in the 17<sup>th</sup> Review Report, the schedule for the completion of the magnets by early 2015 is very aggressive and has no schedule contingency. This leads to a natural tendency to move as quickly as possible from design development activities into fabrication. As was recommended from previous reviews, a clear set of detailed milestones and decision points with criteria based on performance requirements should be maintained.

Overall, the IR magnets remain the area of highest risk for both technical and schedule. Nevertheless, the SuperKEKB is proceeding well in this area.

**Recommendation carried forward:**

The committee recommends making a clear set of milestones and criteria-based decision points for the development and fabrication of the IR SC magnets, corrector and compensation coils, and cryostats so that progress can be carefully tracked and contingent plans enacted in a timely manner if required.

**9) Construction of the Interaction Region**

The interaction vacuum chambers are challenging and KEKB has made significant progress on their designs since the last review. The design of the inner IP chamber is complete and fabrication is underway and expected to be completed in 2013. The IP chamber was prototyped and used to validate the feasibility of the various joint designs (Be-Ti Braze, Ti-Ta HIP, EWB near HIP). Note, the results of the prototype testing were not presented.

Additional fabrication testing is planned for sputtering Au on Ti and other joining tests. Some thermal and stress analyses have also been performed to validate the design and an additional analysis is underway including dynamic analysis. The stress at the junction of the HER and LER should also be examined due to thermal expansion differences in the two legs.

The designs of the two chambers that are outboard of the inner IP chamber are advancing and expected to be completed soon. These chambers incorporate ridges to reduce the backgrounds in the IP. The steep ridges were analyzed and found acceptable for beam

impedance. Fabrication of these chambers is scheduled from April 2013 to March 2014, and is on schedule. The QCS chamber designs are still under development and these chambers will be fabricated in 2014. The overall KEKB schedule shows that the IR chambers are needed by the end of 2014, so there is not a lot of schedule contingency.

The background requirement in the IP has led to the need to achieve a low pressure in this region. The vacuum performance has been extensively studied, but the configuration necessitates that vacuum pumps are a considerable distance from the interaction region (~4m) and so little can be done other than surface treatment to improve the vacuum, as it is almost entirely conductance and outgassing (photon-induced) limited. Also the Au-plated Ta chambers have been demonstrated to have photon-induced desorption rates lower than copper. Photon-induced desorption testing was executed at the Photon Factory to obtain realistic values and used to predict the vacuum pressures. The only other alternative to improve the pressure would be to consider NEG coating of these chambers, but this could lead to other issues (I2R and chamber lifetime). Also, the effect on the backgrounds from the vacuum pressure close to the IP is smaller than the effect of the pressure at about 10m away from the IP. The vacuum pressure beyond 5m was not discussed during this review. It would be useful to have a background budget to evaluate the impact of the vacuum pressures in the IR region.

The commissioning plan of the KEKB Accelerator requires that two fairly separate and self-contained installations of the interaction region must occur. The first has temporary stages and shields in place of the Belle-II detector. The second is the complete interaction region installation, integrated with Belle-II, including complete supports and cryostats for the QCSL and QCSR magnets. There were two installation scenarios presented. Both alternatives have pros and cons and their choice will have impacts on the detailed designs of the VXD, but the decision path was not explained. However, it was stated that this decision needs to be made soon.

No development strategies and decision points were presented to address the technical issues remaining with the QCS Bridge. The present design is understood and acknowledged as being weak and subject to unacceptable vibration amplification, unless the vibration of the QC1E and QC1P occurs with a favorable phase. It was indicated that the timeframe for addressing this issue was quite short, but no specific approach, development plan, or decision tree was presented.

Currently the radiation shielding in the IR region was shown to be insufficient. An acceptable solution needs to be found and simulated. The solution may need involvement from others within KEKB, as the optimal solution may not be achievable with the current boundary conditions.

The schedule and milestones were not presented at a level sufficiently detailed to allow the review committee to assess as to the ability of KEKB to understand and address risks before they become issues and to address issues prior to them becoming major impediments to successful completion of construction, installation and integration.

#### Recommendations:

- 1) Continue the detailed evaluation of all sources of beam induced background to identify and mitigate the major loss terms in the detector to prepare for shielding; this includes the impact of the additional weight on the QCS support system, IR vacuum pressures and possible modifications to the walls of the experimental hall.
- 2) Make a decision on the baseline design for the QCS Bridge and installation. If needed evaluate the risk and develop a mitigation strategy. Evaluate and mitigate the IR

region schedule risks for fabrication and installation.

## **10) Beam Background**

Detailed studies of beam losses around SuperKEKB have been done in order to understand 1) the expected backgrounds in Belle-II, 2) radiation exposures to the detector components, 3) detector channel occupancies for data triggering and analysis, and 4) needed radiation shielding. The backgrounds come from synchrotron radiation, beam-gas scattering, lost particles from the beam Touschek lifetime, and beam-beam radiative Bhabha lost particles. The overall beam lifetime is about 6 minutes at the peak luminosity with each beam losing about 7 to 10 mA per second.

Synchrotron radiation has been controlled by minimizing the dipole bend angles for the beams entering the IR. Remaining synchrotron radiation x-rays are controlled by small masks in the vacuum chamber to avoid scattering them into the vertex chamber.

Beam-gas scattering can direct lost particles into the detector and is controlled by minimizing the vacuum pressure near the IR and around the ring. The IR vacuum group is actively adding pumps to the vacuum chamber design to lower the expected pressure at full currents. Scrubbing runs at high currents will reduce the vacuum pressure in the rest of the ring. Collimators are being added to reduce the losses in the IR. The beam gas lifetime is expected to be about 25 to 46 minutes.

The Touschek lifetime in the rings is determined where the beam size is smallest. The optical quadrupole lattice has been studied to enlarge the average beam size and raise the lifetime. The Touschek lifetime is now on the order of 10 minutes in both the LER and HER at full currents.

The beam-beam radiative Bhabha scattered lifetime is about 20 to 28 minutes for the two rings. The only method to reduce this background is to collimate lost particles away from the IR to prevent scattered particles from traveling multiple turns and striking the detector. The radiative Bhabha beam lifetime is about 20 to 28 minutes.

All these lost particles have been tracked in simulations with known vacuum chambers dimensions and collimator apertures so that the locations of the losses can be determined. These loss rates and locations have been sent to the Belle-II group to allow them to do detector background studies. Extra shielding is being added inside the final focus quadrupole cryostats. With these mitigation methods the detector backgrounds are hopefully within bounds of what Belle-II needs. Further studies are underway aiming at further gains. Measurements of the backgrounds during early accelerator commissioning will be done without Belle-II in place by using a suite of small detector elements called BEAST-II.

## **11) Collision Feedback (dithering)**

The vertical and horizontal systems were presented in separate talks (Collision Feedback (dithering) and in Diagnostics). However, the two tasks are related and best understood as potentially coupled controllers. Each IP feedback system computes a beam collision impact parameter, and applies a correction signal through corrector magnets. The disturbances in each system arise from vibrations in the final focus magnets, and this mechanical system is not going to vibrate with orthogonal motion in the two beam planes. Each system needs to be analyzed as a closed loop dynamic system, and the disturbance rejection can be estimated at the various oscillation frequencies.

The analysis of the combined performance requires considering them as an integrated system.

The essential differences in the Vertical and Horizontal IP feedback systems are the use of beam-beam deflection and BPM measurements in the vertical plane, and the use of the luminosity signal in the horizontal plane. The required system bandwidths are estimated to be very different, based on estimated oscillation frequencies of various modes of motion in the final focus girders and magnets.

### Horizontal System

The Horizontal system is estimated to require a bandwidth of 3 Hz. Examples developed at PEP-II were used to suggest a starting plan for a horizontal dither system based on magnetic deflection, and using a lock-in (synchronous demodulation) detection on the fast beam luminosity signal. There was some discussion about detection at twice the modulation frequency; the choice has to do with the depth of modulation applied to the colliding beams. As the essential goal is to increase luminosity, small modulations that do not significantly lower the integrated luminosity, but still provide a clear error signal are preferable. As mentioned at the review, one can detect both amplitude and phase of the modulation to get a discriminant that has the necessary sign of the error.

We recommend doing some simple modeling of the system based on the knowledge of the final focus optics, and estimates of the count rates in the luminosity monitor (some of this formalism has been done as part of the PEP-II design and is probably useful to adapt for the KEKB case).

As the luminosity signal is probably computed through a digital process, there really isn't any need to purchase or evaluate lock-in amplifiers as electronic systems – the synchronous demodulation algorithm can run on a general purpose or specific DSP/FPGA processor, and drive the deflection dither magnet through a digital control path. One nice aspect of a DSP-based controller is that there can be several related controllers depending on final focus optics, operational currents and luminosity count rates, each optimized for a particular operating point.

The detailed design of the feedback controller is going to require knowledge of the frequency response of the actuators, the bandwidth of the luminosity monitor, signal/noise in the luminosity signal, etc. It may also be beneficial to use information from the vertical system as there may be cross coupling in the mechanical vibration motions.

The operational experience from the PEP-II implementation will be helpful to the system designers.

### Vertical IP feedback system (presented in the diagnostics talk)

We see progress since the last review but some comments from past years are still valid. We encourage a closed loop analysis of the complete system, including the frequency responses of the proposed DSP filters, the planned PID controller, and the actuator including skin effect. We are not sure what sort of closed loop bandwidths, or closed loop frequency responses are possible with the complex CIC filters with 1 ms group delay (for example, at 1 kHz the group delay is  $2\pi$ , so the controller will oscillate with a unity loop gain). We stress that doing some simple control loop modeling is valuable before building the system. We suggest evaluating the planned PID controller and understanding the limits of this approach, while the FPGA based controller implementation is flexible and may be modified later. We think it is valuable to have a starting design that works in simulation. We think this vertical error may be cross-coupled to the horizontal system, and the controller may be a multiple-input multiple

output structure. The required bandwidth of this system may have to suppress motion at 53Hz, so that the overall system unity gain frequency may need to be nearly a kilohertz.

## **12) Vacuum Construction Status and Schedule**

KEKB has shown itself very aggressive and capable in addressing the challenges of the main vacuum design and production. Production of the standard vacuum components is progressing well. A manufacturing facility has been set up for assembly, TiN coating and baking. The HER copper racetrack chambers and the LER Oho RF cavity section have been completed. The rotatable SX section, beam monitor section and Fuji crossing-point chambers are all in production. Gate valves, getters and bellows are near completion. The design of the chambers for beam injection, abort system and the SR monitor in the Fuji straight section will be completed soon, and production will take place in 2014. These are all required for Phase 1 commissioning.

With regards to the dust/contamination issue discussed in the last report (“Preparation before Installation” p.13); the vacuum group carried out an investigation and found that the root cause was in chamber fabrication and welding. The committee recommends working with the vendor to reduce the contamination, as it is difficult to effectively clean dust particles in a chamber and an alcohol wipe may compromise the bake out. In response to the previous recommendation, the vacuum group has established a “checklist” to track the history of all chambers.

The antechamber vacuum chambers do not have cooling at the entrance to the antechambers (the corner). During low current operation (20 mA) with interlocks off, it is unclear whether the chambers can handle a direct SR strike at the corner radius due to a mis-steered beam?

As part of the integrated vacuum system design, a few considerations should be investigated. First, the new RF finger design in the bellows is a novel and clever solution for high current storage machines; however, these bellows only allow for up to 4mm of motion and some small angular motion. During the recent earthquake there was up to 10 mm of motion of the vacuum hardware. The current KEKB bellows were damaged, but protected the more expensive vacuum hardware. The new bellows design should also provide adequate motion to protect the main vacuum chambers from damage during a large earthquake (20-year event?), as these are usually the quickest components to repair and replace.

Another integrated system design issue regards the resistive wall losses and HOMs. The vacuum group has done an excellent job to ensure that they have a low impedance machine with inner vacuum walls made from copper, aluminum or gold. It may be advisable to make sure that susceptible equipment, such as BPMs and strip-lines are not the most resistive items in the system or the only place that TE modes will be absorbed.

The new RF bellows design has been tested successfully in KEKB, however, there is still concern that if the alignment and manufacturing tolerances between the teeth results in a very small gap at the area where the image current is high, this could potentially result in an arc. The peak electric field generated at the time of the bunch crossing should be analyzed to ensure that it is less than the breakdown voltage in vacuum for an infinitesimally small gap.

The committee wants to commend the vacuum group for their excellent progress.

## **13) TiN Coating and Baking**

A large number of vacuum chambers in the SuperKEKB project require TiN coating on the internal surface to mitigate electron cloud effects. 180 HER chambers require baking and 1000 LER and 100 Damping Ring chambers require TiN coating and baking. Since the Fall of 2012, a coating facility at the KEKB Oho Lab has been in operation with 4 baking systems and 4 coating equipment systems. There eventually will be 4 vertical coating systems for straight chambers, with one back-up system, and 3 horizontal coating systems for bent chambers. Processing of a vacuum chamber is time intensive. It takes 3 days for baking and an additional 3 days for TiN coating. Consequently, it takes considerable labor and calendar time to complete all of the processing. At present a 10-person team is assigned for this task.

For baking, a hot-air heating method is employed, and to date most of chambers have met the targeted pressure of  $1 \times 10^{-7}$  Pa. The weekly output is 10 chambers. For coating, the thickness is about 200 nm by Ti sputtering in Argon and Nitrogen gases. The weekly output is 11.8 chambers. The KEKB team has encountered a variety of problems and gained considerable experience. Nevertheless according to the production schedule presented in the construction project overview, the throughput remains below the targeted levels (~75% of target). Significant increases are expected in production by the beginning of April 2013 (a factor of ~2.4 over the present rate) and six months later (a factor ~3.1 over the present rate). These increases in production are very aggressive with completion of coating anticipated by the end of 2014 provided the increases in production can be realized on schedule. This is a very tight schedule.

#### **14) Collimator**

Collimators are necessary for fully successful operation of SuperKEKB in order to address beam halo and Touschek background issues. Presently the plan is to use 10 new horizontal and 3 new vertical collimators in the LER for SuperKEKB. For initial commissioning, only 2 horizontal collimators will be installed on the LER, while the existing KEKB collimators will be reused in the HER. All of the collimators will be installed and upgraded to the new Version 6 design as commissioning and operations progress.

The Version 6 collimator has movable tungsten heads within the vacuum chambers with integrated cooling. The length of this version of the collimator has been reduced to ~1 meter providing reducing the pressure on beam line real estate in heavily congested/instrumented areas of the accelerator. Part of the reduction in length of the collimators is to accommodate higher order mode (HOM) absorbers needed to help eliminate trapped modes. Power deposition levels are estimated to be within what water-cooled copper can handle.

Areas that remain to be developed include the RF connections between the vacuum beam pipe, the movable collimator heads, and the HOM absorbers.

The first prototype of the Version 6 collimator should be ready for initial tests in March 2013. As previously mentioned commissioning will begin without the HOM absorbers as it is estimated that the loss factor resulting from HOM is low. This approach as well as the phased implementation of the new collimator geometry relieves schedule pressure from the collimators.

Two of the technical risks for the collimators appear to be manageable and restricted to the joining of tungsten to copper and the RF connection. Both have been implemented in KEKB and PEP-II, but advancements could be made to improve performance. Consider taking advantage of the CTE mismatch to enhance the joint design (you could butt the

seal in compression). The third technical risk, the design of the HOM absorbers should be advanced to a conceptual level and simulated. The space for the HOM absorbers is limited and could have an impact on its effectiveness. There could be a trade off between the collimator length and the HOM absorber design. The phased implementation approach provides adequate schedule to address these issues without compromising the overall SuperKEKB schedule.

## 15) Normal-conducting cavities for MR and DR

### Main Ring NC ARES cavities:

Relocation of the ARES cavities for the SuperKEKB configuration has been completed. The power couplers are being changed to higher beta to deliver more beam power. The new design has been successfully tested up to 800 kW. Coupler commissioning took about 1 month, but only about 120 Hours of this was RF processing. 14 new couplers are needed. Baking of the couplers before testing may help to improve the conditioning time. Coupled-bunch instabilities driven by HOM and the detuned fundamental mode should be handled by the bunch-by-bunch feedback systems. No further configuration changes are planned for the ARES systems.

### DR NC cavities:

The new damping ring cavity prototype (cavity 0), based on the ARES accelerating cell design, has been tested successfully. The measured Q at room temperature was 93% of the calculated value, which is good. It was only 5% less at 200 kW (0.9 MV), which is also good. The cavity was tested to higher voltage than needed (spec is 0.7 MV). Conditioning took 90 hours of RF processing, finally limited by radiation (with temporary shielding in the test area). The cavity ran stably at 800 kV, 150 kW for 8 hours. Some trips were observed without gas bursts, possibly due to problems with the LLRF system. Some improvements will be made to the power monitoring for cavity #1 testing. Cavity #1 is being fabricated now and will be tested in JFY12. Cavity #2 will be completed and tested in JFY13. The two cavities will be installed in JFY14. An option is being considered to add a third cavity later if needed, but this will require cutting and remaking the welded beam pipe connections. Cavity 1 has been RF tuned and the end plates have been electropolished in an attempt to reduce field emission. It might also be helpful to try high pressure rinsing and to do final assembly in a clean room similar to the SRF cavities. Improved video monitoring will be installed for the next test.

The prototype grooved beam pipe load has been tested separately from the cavity. Up to 400 W was absorbed with no damage to the tiles or fingers.

### **Recommendations:**

Consider baking the power couplers before testing to shorten the conditioning time. This was very helpful on PEP-II and SNS.

Proceed with testing cavity#1 as planned, preferably in a system test with all HOM loads attached.

If field emission is still strong even after electropolishing the cavity consider trying HPR and clean room assembly for cavity#2.

## 16) Superconducting cavity

Recovery of all the SRF systems after the earthquake was completed. One cavity had a vacuum leak on an indium seal. The flange was re-torqued and the leak was sealed but the cavity performance was degraded by field emission. This cavity may be a candidate

for recovery or reprocessing. Several other cavities are strongly limited by field emission and could benefit from improvement.

New estimates of HOM power into beam pipe loads have been made, suggesting that the existing installed ferrite loads may be sufficient for Super KEKB. This is an important question. The new calculation method based on a time domain/wakefield method should be equivalent to the previous loss parameter method or frequency domain analysis. Since the new values are lower it would be wise to cross check, and maybe benchmark the old configuration against historical data from KEKB running. New SiC loads are being developed for the small beam pipes between cavities and these are a good idea in any case to absorb the high frequency HOM power that can propagate between the cavities.

Horizontal high-pressure rinsing has been tried successfully on a test cavity. Performance was recovered from 6 MV/m to 12 MV/m on the second attempt, almost back to the original level. The spare cryomodule has been similarly processed with the power coupler removed as a precaution, then reinstalled. It will be tested in the near future. If successful this would be a very nice way to recover the remaining modules with much less effort than disassembly and reprocessing. If, however, the spare cryomodule is still field emission limited after the horizontal rinsing it may be worth trying helium processing. This has been very successful in recovering field emission limited cavities in CEBAF.

The existing complement of cavities will be used for beam commissioning. Later, a series of hardening measures can be implemented if needed such as higher power HOM loads, reprocessing of cavities etc.

#### **Recommendations:**

Cross check the calculations of the HOM load power carefully, comparing time domain and frequency domain methods and benchmarking against historical data from KEKB running to make sure that the existing beam pipe loads are really stable in the new machine.

Continue to develop the 150mm SiC beam pipe loads for installation between the cavities to absorb the high-frequency HOM power.

Proceed with testing the horizontally-rinsed spare cryomodule as planned.

If field emission still persists, consider helium processing as well.

Continue to develop “hardening” strategies for the SRF systems in case they are needed later as the luminosity is ramped up.

#### **17) Improvement of LLRF system**

The committee notes excellent progress since last year, and we appreciate the “out of loop” measurements of the regulated phase and amplitude. The presentation shows steady state noise and regulation, as well as dynamic responses are interesting. If a step set-point disturbance is applied, what is the step response of closed loop system? How are the P and I gains set in this controller to have adequate gain and phase margins? The measured data is presented in the time domain, is there any information in the frequency domain? (has there been spectral information computed to look at the frequency content in the control signals or error signals?) We are impressed by the work in the last year and hope to see some of these dynamic tests of the closed loop system in the next review.

In this year’s presentation a klystron PLL concept is highlighted which would correct for insertion phase shift vs. operating point of the high power klystron, but as shown this

does not include the gain variation (the overall control loop gain varies as the large signal gain of the power klystron changes due to HV power supply). This gain change will modify the control loop gain and phase margins of the PI controllers as the ring current, and klystron operating point vary. A similar klystron operating point loop was implemented in the PEP-II LLRF (klystron saturation loop) and also in the LHC LLRF (Klystron Polar loop), and the KEKB LLRF designers may want to look at these examples for ideas on how the closed loop margins are held constant as the klystron large signal gain and insertion phase vary over the operating range.

The talk shows that a new design version (B version) will move interlocks from hardware to firmware in the FPGA. While this is a flexible general-purpose approach, what happens if the LLRF system doesn't boot up or load the FPGA properly, or some software process hangs up? Does this leave the expensive klystron and hardware unprotected? Maybe interlocks should be very robust and not a software function.

The system design with the energy storage cavities, or the superconducting cavities does reduce the impact of the high beam current on the cavity fields. However, the beam loading is not zero, and it may be useful to estimate the beam current loading in the RF system, and estimate gap transients for possible fills with gaps or trains. This modulation of the cavity fields will drive the LLRF control loops, and it may be useful to test the RF system controller with simulated beam signals, to see what residual disturbance is left. Because the revolution frequency is roughly comparable to the loop bandwidth (100 kHz) the harmonics of the revolution frequency in the gap transients will not be attenuated by the RF system. We expect these signals to be small – how do they compare to the expected noise and resolution of the controlled system? Is the shift of the IP (the difference between the HER and LER gap transients) acceptably small? It may be helpful to estimate the magnitude of these effects as they interact with the LLRF cavity control regulator performance.

## **18) KEK Roadmap**

The old KEK roadmap from 2008 to 2012 was discussed and most if not all the program items were completed or started as planned. The list included the JPARC upgrade program, enhanced KEKB/Belle program, LHC program, Photon Factory program, and general accelerator and technology programs. The second item on the list is the upgrade of KEKB/Belle. This goal was very successfully launched with the construction start of SuperKEKB and Belle II, being covered at this accelerator review.

The new KEK road map for 2013 through 2018 is in the final stages of being formulated. It includes the strong program of JPARC upgrades including neutrinos, neutrons, protons, and a new beam line, completion and commissioning of SuperKEKB/Belle II, LHC, a global central ILC R&D program with an intent to host, photon science with c-ERL and then later a 3 GeV ERL, and, finally, general accelerator and detector technology studies with a national and health focus. This is, overall, a very strong program and matches well the various programs around the world.

R3: The funding for SuperKEKB and Belle II including those in-house to KEK should be carefully secured over the next few years, so that the start up, commissioning, and operation of this state-of-the-art accelerator and detector will commence in a timely manner.

## **19) SLAC-KEK Collaboration**

The committee is very encouraged by the renewed collaboration between SLAC and KEK on Super KEKB. There is a long and fruitful history of collaboration going back to PEP-

II days and beyond. SLAC has particular expertise in areas such as the positron source, bunch-by-bunch feedback, luminosity dithering and many other areas. This collaboration may leverage the existing US-Japan collaboration funds by bringing in other funds to support design and physics effort. Given the aggressive project schedule for Super KEKB and the ongoing shortage of people on the project, this would be very welcome. The SLAC support is subject to DOE approval but the committee is hopeful that this will be forthcoming and strongly endorses the proposal.

## 20) Overview of Injector Construction Status and Schedule

The Linac Group recovered the machine from earthquake damage by November 2012. The group now concentrates on 4 major issues: (1) lower-emittance and high current electron beams from an RF Gun, (2) high-current positron beams by improved capture section and (3) lower-emittance  $e^+$  beams by a Damping Ring (DR), and (4) finally using time sharing scheme injecting to 4+1 rings. These require improved cooling systems at the Capture Section, DR, and switchyard.

For the high current RF gun producing 5nC/bunch,  $\text{Ir}_5\text{Ce}$  is adopted as cathode material with a high-power laser. Due to the high current, the initial energy spread of the RF gun is large. Time manipulation of the laser is essential to reduce the energy spread during the accelerating. The J-section is used for beam bunching. In order to improve positron capture, they introduce a large aperture section (LAS) of S-band and 9 compact modulators. A spoiler integrated with the flux concentrator is used to reduce the heat density on the FC.

After the recovery from earthquakes, the girders were redesigned, and they have completed alignment of a 600-m long base line of beam transport/acceleration sections. New wire scanners and new BPMs are adopted for better beam diagnostics, and fast LLRF is introduced for better beam controls.

The Linac Group setup prioritized work scopes with back-up options. The overall scheme is very logical, and the committee is convinced by their near term plan.

## 21) RF Gun

Good progress has been made on the RF guns. The DAW structure has been successfully tested and has achieved 5 nC per pulse with a preliminary measurement of emittance indicating  $\sim 14$  mm mrad. This already meets the specification for the electron beam. The QTWSC structure will be installed and tested soon and is hoped to give even better performance. Two cathode materials have been investigated,  $\text{LaB}_6$  and  $\text{Ir}_5\text{Ce}$ .  $\text{LaB}_6$  showed a relatively short  $Q_e$  lifetime at high intensity, but  $\text{Ir}_5\text{Ce}$  showed constant  $Q_e$  over 45 hours running at 2.5 nC per pulse. This is a very promising result. Two laser systems are being developed based on Nd and Yb doping respectively. The Nd system is easily pumped with high power laser diodes, but has a fixed Gaussian profile, while the Yb system allows for temporal pulse shaping. A Ti-sapphire based system was also considered but had a much lower efficiency. Given the parallel approaches being pursued in each area the committee finds it is very likely that the RF gun system will be successful.

### Recommendations:

Install and test the QTWSC gun as planned.

Test the  $\text{Ir}_5\text{Ce}$  cathode and Yb fiber laser system in the gun and operate for a long period to check its reliability and performance stability.

## 22) Alignment and Support

The alignment and support aspects of SuperKEKB were presented and can be divided into two separate areas: the rings (Magnets) and the Linac. The approach and algorithms for the ring survey appears very mature and sophisticated involving the consideration of tunnel settling and geologic deformation including an extensive surface GPS network. The Linac alignment and support is less mature and presently is focused on two technologies that as of yet have not been fully reconciled: the KEK Laser PD system and a laser tracker system based on a Leica Absolute Tracker AT401.

The alignment requirements presented as being necessary for the linac for SuperKEKB are 300  $\mu\text{m}$  (rms) globally and 100  $\mu\text{m}$  (rms) locally (distances  $\leq 100$  m). As reported the KEKB linac alignment was set to be 100  $\mu\text{m}$  previously, but this degree of alignment was not maintained (nor perhaps achieved) as misalignments of the order of 1 mm and angular misalignments of a few mrad have been documented at several locations.

The absolute laser tracker is a very strong technology approach. The published ASME maximum permissible error (MPE) specification over a 40 m straight line is 14  $\mu\text{m}$  and the angular horizontal scale bar MPE is 361  $\mu\text{m}$  at the same distance. A sufficiently dense alignment network can improve accuracy as well.

The linac alignment is first established by component alignment at the girder level and then using the Laser PD / laser tracker to establish girder-to-girder alignment. Geologic or structural settling of the linac tunnel and the corresponding compromise of the survey monuments has not been determined at this time. Final potential alignments are beam based, but details as to the implementation were not presented. A rough plan for developing a complete alignment algorithm for the linac was presented that included the beginning of the incorporation of beam-based alignment in 2013, but with the ultimate goal not being achieved until 2015, coincident with the start of commissioning. There should be some effort to accelerate this to avoid the possibility of impacting commissioning.

In the rings, it may be desirable to look for a survey/alignment solution that is not horizontal but planar to minimize the deleterious effects of the differential structure settling.

Sufficient detail of the support structures was not presented and so the review committee cannot comment on the stability, ease of alignment or realignment of the structures used in either the rings or linac.

The KEKB team may wish to explore the possibility of holding a small workshop or review to examine the alignment and support approaches and algorithms.

### **23) Positron Source**

The Positron Capture Section was redesigned, replacing the L-band system by the Large Aperture S-band (LAS) system, which will give a sufficient positron conversion rate, as high as 49%, and eliminate satellites. The e-beam target design was optimized to improve the efficiency of the cooling and reduce the fields created by eddy currents. A spoiler is integrated with the target to reduce the heat density on the target. The target size should fit into the available space between the yoke and flux concentrator.

The first prototype of Flux Concentrator (FC) was fabricated with the help of SLAC and IHEP. The prototype FC was built for a stand-alone test with a simplified vacuum chamber, and was tested with a prototype modulator up to 1.36 kA. On the FC material, OFC and HRSC will be compared in prototypes I and II. A quick detachable girder is introduced for replacement of FC with the minimum radiation dose. The schedule for

commissioning of the 6 kA FC modulator is set in December 2013. Further improvement of the modulator with currents up to 12 kA is expected before the end of 2014. The beam transport bypassing DR was designed for common e<sup>+</sup>/e<sup>-</sup> injection to main rings.

#### **24) Flux Concentrator Modulator Development**

The basic requirements for the flux concentrator (FC) are the peak current of 12 kA and 5  $\mu$ s pulses in 50 Hz with an amplitude stability of 0.3%. The FC modulator is modified from the KEKB klystron modulator and uses a thyatron as the switch. The parameters of the KEKB modulator are 22.5 kV, 4.8 kA and 5.6  $\mu$ s pulses at 50 Hz. The prototype of the 6 kA modulator was tested successfully. By doubling the capacity bank and coaxial cables, the required 12 kA modulator will be assembled for tests at the end of the November this year. For a stable operation and easy maintenance of the modulator, KEK developed a solid-state switch to replace the thyatron tube as a switch. The jitter of thyatron tubes is within 10 ns and the solid-state switch should have a similar or better performance in term of jitter and long-term reliability.

Recommendation: The discharge waveform of the modulator for the flux concentrator with cables should be checked experimentally, to demonstrate that it meets the requirements of the optics design. On thyatron and solid-state switches, one should make sure that the devices meet the jitter specification with the safety margin.

#### **25) Commissioning of Electron Beam**

The KEK linac will start commissioning with electrons in the fall of 2013. All the beam parameters needed to make the linac injection into the four rings successful in top-off mode were discussed. Somewhat different parameters are needed for each of the rings: Photon Factory PF, Accumulator Ring AR, and SuperKEKB LER and HER. The injected beam parameters for SuperKEKB are significantly more difficult than for KEKB with greater charge and smaller emittances. Simulations of the beam dynamics and tuning techniques have established the required tolerances. The larger beam charge makes the transverse emittances and energy spread more difficult to keep small. The linac has to operate with different bunch charges for different injection scenarios, e.g. top-off or fill from scratch. These various beam conditions will require different control and diagnostic configurations.

The expected beam emittance at the end of the linac depends on the alignment tolerances. However, some of the random seeds in the simulations produce small emittance. Thus, studies should be carried out to determine which error seeds produce small emittances and the mechanism involved. Perhaps, the errors cancel or are compensated, and a similar method can be used in the real accelerator.

The next phase of planning for commissioning is to make detailed plans how each beam parameter will be measured. Following the measurements, detailed tuning procedures should be developed to address the tuning issues for each parameter. Finally, a time schedule should be made to indicate all the measurements and beam tuning that will need to be done in sequence. Part of this time planning is to fit within the injection periods for the PF and AR while preparing for injection into SuperKEKB.

R1: After identifying the parameters that the linac electron beam needs to meet, a detailed set of procedures should be made for each parameter. An overall time schedule to carry out these procedures should be developed to match times needed by the four rings.

#### **26) New Transport Line for PF-AR**

The operation of the SuperKEKB accelerator system will require continuous injection

from the linac. At present, the linac also serves as the injection for the PF-AR ring with two 15-minute duration injection periods per day. SuperKEKB will not be able to accommodate the loss of injection to rings for a period of 15 minutes at a time during normal operations and so the PF-AR ring injection must be reconfigured to allow fast switching of the linac electron beam and top-off injection into PF-AR. The top-off injection is also strongly desired for better stability for PF-AR experiments. These dictate the development of a new transfer line for the PF-AR.

This new transfer line will be housed in a new tunnel that will cross above the KEKB tunnel. The design of the new tunnel is complete and civil construction is slated to start coincident with the 2013 fiscal year and be completed by the end of the fiscal year. The construction the tunnel and installation of the new transfer line should not disrupt the KEKB. However, potential impacts of the removal of soil/shielding above the KEKB tunnel and the installation of the new tunnel on the KEKB tunnel were not presented. Similar disturbances at other facilities have changed the local geological behavior in tunnels (settling or uprising for example) and even degraded radiation shielding. The review committee hopes that such potential impacts have been or will be examined prior to construction and that they present minimal risks to KEKB.

## **27) The Damping Ring, Transfer Lines, and HER Abort System**

The Damping Ring and transfer line civil construction has been completed since the last review, and installation of structures, piping and other systems has made substantial progress as well. For the damping ring, a majority of the magnets have been delivered, a substantial fraction of the power supplies, and all of the vacuum chambers. On the transfer lines, all of the magnets have been received as well as the large majority of the power supplies. Progress seems on track for the completion of both the damping ring and the transfer lines to meet the identified milestones: September 2014 – completion of the LTR and RTL to allow unimpeded Linac commissioning; May 2015 – injection from the damping ring into the LER.

The beam abort system (BAS) forms a critical part of the machine protection system for SuperKEKB. There are several technical and practical risks that the SuperKEKB team has addressed. The baseline BAS design consisted of nine principal components on both the LER and HER:

- a) Horizontal kicker to deflect the beam from the ring
- b) Vertical kicker to spread the beam to decrease energy deposition on the extraction window
- c) Pulsed quadrupole on the LER and DC sextupole pair on the HER to increase the horizontal size of the beam to decrease energy density
- d) Lambertson Septum to bend the deflected beam
- e) Power supplies
- f) Pulse compression
- g) Beam dump
- h) Titanium extraction window

The approach is to kick the entire stored beam out of the rings within one orbit revolution with a rise time sufficiently fast to avoid intermediately perturbing the back of the bunch train once the abort is triggered. This requirement is necessary in order to avoid damaging the machine or disrupting the RF system. The requirement of the rapid rise time results in a practical limit of one power supply for each ring. There is a need to spread the beam as much as possible in order to reduce the energy density deposition.

The KEKB team has adopted an alternative presented previously of using two sextupole magnets instead of pulsed magnets to enlarge the horizontal beam size at the extraction window on the HER. Careful beam dynamics modeling were presented that included the determination of the dynamic aperture. These showed that the use of the two sextupole magnets did not degrade the stored beam. The sextupole magnet specifications are not stringent and present little technical risk. The review committee agrees with this simplification of the system since reducing the complexity will make ensuring reliability easier.

During Phase I commissioning, only the HER abort system will be installed and the existing LER abort system will still be in place. This will mean that during commissioning runs, the current in the LER must be limited to 500 mA to avoid catastrophically damaging the existing abort window. This maximum current limit can be exceeded during beam scrubbing runs by increasing the emittance of the beam to decrease the energy density of the aborted beam. The new LER abort system would be installed for Phase II commissioning.

A number of open technical/engineering issues were discussed during the prior review that were not followed up on during this review. Consequently, the review committee cannot comment on the adequacy of implemented solutions. These issues included such things as the loss of the supplier for the ferrite cores necessary for the BAS, and the recommendation that the use of a *striped* type coating ceramic chamber or a slot type kicker be studied for generating this pulsed magnet field with a rise time less than 200ns.

## **28) Beam Diagnostics**

The committee is impressed by the effort and depth of the diagnostics team.

The machine diagnostics include multiple BPM systems, DCCT, bunch-by-bunch current monitors, loss monitors, tune monitors, and several innovative photon-based beam diagnostics. They are a mix of evolutionary designs proven in KEKB and some new ideas specifically developed for SuperKEKB. The damping ring also requires diagnostics and feedback systems.

In this review we learned about the plans to install 100 “displacement sensors” in the main rings, which we understand are capacitive systems to measure the locations of select BPM assemblies with respect to magnet positions. We have not had any sketch or schematic explaining if these are in the vertical plane, horizontal plane, how they are calibrated or read out, etc. If these displacement sensors require resolution consistent with the BPM systems, and long-term stability is important, the mechanical and electrical review of this system may be helpful. In this review we have no detailed presentation of their performance or operating principles

The heterodyned HER 1018 MHz and LER 509 MHz narrowband systems are fixed in design and their performance is understood. The HER systems are from KEKB, a small number of the new LER systems have been fabricated and performance tests are presented. The plan is to ramp up production of these units, and the turn-by-turn gates, in the next year.

The gated turn-by-turn systems are intended for injection studies and are based on log-ratio detection with external gates.

There is still some uncertainty on the technology for the medium-bandwidth processing used for faster orbit motion studies, abort signal generation and a special longitudinal position monitor (bunch phase monitor). Commercial processing systems have been

evaluated and measured results of resolution are presented, but we do not see a specification on what performance these systems must have. We think having some necessary specification for each would help make this decision, and help finalize the plans.

If the abort signal latency is too long in the commercial system, who is going to modify the firmware/implementation in the commercial processor? If it is someone at KEK, we caution that the manpower to do this comes from a very busy team.

The mechanical designs and fabrication of the physical BPM buttons and vacuum components is well underway.

### Coupled-bunch Feedback

The plans are well underway and most, if not all, of the components for the transverse and longitudinal coupled-bunch feedbacks are in progress. The KEK experience and expertise with these systems is impressive. The damping ring will also use the same general transverse feedback processing and hardware.

The transverse systems are evolutionary developments from the original KEKB systems, but for SuperKEKB, longitudinal feedback will be installed in the LER. The longitudinal kickers will be of the over-damped cavity (Frascati) style design.

As in past reviews we caution the beam induced power in the kicker assemblies can be difficult to manage, and the plan is to use a mix of low-pass filters (absorptive?) and circulators to protect the power amplifiers. Based on the PEP-II and KEKB experience, we strongly urge care with temperature monitoring and interlocks for all the feed-through and high-power cable assemblies on the beam line. We complement the team for having planned for spares on the high-power amplifiers at this early stage.

The original KEK bunch-by-bunch beam orbit detector is available to implement tune monitors and provide diagnostics for the feedback systems.

### Vertical IP feedback

Considerable design and measurement information is presented on the signal processing for the vertical IP orbit feedback systems. In the last year considerable technical progress has been made on improving the system resolution to the 0.1 micron level, and a feedback controller processor is in development (based on the LLRF micro-TCA hardware). However, we feel strongly that this sub-system of the IP feedback needs to be developed as a part of an integrated feedback model, which allows the closed-loop performance of the IP feedback to be estimated. We are concerned that this beam detector function is being developed as a stand-alone BPM function without consideration of the technical impact it has inside the overall IP feedback loops.

The original DCCT is being refurbished for SuperKEKB, and it is planned to re-use the Loss Monitor system. In the next year the resolution of the system will be evaluated and, if necessary, a new readout system will be designed. Again, manpower to do this evaluation and design is in competition for many other tasks, and the team may want to prioritize the importance of the loss monitor in the initial stages of commissioning without the Belle detector.

Plans for the damping ring BPM and feedback systems have been presented mostly in schedule timelines, without specific requirements or technical specifications.

### Photon Diagnostics

Three types of photon monitor are envisaged for the SuperKEKB, described in some detail in the previous Review. The Synchrotron Radiation Monitor (SRM) will use a streak camera for the bunch length and an interferometer for the horizontal beam size measurement. It can also be used for the vertical beam size measurement in the early stage of the commissioning, however the design vertical beam size cannot be resolved.

The X-ray monitor (XRM) for the small vertical beam size will use the coded-aperture technique. The experience with XRM gained at CESR-TA beam is of vital importance for speeding-up the development of SuperKEKB XRM.

Finally, the Large-Angle Beamstrahlung Monitor (LABM) will be used for the collision tuning. Its experimental test is being prepared. For the exceptionally small vertical beam sizes in the SuperKEKB IP, a coherent regime of beamstrahlung should be considered, its potential applicability to the beam-beam collision offsets monitoring should be evaluated.

The committee is satisfied that the development of photon monitors of all three types shows good progress since the last Review. The construction plan for the visible light and X-ray beam lines, optical and electronic component in both DR and Main Rings is in agreement with the current commissioning scenarios.

#### Construction Plan

The timeline for the next three years shows many design and evaluation projects in parallel, as well as many production projects in parallel. We are concerned about available technical resources to do so much in parallel. The testing and installation of hundreds of cable assemblies, BPMs, complex electronic systems, etc. is going to be a major task and critical to manage with the limited human resources.

#### **Recommendation**

The dynamics of the IP feedback loops should be studied using a method that captures the frequency responses of the critical elements including the beam dynamics, the magnet motion dynamics, the responses of the BPM system, and the controller and the correction magnet/power supply/eddy current effects. Ultimately this model should be coupled and integrated into horizontal IP feedback model, as we would expect there would be cross coupling in the system dynamics.

### **29) Estimation of Beam Loss**

A comprehensive simulation of the beam loss distribution around the main rings is done in order to provide correct input for the detector background estimation, for the radiation protection design, and for development of beam loss monitor system. Beam-gas Coulomb scattering, radiative Bhabha and Touschek loss are studied. The total LER loss rate per bunch of 1 mA amounts to about  $10^7$  pps and about 5 times less in HER. Touschek loss is dominant in the both rings. Physical rather than dynamic apertures were applied in the particle loss condition. Tracking included only one to ten turns.

The Committee recommends multi-turn tracking of particles to be lost, so that the dynamic aperture limitation would be a cause of their loss, because the resulting loss distribution around the ring may significantly differ from that obtained in a few-turn simulation.

### **30) Control**

The overall control approach is a mature system, based on EPICS. We endorse the plan to re-use as much as practical from the existing controls infrastructure given manpower limitations.

The committee enquired about the issues in maintaining CPU and software systems in the IOCs over long lifetimes of the project, as commercial product lifetimes often are a few years. We understand the group plans on buying spares as part of the development of the new system. We endorse this approach, and recommend that even with tight budgets there be designation of spares for critical IOC CPU and module functions.

We also encourage the controls effort to collaborate with other laboratories on security and network protection through the ICALEPS and other mechanisms, as lab facilities are attractive targets for external attacks and malicious people. The reconfiguration of the general networks at KEK to minimize the connections across firewalls between external and machine specific control networks seems a smart move towards more secure operations.

This year there was not much discussion of the timing system, we assume it is on track to deliver the necessary RF distribution and timing/synchronization signals for KEKB. We encourage efforts to include diagnostics into the distributions system as part of the initial design.

### **31) Ring Commissioning**

The two rings of SuperKEKB will be difficult to commission due to high beam currents and low emittances, as discussed by the presenter. The beam and interaction region parameters will be the most demanding of any collider operated so far. The QCS on the right side of the interaction point will be delayed by its production schedule triggering a scenario where a relaxed IP must be commissioning for about the first year. The parameters that are needed were presented for each scenario of the combined SuperKEKB and Belle II plan. A phased approach to ring commissioning was adopted in three parts. Ring Commissioning Plan I included the standard relatively simple activities of storing a beam, correcting the orbit and beta functions and getting the diagnostics to work. Ring Commissioning Plan II was mainly beam scrubbing where extended beam storage time is used to scrub the vacuum chamber surface with beam x-rays to improve the vacuum level. Finally Ring Commissioning Plan III is used to perform detailed lattice and beam corrections, where extended beam time is needed to fix all the subtle first and second order optics and IR related parameters. This proposed commissioning plan was overall quite detailed and was a natural extension of the actual plan extensively developed for the highly successful KEKB.

R1: At some point in the commissioning plan, large beam currents will need to be stored in both storage rings. This leads to a large AC wall plug power usage. The availability of AC power from the local power companies may be limited due to nation wide external issues. A long-range high power agreement may be worth negotiating for operation of the rings in later years.

## Appendix A

### KEKB Accelerator Review Committee Members

Andrew Hutton, Chair	JLab
John Fox	SLAC
Stuart Henderson	FNAL (unable to attend)
Miguel Jimenez	CERN (unable to attend)
Nadine Kurita	SLAC (replacing Miguel Jimenez)
Gwo-Huei Luo	NSRRC
Won Namkung	POSTECH
Evgeny Perevedentsev	BINP
Bob Rimmer	JLab
Kem Robinson	LBNL
John Seeman	SLAC
Zhao Zhentang	SINAP
Frank Zimmermann	CERN (unable to attend)
Katsunobu Oide	KEK, Ex Officio Member
Kazunori Akai	KEK, Secretary, Accelerator
Kazuro Furukawa	KEK, Secretary, Accelerator
Haruyo Koiso	KEK, Secretary, Accelerator

## Appendix B Agenda of the 18th KEKB Accelerator Review Committee

March 4 (Monday)		
08:30 - 09:00	Executive Session	
09:00 - 09:30	Overview of Ring Construction Status and Schedule	K. Akai
09:30 - 10:00	Belle II Construction and Schedule	Y. Sakai
10:20 - 10:50	Beam Dynamics Issues in SuperKEKB	Demin Zhou
10:50 - 11:20	Optics Issues	H. Sugimoto
11:20 - 11:35	Magnet Overview	M. Masuzawa
11:35 - 11:45	Magnet fabrication and field measurement	K. Egawa
11:45 - 12:00	Magnet Power Supplies	T. Oki
13:15 - 14:10	IR Magnet	N. Ohuchi
14:10 - 14:40	Construction of the Interaction Region	K. Kanazawa
14:40 - 15:10	Beam Background	H. Nakayama
15:30 - 15:50	Collision Feedback (dithering)	M. Masuzawa
15:50 - 16:05	Vacuum Construction Status and Schedule	Y. Suetsugu
16:05 - 16:25	TiN Coating and Baking	K. Shibata
16:05 - 16:25	Collimator	T. Ishibashi
16:45 - 17:05	Normal-conducting cavities for MR and DR	T. Abe
17:05 - 17:20	Superconducting cavity	Y. Morita
17:20 - 17:35	Improvement of LLRF system	T. Kobayashi
March 5 (Tuesday)		
09:00 - 09:30	KEK Roadmap	Y. Okada
09:30 - 09:45	SLAC-KEK Collaboration	U. Wienands
09:45 - 10:00	Overview of Injector Construction Status and Schedule	K. Furukawa
10:00 - 10:30	RF Gun	M. Yoshida
10:50 - 11:10	Alignment and Support	T. Higo
11:10 - 11:40	Positron Source	T. Kamitani
11:40 - 11:50	Flux Concentrator Modulator Development	M. Akemoto
11:50 - 12:20	Commissioning of Electron Beam	M. Satoh
13:30 - 13:50	New Transport Line for PF-AR	H. Takaki
13:50 - 14:10	HER abort system	N. Iida
14:10 - 14:55	Beam Diagnostics	H. Ikeda
14:55 - 15:05	Estimation of Beam Loss	
15:25 - 15:55	Control	T. Nakamura
15:55 - 16:25	Ring Commissioning	Y. Funakoshi
March 6 (Wednesday)		

08:30 - 12:00	Executive Session / Report Writing	
14:00 - 15:00	Close-out	