The Twentieth KEKB Accelerator Review Committee Report

February 25, 2015

Introduction

The Twentieth KEKB Accelerator Review Committee meeting was held on February 23-25, 2015. Appendix A shows the present membership of the Committee. One member of the Committee, Stuart Henderson, was 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 in the year since the last review is impressive; however the budget cuts have resulted in a significant delay to the project. As always, the high standard of the presentations impressed the Committee, particularly the photographs of the impressive evolution of the new hardware that is now installed in the tunnel. The Committee examined the progress of the project, and evaluated the proposed response to the budget cuts. The 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/**.

Contents

A) Executive Summary

The SuperKEKB project has made spectacular progress in the last year. An enormous amount of hardware has been delivered, tested and installed in the tunnel. The status of the various detailed hardware systems was given in the talks with many photographs of the equipment. The main ring magnets are already 99 percent installed and alignment is well advanced; the vacuum system is 97 percent installed, and the activation of the NEG pumps is ongoing. The reinforced RF system for Phase 1 is complete, and is capable of supporting up to 70 per cent of the ultimate beam currents. The beam position system is being installed and tested, and the bunch feedback systems have been installed. The x-ray and visible beam size monitors are being constructed and will be installed later this year. The control system using EPICS is well advanced, and the collimator system is nearly completed. The linac injector upgrades have been nearly completed and commissioning has begun. The existing thermionic gun will be used for Phase 1 and Phase 2 commissioning. The damping ring vault is complete, the magnets are being measured and installation is ongoing, and testing of the damping ring RF cavities is complete. The damping ring vacuum chambers and RF will be installed later in 2015. The superconducting quadrupoles for the interaction region are either finishing design or are in construction. These superconducting quadrupoles and the installation of the entire interaction region are on the critical path for Phase 2 commissioning.

The Belle II experimental equipment is also advancing steadily. The plan is to install a detector package, BEAST II, during Phase 1, when initial beam commissioning and beam scrubbing to reduce the ring vacuum levels will be carried out. A modified BEAST II will be used in Phase 2 in conjunction with the Belle solenoid magnet to determine the background levels. When the background levels are acceptably low, the delicate vertex detectors will be installed in the detector, which will complete the detector packages. A successful Phase 2 beam run is crucial for early advancement of the ultimate particle physics program. Phase 3 of the accelerator commissioning will begin when the Belle detector is complete.

KEK has suffered sizeable budget cuts in JFY14, which have had a drastic effect on the schedule. Ring commissioning, which had been scheduled to start in April 2015, will now be delayed until the beginning of 2016. Full operation with the complete Belle II detector in place has been delayed by two years. However, the international competition for CP violation and rare decays physics has intensified in recent years. Some important B physics results are liable to be published first by LHCb at CERN, where accelerator operations have started on time. The Committee feels that every effort should be made to ensure that SuperKEKB obtains these physics results first. Some data taking with the Belle II outer detector could take place at the 3S resonance or above the 5S resonance during accelerator commissioning; this would enable some unique and special physics results to be obtained in 2017. This data taking might occur while the SuperKEKB commissioning is investigating tuning algorithms to increase the luminosity. The Committee encourages the SuperKEKB accelerator staff and the Belle II physicists to work closely together to advance and plan the first physics luminosity runs. An optimum set of beam run parameters should be decided on for the Phase 2 commissioning period as the beam currents will be limited.

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 be 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, 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) It is highly recommended that the gun group focus on the production of a simple, robust and reliable photo cathode RF gun system for the injector commissioning this year, with a goal of achieving the required performance in the injector commissioning well before the Phase 2 commissioning run.

4) Develop a complete, detailed commissioning schedule for the guns, linac and rings for all commissioning Phases.

5) Expand efforts to involve collaborators (e.g. from BINP, BNL, CERN, Cornell, FNAL, IHEP, INFN, SLAC, other light sources and/or KEK-ATF, ERL, J-PARC and PF in the commissioning of all three SuperKEKB rings (damping ring, LER, HER).

6) Re-examine the testing, design and other aspects of the IR superconducting magnets and implement as many activities in parallel as possible in order to advance the start of commissioning and provide more time for the *in-situ* tests. Produce a detailed plan and schedule after this reexamination.

7) Belle II and SuperKEKB management teams should jointly develop the run objectives and parameters for the early physics running in SuperKEKB Phase 2 commissioning by fall 2015. In light of the delays caused by the budget shortfall, every effort should be made to take physics data as soon as possible, preferably during Phase 2 commissioning.

8) The SuperKEKB/Belle II interaction region IR is extremely complex and 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.

9) While complete optics solutions exist for Phase 1 and 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 Committee recommends that the online version of the SuperKEKB Technical Design Report be regularly updated.

C) Findings and Comments

1. Overview of Ring Construction Status and Schedule

The construction of SuperKEKB is well advanced, aiming at 40 times the luminosity of KEKB, using the techniques of a nano-beam scheme and doubling the beam current in each of the rings. There are many upgrades to both the HER and the LER but mostly in the LER, which will have nearly all new magnets and vacuum chambers. The RF systems are based on the KEKB system with reinforcements to support the higher beam currents. The interaction region is entirely new to generate very small vertical beta functions and large crossing angle with support for the new detector Belle II. The injection into SuperKEKB is from the existing linac but with the addition of a new RF photocathode gun, new positron target, a new positron damping ring and new damping ring transport lines. The RF photo-cathode gun and positron source are in beam test and the damping ring with transport will be completed and tested in 2017.

The ring construction is in three phases. The planning for construction and commissioning has changed over the past year as the funding for KEKB operations was reduced earlier in JFY2014. Presently, the HER and LER rings are fully installed in Phase 1, but with a temporary interaction region and only 70% of the final RF system. Phase 2 has a full interaction region with superconducting IR quadrupoles and the Belle II detector, but without the vertex chamber. Finally, Phase 3 has a complete accelerator and full detector. Phase 1 commissioning aims at starting January 2016, Phase 2 starts in mid-2017, and Phase 3 starts in early 2018. The luminosity goal for Phase 2 is $1 \times 10^{34}/cm^2/s$, while the luminosity goal for Phase 3 is the ultimate $8 \times 10^{35}/cm^2/s$.

The status of the various detailed hardware systems was given. The magnets are 99 percent installed. The vacuum system is 97% installed. NEG activation is ongoing. Alignment is well advanced. The reinforced RF system for Phase 1 is complete and can support up to 70% of the ultimate beam currents. The beam position system is being installed and tested. The bunch feedback systems have been installed. The x-ray and visible beam size monitors are in construction and will be installed later this year. The control system using EPICS is well advanced. The collimator system is nearly completed. The damping ring vault is complete and the magnets installed. The testing of the damping ring RF cavities has started. The damping ring vacuum chambers and RF will be installed later in 2015. The superconducting quadrupoles for the interaction region are either finishing design or are in construction. These superconducting quadrupoles and interaction region installation are on the critical path for Phase 2 commissioning.

The project has done an analysis of the human resources needed to work on the project. The project has now about 62 people but full staffing is estimated at 77 people. The project has added about 6 people this past year. The project has been helped with recent retirees that have returned to help on crucial topics. Even with the reduced staffing, the project is working well and is proceeding rapidly. The project plans to continue to improve the staffing levels.

Recommendations:

R1: Explore advancing Phase 2 commissioning by 3 months to avoid interruption by the summer shutdown.

R2: Complete the minimum work needed to make sure that two-ring commissioning with stored beams happens in January 2016.

R3: Complete the minimum work needed to make sure the IR is complete for commissioning in Phase 2 in June 2017.

2. Belle II Construction and Schedule (Ichiro Adachi)

The construction status and the schedule for Belle II production, installation, and testing were shown. The physics case for Belle II was discussed in comparison with the LHCb experiment including the origin of flavor structure, naturalness, dark matter, dark energy, and baryon asymmetry in universe and how quickly Belle II will catch LHCb in statistics. The construction for the new Belle II includes upgrades to the beryllium chamber, vertex tracker, time of flight particle ID central drift chamber, muon detector, and calorimeter. Many of these upgraded systems have already been completed or well along with completion.

The time of flight particle ID is on the critical path with the production of the quartz plates and the gluing of the quartz blocks together. The first unit has been produced and assembly difficulties have been discovered with likely fixes determined. Full production will start again in March 2015. A cosmic ray test of a full module will happen soon.

The new vertex chamber (VXD) has had difficulty with joints of the "origami hybrid" ladder system cracking during production. This problem has put this detector on a critical path. A task force was formed last fall and a solution found. Full-scale production has resumed recently.

The first round of communication links and data flow between the detector and the SuperKEKB controls has been determined and a plan to provide the hardware is on track.

Installation of the BEAST II detector is planned for the Phase 1 and 2 commissioning periods to study beam related backgrounds in anticipation of Belle II. The design of BEAST II is partially determined but not yet complete. A specific need is to study the radiation damage of the TOP photomultiplier detectors.

The delay in funding for the accelerator and the detector has caused a delay in the delivery of the detector as well as the accelerator. With the present anticipated funding level, Belle II will be ready to be installed (roll-in) at the end of CY2016 after a short cosmic ray run. The vertex detector will be installed in early CY2018 so that full data taking can start in JFY2018.

At the next ARC review, the Committee would like to hear a technical description of the slow (accurate) luminosity measurement using Belle II, as well as the rapid luminosity monitor used for accelerator tuning, including the detector hardware and electronics.

Recommendations:

R4: Formalize how the Belle II collaboration will help the SuperKEKB accelerator group turn-on and commission more quickly.

R5: Finalize the design and technical scope of the BEAST II detector so that as much as possible can be studied during the Phase 1 and 2 accelerator commissioning periods.

3. Beam Dynamics Issues

Following the recommendations of the last Review, beam dynamics issues relevant to SuperKEKB collider were further advanced and previous work was re-analyzed. An important step towards systematic presentation of the results is presented in the Draft TDR.

A tentative longitudinal impedance budget has been developed for both LER and HER. The impedance model includes the effect of clearing electrodes in LER, wigglers, and grooved chamber walls in the dipole chambers. The resulting total inductive impedance is 33.4 nH for the LER, and 62.1 nH for the HER. For the SuperKEKB LER, a large part of the inductance is due to the collimators with small gaps and new components such as the clearing electrodes.

As was recommended last year, the potential-well effect together with the microwave instability were analyzed, including longitudinal wakes from coherent, to assess the bunch lengthening. The result is that in both LER/HER, bunch lengthening of 20% is found at the design bunch current, but the microwave instability thresholds are above that. For the LER, the design included this blow-up, but in the HER this is an unexpected new development, and either lower x-y coupling or higher bunch currents must be used to recover the luminosity.

The interplay of coherent synchrotron radiation with other impedances reduces the microwave instability threshold from ~1.7×10^{11} to about 1.2×10^{11}, 20% above the design value. The difference between computation and measurement was about 90nH for KEKB LER. The calculated inductance for KEKB LER was around 26 nH, whereas the inductance inferred from the measured bunch lengthening was 90 nH (or a factor 4) larger. If a similar difference between actual and measured inductance is found for SuperKEKB, the design parameters could be a factor of 2 above the microwave instability threshold.

Significant efforts have been devoted to unraveling the interplay of lattice nonlinearity, space charge effect and the beam-beam kick. The *weak-strong* simulation of the specific luminosity shows degradation starting from low currents, when the realistic nonlinear lattice is used. Studies with a simplified lattice (no solenoid, etc.) revealed that the solenoid and high-order terms in the QC* magnets are the main sources of nonlinearity causing luminosity loss in the real lattice. In particular, the latter introduces a large nonlinear X-Y coupling, which is not present in the simplified lattice. Among other terms, the solenoid introduces a skew sextupole component. Introducing a compensating skew sextupole in LER can improve the nonlinear coupling, but it does not (yet); instead it tends to degrade the Touschek lifetime.

Pure *strong-strong* simulations for SuperKEKB are extremely slow, and so far do not include lattice nonlinearities. A *quasi-strong-strong* simulation tool has been developed. The pertinent simulations predict a vertical blow-up of the LER beam by a factor of two, and much less blow-up for the HER. As a result, for LER studies strong-strong studies are not needed and a weak-strong model appropriately describes the behavior.

Although the space-charge effect in LER can produce a tune spread of almost the same value and with opposite sign to that of the beam-beam kick, the difference in s-distributions of these nonlinear forces leaves little hope for their "compensation". Indeed, when the space charge effect in LER was investigated using field map analysis techniques the region of stable trajectories was found to be very small in the presence of both space charge and beam-beam interaction.

Extensive scans of the two transverse tunes did not show any working points with much better performance. A possible re-matching of the optics including space charge needs to be further investigated which may require an upgrade of SAD.

Luminosity calculations for the detuned optics re-confirm the optics parameter tolerances and show that space charge and lattice nonlinearities are not likely to cause any luminosity loss in Phase II. The target of $L=10^{34}$ cm^{-2}s^{-1} should be achieved and $L=10^{35}$ cm^{-2}s^{-1} appears possible. Reducing the vertical emittance lowers the beam current when the beam-beam/space-charge limit is encountered.

SAD benchmarking with BMAD, in collaboration with Cornell University, has revealed a good agreement with the field map analysis results, and will be continued together with additional international collaborators. Other benchmarking simulations were performed with the SCTR code where some discrepancies are still to be understood.

The team should compare the field map analysis for SuperKEKB LER including beam-beam and space charge with the equivalent plot for KEKB.

Recommendations:

R6: Define a set of parameters that would beat the KEKB luminosity record in Phase 2.

R7: Try to find an optimum configuration where the two beams are about equally strong, and no beam blows up much more than the other in collision.

R8: Investigate the effect of bunch-by-bunch synchronous phase modulation due to the abort gap in beam-beam simulations.

R9: Perform a realistic simulation of the continuous injection efficiency, including the serious dynamic aperture reduction caused by interplay of the non-linear optics model and beam-beam effect. Provide the resulting distribution of the injection beam loss as input to the Belle-II background simulation.

4. Optics Issues

In line with the last Review recommendations, the optics modeling has been updated and improved so as to include the measured field of the Belle II solenoid, and measured field errors in the warm magnets as well as of the superconducting final quadrupoles QC1LP and QC2LP. The impact of these changes on the beam lifetime and dynamic aperture with crab waist was evaluated. Past emittance studies were also summarized with regard to the effect of tunnel subsidence and random errors.

The tunnel subsides by about 2 mm per year over about 800 m of the ring. Only a local realignment is planned. Simulations show that the vertical emittance after orbit and dispersion correction can be at an acceptable level (below 3 pm), even after 20 years of operation, by improving both the local alignment around V-LCC and the correction algorithm at the high-beta regions.

The design vertical emittance can be achieved even with realistic large random errors (displacement, tilt, field errors of dipoles, quadrupoles, sextupoles, BPMs) after orbit and optics corrections. Recovering the full dynamic aperture will require further tuning of the sextupoles.

The center of the Belle II solenoid has shifted by 44 cm toward the Oho side due to coil movement during cool-down. The compensation solenoids needed to be readjusted accordingly. The model of the compensation solenoids was also refined and rendered more realistic, representing many individual coil blocks used in the hardware design. Effective lengths and fringe fields of warm dipoles and quadrupoles were measured and the new values introduced in the LER optics model. The corresponding update for the HER is underway. The LER circumference changed by about 800 micron due to these updates, which is considered tolerable and can be mitigated easily.

Due to the inclusion of the warm-magnet field errors, the dynamic aperture is reduced from about 18 to 12 sigma in the horizontal plane but the optimization is not yet complete.

Field measurements of two left-side QCS magnets revealed large sextupole and skew octupole components, plus a considerable dodecapole error. The dynamic aperture can be recovered by using both normal and skew sextupole coils, a normal octupole coil in the QCS magnet, and the sextupole families in the arc sections. Although 12-pole correction coils in QCS are not envisaged, the dynamic aperture limitations can be improved by correcting the resulting nonlinear map using correctors available elsewhere in the lattice.

The degradation of the LER Touschek lifetime by the measured QCS field errors depends on the multipole errors of QC2R and QC1R, which are still to be produced and measured. The effect can be significant (factor of 2 reduction) in the worst case. For the HER the effect will be benign.

No solution has been found for implementing a crab-waist scheme at SuperKEKB. The on-momentum aperture of SuperKEKB lattice with a crab waist with thin-lens sextupoles is degraded even without any local chromatic correction sextupoles. The difficulty is attributed to the extremely strong fringe-field effect of the final focus quadrupoles; a factor 100 stronger than for KEKB, and a factor 20 stronger than for CEPC.

Important operation and commissioning software tools are being developed, including programmable tune changer, optics measurement & correction, chromaticity tuning, continuous orbit correction, local orbit bumps, luminosity tuning, calibration, etc.

Recommendations:

R10: Identify all relevant interaction region nonlinear optics errors affecting the dynamic aperture, e.g. through a map analysis, or through a tracking-post-processing tool like SUSSIX, and develop a suitable correction scheme.

R11: On the basis of realistic LER/HER optics model simulations, with and without beam-beam interactions, develop correction procedures aimed at the dynamic aperture control, suitable for the control room implementation in Phases I, II, and III of commissioning.

5) Interaction Region Mechanicals Overview

The Interaction Region (IR) is by far the most complicated area of the SuperKEKB. It consists of a remarkable number of highly sophisticated coupled systems with extremely demanding physical, mechanical, vacuum, and magnetic requirements and constraints. Almost no single item within the IR is simple. Physics detector demands put physical space at such a premium that standard connections are essentially nonexistent. The KEKB team has done a remarkable job at developing concepts, approaches, designs and procedures to meet these competing, conflicting and closely coupled demands and constraints.

The IR vacuum chamber is extremely complex and fragile. The assembly does not allow for any vacuum pumping for nearly ±4m from the centerline of the IR. At the same time the vacuum level is desired to be as low as possible. For Phase 1, the aluminum vacuum chamber will be TiN coated to counteract electron cloud instabilities. The fragility of this vacuum chamber has resulted in the need for additional reinforcement, following an incident where a weld cracked while the chamber was being prepared for coating. The TiN coating of the IR beam pipe is not in the baseline for Phase 2; instead Au and Cu coating are foreseen in the central part. The SEY of such coatings does not decrease as fast as for TiN during beam scrubbing. Relying on the axial component of the residual magnet field to mitigate electron cloud is a guess that should be substantiated by detailed calculations and simulations. As a result of the lack of physical space, a very complex, remotely actuated, vacuum-coupling joint– the Remote Vacuum Connection (RVC) – connects the IR vacuum pipe with the rest of the vacuum system. The next generation of the IR vacuum pipe has a combination of hot isostatic pressing of beryllium-to-titanium and titanium-to-titanium electron beam welds.

The RVC in particular presents challenges. The design developed at DESY has been prototyped and uses compressed N_2 (~50 bar) to apply pressure between the mating vacuum flanges and then a large screw nut is turned to apply static clamping force between the mating flanges after which the air pressure is released. The mockup of the RVC has been tested and is leak tight. Understanding the number of cycles that can be achieved with the RVC is something that should be pursued as time permits.

The assembly and integration of the IR vacuum system and the IR cryostats has been developed conceptually, but much work remains in order to ensure that this delicate operation can be accomplished without damage to the vacuum system, the superconducting magnets or the cryostats. There is a large number of unknown aspects in these highly coupled IR systems: the coupling between the cryostat and the RVC, the potential transmission of moments and stress to the IR vacuum pipe from the cryostat through the RVC, the vibration/modal analysis of the systems, the interaction and coupling of the cryostat support and alignment rods, and coupling with the vacuum system.

Finally, in addition to all of the technical systems necessary for the proper functioning of the beams within the IR, shielding must be provided to reduce the background within the detector. Background simulations of the IR region show a hot spot where losses occur near where the RVC is located. This hot spot can have line of sight into the detector. This area has very little space to install additional shielding. However, creative solutions to this problem could significantly reduce backgrounds.

Recommendations:

R12: Look at the possibility of collaborating with local/regional Japanese engineering schools that could provide the more detailed coupled modeling necessary to guide the prototyping, assembly and integration development of the IR systems. Expanding the collaboration with DESY to help understand all the interfaces with the RVC would also be beneficial.

R13: Evaluate the electron cloud density, considering the secondary electron yield reduction of copper and gold during scrubbing, and taking into account the residual magnetic field generated in the focusing magnets. The help of electron-cloud specialists should be sought at KEK or in another research center.

6. IR Superconducting Magnets: KR/RR

The Interaction Region (IR) superconducting magnets continue to make strong progress. The collaring process for the 8 superconducting quadrupoles was completed in March 2014. The construction of the 43 corrector magnets and leakage field cancellation magnets has been completed at BNL, with the final set of corrector magnets to be delivered to KEK in February 2015. All 43 of the corrector magnets have been tested at room temperature, and 35 have had cold tests (4°K) and been excited to ±60A. The 16 correctors associated with the QCSL have been integrated with the quadrupole and tested at 4°K with various excitation combinations. Only two correctors (QC1LP-b1, and QC2RP-b1) were reported to be slightly below the beam optics requirement. The compensation solenoid (ESL) was completed in December 2014, subsequently tested at 4°K, and powered at its design current without quenching.

A complete battery of cold tests and field requirement tests has been performed on the IR quadrupoles. All of the quadrupole measurements reported had a sextupole component that exceeded the design specification, but sextupole correctors allow the recovery of the Touschek lifetime to 550 seconds.

The leakage field cancelation magnets have been measured and the measurements correlate very closely with the calculated fields. The compensation solenoid ESL also underwent cold tests in January 2015 and was operated at the full design current of 404 A without quenching. The assembly of the cold masses for the complete quadrupole assemblies (quadrupoles, correctors is well underway and progress is strong.

The IR from all aspects is an extremely complicated ensemble of systems and this extends to the magnetics. While the quadrupoles and their attendant correctors appear to be very rigidly attached to each other, the interaction between quadrupoles and the other magnets within a single cryostat is much more complicated, and it is difficult to do a summary assessment of the complete system. The alignment support rods are of particular concern from a stability standpoint. The support rods appear to be ball-end rods of a similar conceptual mechanical design to those used at other operating accelerator complexes (however, the constraints on the KEK usage does make them unique in several respects). Such rod systems have worked well, but have also been found to have weaknesses that must be understood and counteracted.

Inherent material stiffness as measured by KEK is important, but the ensemble rod stability is perhaps even more important from an operational perspective. It is this composite stability that forced some facilities (LBNL and FRIB for example) to move away from the use of such rods in specific applications. Likewise, such rods may not have robust resistance to emergency or off-normal events such as a rapid non-symmetric depressurization from a quench or other event. Such events could produce large unbalanced forces and it is important to understand the resilience of the system. Consequently, the vibrational modes, asymmetric loadings, repeatability, etc. are all extremely important. Additional analysis and modeling is needed as the design progresses that specifically examines the stability, vibrational characteristics, response to asymmetric loads, and other off-normal events on the cryostats.

An enhanced measurement and characterization campaign of the cryostats and systems when installed and tested on the IR, including repeated thermal cycling, quench simulations and other off-normal configurations should be undertaken in order to fully understand both the capabilities and limitations of the design as implemented and the ensemble system in operation.

In a similar vein, the concrete supports for the IR have now been completed. Careful vibrational analysis and modeling of these structures were presented at previous reviews. If possible, it would beneficial to verify the actual vibrational response of these structures as they could couple to, or excite, mechanical modes in the cryostats.

At the present time, magnetic measurements are scheduled in series. This decision should be reexamined and every opportunity to perform tests in parallel should be determined and implemented. This is needed for two important reasons: the IR superconducting magnets are on the critical path and so any delay in them will delay the start of physics runs. In addition, any time that can be saved will advance physics runs. Likewise, and *without a doubt,* the ensemble tests of the IR cryostats on when mounted on the ring will uncover issues that have not been anticipated, and time will be needed for these to be addressed.

Recommendations:

R14: Model and prototype to the extent possible the vibrational, stability and repeatability of the support/alignment rods that are planned for the IR quadrupole cryostats.

R15: Develop a detailed plan for *in situ* testing that will fully characterize the operational mechanical behavior of the cryostats, quadrupoles and attendant systems in order to fully understand the limitations, and determine issues that could impact operations.

R16: Produce detailed procedures for the testing and decision trees with sufficient staffing should be included. KEK is encouraged to solicit testing help from other international laboratories that may have staff that can benefit from participating in such testing.

7. Beam Background and BEAST

A new Belle II Beam Background Group has been formed by merging two previous groups. The goal of the background group is to estimate, measure, mitigate, and protect against beam backgrounds. Background simulations have been methodically and continuously pursued over many years. Most recently, the simulations were updated using the latest LER lattice, and results of the 11^{th} background simulation campaign were reported.

The effect of Touschek scattering and Coulomb gas scattering are well mitigated by tungsten shields. Synchrotron radiation background is predicted to be negligible, even including orbit errors and beam-beam tails, according to extensive simulation studies. Radiative Bhabha scattering is the main remaining loss mechanism with widely distributed loss locations. At the presently simulated rates, almost all of the detector can survive for 10 years except for the time-of-flight photomultiplier, where a factor 3 improvement is needed.

As a further mitigation measure, adding a shield around the BPM/bellows between the QCS and the IP is being investigated, but this area is quite crowded already. For future background studies, it is planned to also include other background sources such as "elastic" Bhabha scattering, and the spent e^+e^- from 2-photon process.

SuperKEKB will feature a large number of new collimators, installed at several straight sections, with a total of 50 parameters to be set, monitored and optimized. Many of these collimators are horizontal ones and effective for Touschek-scattering background control. These horizontal collimators can also strongly affect the Touschek lifetime. By contrast, there will be only a single vertical collimator per beam, located several tens of meters from the IP, to control the Coulomb background.

For BEAST II, two different configurations for the commissioning Phases 1 and 2 should be ready by January 2016 and May 2017, respectively. Various critical and desirable BEAST activities are foreseen in these two setups. The BEAST II activities during Phase 1 should ensure the safe rolling-in of Belle II and the VXD BEAST II setup for Phase 2, and also allow the benchmarking of simulations against measurements, and experimentally separating the different types of background sources by varying beam parameters and vacuum levels.

A collimation optimization study during the BEAST II period is crucially important to develop the collimator strategy for Phase III. Collimator studies will be performed with help from the accelerator team. To perform these studies, one week of beam time is requested during Phase 1, and two weeks in Phase 2. Injection-noise damping measurements during Phase 2 will address the background caused by continuous injection.

Numerous types of Phase 2 sensors for the VXD volume are under discussion.

The Committee is satisfied with the continuous progress in background simulation studies and encourages further efforts aimed at an ever more realistic modeling of the various beam loss processes.

Recommendations:

R17: Compare distributions of lost particles with and without the beam-beam effect, which modifies the beam phase-space and densities around the ring. This effect is roughly represented by "dynamic beta" and "dynamic emittance" and may require a modification of the scattered particle generation procedure.

R18: Perform a dedicated simulation of the continuous injection and beam losses caused by dynamic aperture reduction due to the interplay of the nonlinear lattice and beam-beam effect. This recently discovered effect is relevant for Phases 2 and 3, and potentially detrimental to the detector background conditions.

R19: The collimator apertures optimized with the help of the background simulation studies should be timely reported to the impedance police in order to keep track of the acceptability of the impedance budget.

8. Magnets

The Committee appreciates the very professional achievement for magnet production, field measurement, installation, integrated testing with power supplies, survey and alignment. The last normal conducting magnet will be installed in the 2nd quarter of 2015 in the arc section. The power supplies necessary for Phase 1 operation, have been delivered and the integrated low-frequency ripple and stability have been measured to be within several ppm, meeting specifications. The first iteration of alignment, relative to nearby magnets, for the new magnets has been completed. However, the survey data shows that ground settlement continues near several construction sites, and this movement of tunnel monuments can be as much as 6 mm within 12 months. It will be a challenging task for the system alignment without proper temperature control in the tunnel and while floor settling continues.

The Committee is pleased to hear that the field measurement data have been summarized and shared with the Optics Group. The re-alignment of magnets for Phase 1 commissioning will start in June 2015. The most critical and tight tolerance area is, of course, in the Interaction Region. The team is focusing more effort and instrumentation to help in monitoring ground motion and addressing it. The tunnel installation coordination by the group is a noteworthy practice, and has, and will continue to, smooth out potential schedule or siting conflicts.

An alloy-brazing defect of the cooling pipe couplings has been found in several magnets. These defects have caused water leaks and a delay in the power supply tests. So far, the leakage points could be fixed *in situ*. If possible, we suggest the cooling piping be tested with either compressed air or deionized water with an adequate engineering safety margin to ensure all leaks have been identified prior to operation or installation in an inaccessible configuration.

Recommendations:

R20: Consider testing the high frequency ripple of the power supplies with a vacuum chamber in place within the magnets to confirm that the cutoff threshold won't affect the associated magnetic field.

R21: The interlock system of power supplies near the injection section should be checked with the pulsed magnets running to confirm that the protection functions function properly as designed, with sufficient immunity to pulse noise.

9. Vacuum

The vacuum system is almost complete. Remarkable progress towards Phase 1 was presented. The production of the vacuum chambers of the main rings is finished, including the pre-installation phase. About half of the DR's beam pipes have been coated with TiN; the rest will be coated in the next fiscal year. The installation of the vacuum chamber of the main rings is nearly finished (97%); by September 2015, the last vacuum chambers will be connected in the IR (Tsukuba area) and the beam injection region. The activation of the NEG pumps has already been performed in several vacuum sectors (30% in the HER and 15% in the LER). As expected, the attained pressure in those sectors is in the low 10^{-8} Pa range.

As with any new large vacuum system, a few problems have appeared during installation. Once identified and fixed, leak tightness issues attained a rate of less than 5% of the connected flanges. Typical problems have been scratches on the sealing surfaces, cracks in the welding joints resulting from lack of penetration, and integration issues. Some of these difficulties could have been avoided if the manufacturers had put additional quality assurance and control in place. This important point should be considered for any remaining orders and for future series productions, e.g. spare parts and modified beam pipes.

Additional vacuum leaks could appear after the installation, for example during the alignment or because of thermal expansion. It is important that the vacuum tightness of all components be monitored, so that any change in the integrity of the vacuum system can be promptly detected and addressed.

The efficiency of the scrubbing run in Phase 1 relies heavily on the rate of decrease of the TiN secondary electron yield. Given that the vacuum chambers have been in air for several months after coating, it is important that growth rates of the initial secondary electron yield are identified. Towards that end, a measurement campaign should start as soon as possible.

The design and production of collimators for Phase 1 is progressing at an appropriate pace; their installation is expected at the beginning of the next fiscal year. All recommendations formulated during the last review have been taken into account and implemented.

The installation of the vacuum control systems is progressing as expected. Interlock procedures are now fully defined. Although several months are needed for the tests of the control system, there are no identifiable showstoppers.

Recommendations:

R22: Additional TiN coated vacuum chambers (modified or spare) will certainly be needed over the next several years. The Committee recommends that the TiN coating facility remain available as long as SuperKEKB is operated.

R23: We recommended that a follow up evaluation to address the sources of vacuum leaks be put in place so that handling and quality assurance processes are reviewed.

R24: The changes of the secondary electron yield of TiN after long air exposure should be studied as soon as possible.

10. Status of RF System

Great progress has been made in the last year and the RF systems are ready, or very nearly ready, for first beam. All of the cavity moves have been completed and 13 couplers have been conditioned to 800 kW and installed in the ARES and "one-to-one" SRF cavities. Coupler conditioning time has been reduced to ~2 weeks and no couplers have failed to reach the new specification. All of the remaining couplers will be ready and installed before start up in 2016. While this is a very successful outcome, the Committee would like to see an estimation of the remaining safety margin in the coupler design, either by simulation or test data, to verify that 800 kW operation is not close to the limit.

Maintenance of the existing stations and hardware is under way since many of the components have seen a lot of years of service. The aim is to make the systems fully reliable for Phase 1.

Damping ring cavity #2 has been successfully tested and is ready to be installed. Both damping ring cavities exceeded specification and together will provide enough voltage (1.4 MV) to commission and operate the damping ring. The requirement for the third cavity is therefore less urgent and given budget constraints this may be delayed. It would be good to have it as a qualified spare or installed to provide on-line redundancy, but this can come later.

The SCRF cavities are in place and there are slots for two more to be installed later if needed. New beam line HOM loads will be added on both sides of the cavities to absorb a significant fraction of the high frequency HOM power generated by the higher current and shorter bunches. This should reduce the load on the existing absorbers to acceptable levels. The prototype absorbers were tested to high power in a coaxial test stand. These will be installed outside of the gate valves so there is low risk to the cavities. It would be worth checking that the heating profile from the HOMs is equivalent to the coaxial test stand conditions (there might be a longitudinal temperature profile on the beam line since the HOM power will be attenuated with distance from the cavity). The impedance of these new absorbers should be included in the overall ring budget. The Committee would like to see a test to validate that the RF shielding in the gate valves is adequate to transmit the high frequency HOM power without it leaking into the body of the valve.

Updated analysis of the gap-transient response of the RF systems in the two rings has been started. Initial results show that the peak excursions in cavity phase are similar to those seen in KEKB. Modeling the ARES cavities as a coupled-cavity system shows short-range transients that match those observed in KEKB and show that they are due to the time response of the low-Q coupling cavity. Any difference in the gap transients between the two rings will move the collision point, and because of the crossing angle, and beta function variation with z, there will be interplay between the beam cross-section variations and some finite variation in beam-beam tune shifts. We are concerned there might be a beam lifetime impact, where bunches immediately after the gap lose charge at a faster rate, possibly increasing the gap and gap transients. We encourage a continued study with the LLRF and RF models to estimate several possible gap transient effects for foreseeable fill patterns and RF configurations. This estimate should be studied with the beam dynamics team to estimate any possible lifetime or dynamics impacts. The Committee recommends study of a variety of operating scenarios, including running with some cavities off and parked.

The high power RF station modifications are complete and 9 new LLRF systems have been installed; the remaining stations will use the existing LLRF system. The LLRF system has been demonstrated with a high power station using a cavity simulator to model the beam loading. The demonstration of the klystron PLL function in the LLRF system is very good. This important test at the 800 kW power level shows the phase variation with klystron HV supply is being well compensated. The new digital LLRF systems will be used for the damping ring RF stations, due to be installed next year.

Recommendations:

R25: Evaluate the safety margin of the upgraded coupler at full power.

R26: Evaluate the longitudinal heating profile of the new beamline HOM absorbers assuming the HOM power comes from one end to verify there are no differential stresses.

R27: Continue modeling of the gap transients with the new RF configuration, including cases with cavities off and parked. Work with the beam dynamics team to understand the sensitivity of luminosity to variations in phase of the beams.

11. Overview of Injector Linac

The injector linac upgrade has been carried out step-by-step after recovering from the earthquake damage. In order to dramatically increase beam currents and to preserve low-emittance for the beams, a special photo-cathode system has been developed along with the Damping Ring. The linac system is also designed to support 4+1 rings with top-up and continuous injection operations. The Committee is impressed with the recovery of the injection system back to operation for the Photon Factory in a very short period after the earthquakes. The displacements of the tunnel joints, which affected the alignment of accelerator components, were re-aligned to reach the specification of 0.2 mm. However, there seems to be ground movements along the linac. The positron beam was first obtained after the shutdown of KEKB operations, and the measured parameters are in good agreement with simulations. The performance of the injection system, e-gun and the linac, is steadily progressing towards Phase 1 operational requirements. However, in order to secure beams for Phase 1 operations and beyond, an Electron Gun Review Workshop was held, during which it was recommended that the existing thermionic electron gun system be immediately reinstalled on top of the photo-cathode gun system. The cable burning and overheated modulator problem drew the attention of the Committee members because of the operation safety issues. More safety and quality assurance measures should be taken to protect the accelerator systems in normal operations. It should also be noted that providing electron beams continuously to the Photon Factory would influence the planned work schedules.

Recommendations:

R28: Most of the components are pushing the engineering design margins. Quality assurance of all components, both new and refurbished, should be emphasized and more safety measures should be taken to avoid accidents and to ensure safe operation at the laboratory.

12. Alignment

The Committee recognizes that with a floor system as complicated as that which KEKB must contend with, alignment is a challenge and the team is to be commended for their efforts and accomplishments.

The alignment in the Linac area is targeted to be better than 0.1 mm and 0.3 mm in local and global, respectively. In the C3-5 sector, alignment was complicated by concerns of PF operation and the mechanical stress-induced vacuum leaks after the earthquake. The team setup a 500 m laser reference line over the C-5 region and completed the initial alignment in C3-5 in January 2014, with a standard deviation better than 0.3 mm in both horizontal and vertical directions. The alignment of the C-5 sectors was also shown in detail; it is generally quite good, but a few outlier alignment points are of note, if not a concern. For example, in C-5 the vertical $\sigma = 250\mu m$ while there are 3 outliers that exceed $\pm 1000\ \mu m$.

Floor movement is dominated by floor joint displacements and shows a seasonal variation approaching 2 mm. The group is actively trying to understand these floor movements and is looking into a continuous monitoring of the alignment. Wherever possible, the group should attempt to minimize critical beamline elements straddling floor joints without having a continuous (active or passive) way of quickly identifying movement and compensating (such as the stretched wire technique that SLAC uses). The group has strengthened part of the support girders making them more rigid and easier to reliably align.

Recommendations:

None.

13. Gun Review

To meet the SuperKEKB requirements, a sophisticated quasi-traveling wave (QTW) RF gun and drive laser have been constructed, to provide state-of-the-art performance, such as high bunch charge above 5nC and low emittance around 20/50 mm-mrad.

Although significant progress has been made on the photoinjector, KEK Lab Management has decided to use the KEKB thermionic gun for Phase 1 commissioning. A very effective RF gun review was held February19-20, 2015. The Committee congratulated the team for discovery of Ir_5Ce photocathode and invention of QTW side-coupled RF-gun, but suggested that the drive laser be constructed in a phased approach, beginning with a simple laser that does not include temporal pulse shaping, and then adding laser features and complexity over time.

Recommendations:

R29: The Committee fully agrees with the Gun Review Committee philosophy and strongly recommends that the Gun Review Committee meet every 6 months to check the status of specific gun/laser components, focusing on realizing reliable and robust gun performance before the start of Phase 2 commissioning.

R30: Consider an independent RF gun test facility for long-term performance optimization

14. Electron Gun and Transport

There are two RF guns presently installed in the KEK accelerator complex; the quasi-traveling wave (QTW) gun at the injector region A1, and the disc and washer gun in the long linac straight section, downstream of the positron source, at region 3-2. The disc and washer gun can be used to fill one of the photon factory rings however it is possible (and desirable?) that all 4 + 1 beams originate from the QTW gun at A1.

The disc and washer gun meets specifications; however 2 MeV beam production is not sufficient for SuperKEKB operation. The QTW gun does not presently meet specifications. It provides 6 MeV beam with 12 MW of applied RF power, but SuperKEKB requires 10 MeV beam with 20 MW of applied RF power. Performance is presently limited by RF breakdown presumed to be a result of photocathode material accidently sputtered onto the gun chamber walls and, more specifically, the anode, which has a tight aperture. This condition likely stems from inadvertently focusing the drive laser light too tightly at the photocathode.

A new QTW RF gun is being constructed, with a bigger anode aperture. When construction is complete, this new gun will be located on a new short beamline oriented at 45 degrees relative to the main injector beamline. Light can be directed onto the photocathode of this gun at normal incidence, which should result in better beam quality compared to side-port illumination of the photocathode at ~ 60 degree angle of incidence. In addition, the gun/laser group intends to test CsTe photocathodes using this gun, which could provide higher QE than the Ir_5Ce photocathode. There was brief mention of employing plasmons to enhance the QE of the Ir_5Ce photocathode.

Recent beam commissioning identified drive laser problems that result in variations in bunch charge of the order 20%, far exceeding the 2.5% goal. This variation makes it very difficult to characterize the beam properties, such as the emittance. Bunch charge variability can result from a variety of drive laser problems including laser pulse timing instability, laser pointing instability, laser pulse width fluctuation, and laser pulse energy/amplitude variation.

In light of these gun and drive laser problems, it was decided to re-install the older thermionic gun that was used for many years for KEKB physics. The thermionic gun will provide reliable beam for Phase 1 and much of Phase 2 commissioning, albeit at lower bunch charge and with higher emittance than required for SuperKEKB operation. This is a very sensible approach and it will provide time for the gun/laser group to address laser and RF gun issues.

The final SuperKEKB beam specifications are demanding, including high bunch charge (~ 10 nC near the gun), low emittance, small energy spread, and a 50 Hz "two-bunch" time structure. These specifications impose significant technical challenges on the drive laser, which, as originally proposed, is rather complicated. It is likely the KEK gun/laser group could purchase an entire drive laser system from a commercial laser company, the way SLAC did for LCLS, but the KEK gun/laser group has chosen to build their laser in-house. As originally presented, the drive laser is a hybrid system composed of a mode-locked Yb-fiber master oscillator, a pulse stretcher and spectral shaper, fiber preamp(s), electro-optic pulse-pickers, a series of Yb:disc multi-pass amplifiers, and frequency conversion stages. The gain medium Yb was chosen because it provides sufficient spectral bandwidth to allow temporal pulse shaping deemed essential for ultimate SuperKEKB operation at full luminosity.

A separate RF-gun review Committee (Tsumoru Shintake, Sasha Gilevich, Yosuke Honda and Matt Poelker) met the week prior to the Review and suggested that a simpler laser system should be constructed, one that does not incorporate temporal pulse shaping. Such a laser, with a Gaussian temporal profile, would be more reliable and still satisfy Phase 1 and Phase 2 commissioning requirements. There would be fewer components in this simplified laser system and it could employ rugged Nd:host amplifiers, providing better spatial mode quality at high gain compared to the Yb:disc amplifiers that suffer more thermal lensing. The KEK gun/laser group agreed this was a sensible approach and they presented plans for a simplified Nd:based laser system. Such a laser system should be relatively easy for them to build, since they already built something similar for driving the DAW gun, although it too suffered timing instability. A more complicated laser system with temporal pulse shaping can be developed over time, and installed much later, for Phase 3, if needed. The RF Gun Review Committee was encouraged to reconvene every 6 months.

A detailed accounting of problems related to the Yb-based laser system was presented. Diagnostics will be added at multiple locations along the laser system chain to help pinpoint the origin of instabilities. To produce the 50 Hz two-bunch time structure, the plan is to combine two 25 Hz laser beams, with pulses interleaved and separated by the requisite 96 ns. In addition, spare lasers will be constructed as back up. In the interest of keeping the "simple" laser system simple, perhaps a passive approach could be implemented to create the two-bunch beam. One concept would be to pass a single laser beam through a beam-splitter to produce a two laser beams, and recombine the two beams with the first beam delayed by an appropriate amount, to produce the correct 96 ns spacing between bunches.

Unexplained beam loss remains a significant issue from the last review. More than 5 nC was extracted from the gun but less than 1nC delivered to the end of the linac. An unused accelerating cavity near the gun at A1 will be removed to provide more aperture.

Recommendations:

R31: Add a laser shutter and beam-splitter near the entrance window of the QTW gun, to direct a small portion of the drive laser beam to a CCD camera or viewer to create a "virtual photocathode". With the laser shutter closed, the size of the laser beam can be adjusted using the virtual photocathode, eliminating the possibility of accidently focusing the laser beam too tightly at the real photocathode.

R32: To minimize the pointing instability, “image” the laser output plane at the photocathode, for example an aperture on the laser table, by designing a suitable optical transport system.

R33: Add diagnostics along the laser system chain, to help pinpoint the origin of problems, and thereby provide efficient troubleshooting. Do this for both the “simple” and “complicated” drive lasers. Diagnostics include fast photodiodes and/or autocorrelators, photodiodes for phase noise measurement, CCD cameras for position sensing, and power meters for amplitude stability.

R34: Ask commercial vendors for a price quotation for a complete laser system that meets SuperKEKB requirements (Coherent, Thales, neoLASE, Lumera, etc.). The cost may be too high to purchase but knowing that a commercial solution exists will be reassuring and it will put the in-house laser initiative into perspective.

R35: Determine if the electron bunch temporal profile can be shaped to meet SuperKEKB specifications, rather than the laser pulse temporal profile.

R36: Verify the speculation that sputtered photocathode material limits the performance of QTW gun#1.

R37: When re-conditioning QTW gun#1, and for new QTW gun#2, condition above the operating gradient use a dummy cathode first, if that was not done previously.

15. Positron Generation

The positron production target and capture section have been upgraded for injection into the new damping ring and then SuperKEKB. The new target has a small hole in the center to allow the low emittance electron beam to pass through unaffected to fill the HER ring. A 3.3 GeV electron beam is kicked transversely about 3 mm on the target to make positrons. Following the target is a flux concentrator, which is a 12 kA pulsed solenoid making a field of 3.5 T surrounded by bridge solenoidal coils providing an additional 1T field. These solenoids are followed by a 14 MV/m RF capture section, a 10 MV/m RF accelerator, and a four-magnet chicane to separate the positrons from the secondary electrons (collimated). The flux concentrator has been tested for several days at a time on a stand-alone test stand. The first positron beam produced with the new system was detected and measured in June 2014.

The full positron system has been commissioned at reduced parameters starting in June 2014. A positron-to-electron yield of 20 to 30 % was produced in 2014, which is already a very important result. The ultimate goal is to have a 63% yield. The positron yield has been studied as a function of several parameters such as flux concentrator current, capture section RF voltage, bridge coil strength, and capture section solenoid strength. The results of the yield studies are essentially in agreement with what was expected, which is very good. To reach the positron yield goal required for the ultimate performance, the linac team has to increase the flux concentrator current from 6.4 kA to 12 kA, increase the capture DC solenoid current from 370 A to 650 A, increase the capture section RF voltage from 10 MV/m to 14 MV/m, and increase the radiation shielding above the target from 200 mm to 400 mm of steel. Each of these requires different hardware and operating improvements, which are in progress.

During the past year there have been two cable fires with the flux concentrator pulser system: one near the flux concentrator magnet and one near the power supply but for different reasons. The cause of the fires may be more complicated than just cable connector issues, thus, a more thorough investigation is warranted. There are solid, ongoing efforts to improve the flux concentrator cable plant including flat plate (triple) power leads near the flux concentrator magnet, the use of larger diameter high voltage cables from the power supplies to increase the cable voltage limits, and reinstalling and improving the snubber circuits to limit voltage spikes. Due to these changes, the flux concentrator pulse length will increase from 4.7 to 6.7 microseconds.

Recommendations:

R38: Carefully check all power cables from the power supply to the flux concentrator for potential hot or loose connections. Add real time cable monitoring devices to anticipate overheating.

R39: Test the full positron system at full specification for an extended period as soon as possible to expose the next round of problems, if there are any. The Committee concurs that the long accelerator section RF voltage may be able to be increased with just long term steady running and conditioning.

R40: Investigate the flux concentrator vibration and stresses during pulsing to see if they are within expectations.

16. Linac Commissioning

The SuperKEKB injector is a multi-purpose injector, simultaneously providing beam for PF, PF-AR, DR, HER and LER working at different energies, bunch charges, emittances and rep rates. Emittance growth and energy spread have to be strictly suppressed in various ways. In the meantime, delivering 5 nC electron and 4 nC positron injector bunch charges to MR are really challenging tasks which are only achievable using photocathode guns.

Currently the schedule of the Main Ring (MR) commissioning is shifted from early this year to January 2016. The delay provides valuable time to develop the new electron and positron sources, but the injector commissioning time is still very tight.

Since October 2013, the injector commissioning has been carried out with the RF gun in three periods, October to December of 2013, April to June and October to December of 2014. However, the planned commissioning at January to March of 2015 was canceled due to the operation budget cuts. Good progress in the injector commissioning has been achieved in the limited available time, maximum electron bunch charge of 5.6 nC was produced from the RF gun, but a big loss occurred in the following sectors and only about one tenth reached the end of the linac in the initial commissioning. Bunch charge fluctuations from the RF gun increased as the bunch charge increased; at around 1nC the fluctuation is about 10-20%. The offset injection effect to the linac emittance preservation was studied at low bunch charge of 0.3 nC and will be examined at various bunch charges. First positron beam was produced at current linac system in June 2014, with an electron bunch charge of 0.5nC, a positron bunch charge of 0.02nC was obtained at SP_28_4.

In order to facilitate the initial Phase 1 commissioning with 1.0 nC in each beam, the existing thermionic gun is going to be reinstalled on an upper deck in May 2015. The Committee strongly supports this decision, while photocathode guns should be developed for Phase 2 and Phase 3.

Recommendations:

R41: It is highly recommended that the gun group focus on the production of a simple, robust and reliable photo cathode RF gun system for the injector commissioning this year, achieving the required performance in the injector commissioning before the Phase 2 commissioning.

R42: Make the emittance measurement comparison by the data of Q and wire scan methods at nearby positions, and confirm different emittance values.

R43: There seems to be ground movements along the injector linac in time, which requires frequent measurements of components. The Committee recommends providing more manpower and equipment to the survey and alignment team.

17. Abort System

The abort system for the HER consists of four horizontal kickers and one vertical kicker, a sextupole magnet to enlarge the beam size, and a Lambertson magnet. The LER system comprises one vertical and two horizontal kickers, one pulsed quadrupole magnet to enlarge the beam size, and a Lambertson magnet. New power supplies for the kickers were successfully developed. Pulse compression circuits using magnetic switches are located close to each horizontal kicker, and at the pulsed quadrupole. The final system meets all the specifications, i.e. it provides a rise time shorter than 200 ns, and a flat kicker pulse over 10 microseconds. One thyratron fires all the kickers (and the LER pulsed quadrupole) of each beam, so that the system is intrinsically fail-safe with regard to single-kicker pre-firing or single missing kickers.

One concern is the possible radiation damage to the diode in the pulse compression circuit. Adding a radiation shield to reduce the radiation level at the diode by a factor ten, should mitigated this. Based on KEKB experience, the diode should survive with a large margin. New water-cooled ceramic vacuum chambers have been developed for the kickers. For the HER chamber a 100 micron copper coating has been applied. The fabrication status of the abort system is as follows. For the HER almost all tasks are either complete or in progress. For the LER the fabrication will happen during 2015. The schedule looks tight.

The local maximum power density at the extraction window is reduced by a vertical beam-scan advancing with a speed of 15 mm/10 μs, and by enlarging the horizontal beam size (to rms values larger than 1 mm) using either a pulsed-quadrupole (LER) or offsetting the beam in a sextupole (HER). An analytical method was developed to compute the resulting dynamic stresses in the extraction windows, taking into account the speed of sound (5,200 m/s). The stress waves move faster than the scanned beam and are reflected at the outer boundary. Model predictions are, among others, that for a Gaussian distribution the dynamic stress never exceeds the initial thermal stress, and that the maximum von Mises stress, including possible overlap with reflections, is about 260 MPa (about 80 MPa higher than for KEKB), and larger than the yield strength of pure Ti (≤200 MPa). A Ti alloy, like Ti-6Al-4V, could be a candidate window material.

Recommendations:

R44: Study the effect of possible shear waves driven by longitudinal expansion (local change in the window thickness).

R45: Consider the possibility of pre-stressing the foil to reduce the peak stress.

R46: Contemplate the collaboration of experts of other Institutes (for example CERN) to design titanium beam windows. Numerical simulations using a commercial software package should also be considered. A beam test would be useful to validate the window stress & survival calculations.

18. Status of Damping Ring, Beam Transport

The positron damping ring will be located at the end of linac Sector-2. The civil construction is completed. The damping ring will operate at a beam energy of 1.1 GeV. The injected bunches are damped for 40 ms, before they are extracted and re-injected into the linac. The linac-to-ring LTR transport line accommodates an energy compression system and the ring-to-linac RTL line a bunch compression system.

Magnet installation is almost complete for the transfer lines, and the magnet power cables and monitor cables are also installed. In the damping ring tunnel, magnet power cables are installed and everything is ready for the installation of beam-line components. The installation work for the damping ring will continue in FY2015 and FY2016.

Field measurements have been performed on most of the damping ring magnets except for the arc quadrupole magnets, which are scheduled to be completed by June 2015. The measurements of the dipole transfer functions are satisfactory.

The damping ring will operated with two trains of two bunches each, leading to the requirement that the injection and extraction kicker rise and fall times should both be less than 100 ns (achieved with a saturated inductance). The injection and extraction kickers are identical. The kicker pulse shape is a double half sine wave. The pre-pulse and tail noise should be (and are) less than 5% of the peak kick field. In addition a bunch-by-bunch feedback system is required to compensate the effect of the residual kicks. The stray field of the pulsed septum is estimated to be negligible.

The issues for the kickers include minimization of the pre-pulse and tail noise, radiation hardness (shields for magnetic switch), timing jitter (the plan is to replace the thyratron by a solid-state switch for Phase 3), the ceramic duct with Ti coating, and installation in the damping ring tunnel.

The coil of a prototype septum broke after only one hour of operation at 50 Hz, but the reason was not clear. As one mitigation measure, the conductor size was increased, and the modified prototype has been tested for over 20 hours without any problem. In addition, as a further remedy, the number of coil hooks will be doubled, which should reduce the stress by a factor of four.

Shim shapes for the septum core were optimized to minimize the nonlinear distortion of the injected beam. Following the KEKB experience, the stability of the septum power supply was improved so as to be better than $<10^{-4}$. In the process many broken parts were discovered that need to be repaired before beam operation.

As for the installation schedule, the HER Septum & HER abort kicker components will be fabricated by this summer. The LER septum and LER abort kicker components must be fabricated in FY2015 and will be installed between Phase 1 and Phase 2. The fabrication of pulsed magnets and power supplies for the DR will be completed in the present fiscal year.

The schedule and commissioning plan shows more than 10 weeks of time allocated for DR commissioning, which is a factor 2.5 longer than had been planned at the time of the 19^{th} Review, This appears to be a more realistic number.

A response to an LER beam abort was developed (closing the beam shutter at the end of RTL, and then firing the DR extraction kicker).

The plan for the Damping Ring instrumentation and diagnostics seems reasonable.

Recommendation:

R47: Consider advancing the first tests of two-bunch injection to allow more time for understanding possible problems.

19. Diagnostics

The progress in the past year has brought the beam diagnostics and related instrument systems well into production and into early installation. The Committee enjoyed the excellent presentation, with many details presented via photographs of production hardware as well as measurements of final systems with details on achieved resolution, noise floors, etc.

The 4 types of BPM systems were presented, the original and newly upgraded high-resolution narrowband systems, the gated turn-by-turn monitors, and the special system for orbit motion and emittance estimation. All of these functions are well into production and in some cases ready for commissioning. The Committee appreciates the details on the capacitance displacement sensor system, which will be helpful in clarifying motion of the beam pipe relative to the magnet poles. The details of the orbit abort system, with two BPM's per ring, 90 degrees apart in betatron phase, were presented.

The wideband feedback systems are ready to be commissioned, with the exception of the longitudinal kickers, which still need installation on the beam line. The numerous special monitors (bunch-by-bunch current monitors, tune monitors, oscillation detector, beam loss monitor, etc.) are ready to be commissioned.

The synchrotron light diagnostics (including the interferometric beam size monitor) are well along, as is the X-ray mask beam size monitor, all of which are based on existing techniques developed at KEKB, and a longstanding collaboration with the University of Hawaii. One of the new SuperKEKB diagnostics in fabrication is a large angle beamstrahlung monitor, the product of a collaboration with Wayne State University.

The presentation on the IP feedback systems showed great progress. On the hardware side, the dither coils have been fabricated by SLAC and delivered to KEK. The Committee was very pleased and impressed by the modeling and Simulink code development to study the stability and dynamics of the vertical loop. The power spectra of ground motion were used to estimate the differential motion of the beams, and a time domain simulation used to quantify the anticipated motion attenuation from the feedback. These results show a reduction of IP orbit motion by roughly a factor of 3 or 4.

The Committee suggested this study last year, and we greatly appreciate the work. We think this work will be valuable to help commission the loops. To this end we suggest that the BPM model in the loop be driven with a wideband noise model of some realistic amplitude, and the impact of the noise within the control loop quantified. As we understand the Simulink model shown, it has no noise in the feedback loop except for the numerical noise in the simulation. This study may help the choice of the PID loop parameters.

As the construction of the bridge and FF support structures is well underway, it may be helpful to measure the excited motion and modal spectrum of the constructed hardware, and compare to that estimated from the ANSYS models. The structure of the SC final focus quads was presented in the magnet talk; as the final hardware is now available, measuring the eigenmodes of the quadrupoles in the cryostat may also provide data that can be used in the Simulink models of estimated disturbances.

In the horizontal plane, the luminosity-based dither technique is being studied with a numerical simulation. The statistics and noise of the luminosity measurement are a concern, especially at low currents or larger beam sizes; this noise in the luminosity measurement should be included in the loop models.

The Committee sees great progress, and compliments the diagnostics group for their dedication and level of preparation. This hard work will be rewarded with smoother commissioning because of the state of readiness of the many monitors. Many pragmatic decisions were necessary to adjust to the various funding and production conflicts, we respect the priorities decided by the diagnostics group and look forward to seeing the results of their efforts during ring commissioning. We also continue to counsel that the ultimate currents anticipated will be very stressful for the beam line BPMs and kickers, and that during commissioning the temperatures and beam induced powers on these vacuum structures and cables should be carefully watched.

Recommendations:

None.

20. Controls

There has been steady and important progress since the last review on the Control System for SuperKEKB. The work has followed the outline and direction as presented in the last reviews, and the readiness and maturity of the system today shows the skill and planning that was carried out by the team.

The SuperKEKB Control system is EPICS based, with a pragmatic integration of some legacy functions from KEKB, and integrating new physical fiber and electrical communications paths, upgraded IOC and PLC control platforms, and a mix of commercial and custom designed new timing functions. The system design provides a core backbone of control and monitoring through EPICS, with significant data logging and communications to and from the Belle detector. The core team is focused on this backbone, and for some functions, applications programs are written by the engineers and physicists of other system groups. The system is flexible, and some related smaller control tasks, such as the quench monitor, cryogenics control and magnet field measurement systems have been built using the core architecture.

Significant progress has been made in the last year integrating and demonstrating the timing functions implemented in a three-layer mix of event generator and event receiver modules. This new system is running the LINAC, and has successfully injected into the PF and AR rings. This is an important milestone and brings confidence the timing and control of the new rings will be smoothly commissioned in the next year.

There is still new hardware in final design and development for the Damping Ring timing system, we think the schedule as presented is adequate to have this development done before the damping ring is commissioned.

The new abort system was presented; it is based on a set of modules that can report and issue an abort command as necessary from faults from the Orbit monitor, RF systems, etc. as needed. The design incorporates signal redundancy so that the absence of any input signal initiates an abort command (fail safe).

The Committee appreciated the comments about the spares philosophy and the test plan for the magnet control modules.

The presentation mentioned that there are some technical decisions and complexities in synchronizing the timing functions for the Linac (2856 MHz, 114 MHz timing clock) and the DR and HER, LER rings (509 MHz RF, 101.78 MHz timing clock). The presentation didn't expand on the issues, but the Committee is curious whether the solution uses an approach of running the timing functions off both clocks, selecting one or the other clock as determined by the timing client, an intermediate IF common frequency, or something else. The Committee is curious, but also confident the solution to this complexity is well in hand with the timing and controls group.

It is exciting to see the photograph of the new control room layout and the preparations for the accelerator operations and commissioning.

We think the overall schedule, and response to the funding profile, are reasonable choices. It is going to take somewhat longer to fully produce all the hardware and integrate the final configuration because of the reduced funding profile.

We look forward to the exciting commissioning of the SuperKEKB machine, which will be based on the solid foundations provided by the new timing and control systems. The design is modular and will allow the basic system to be expanded and augmented going forward over the years.

Recommendations:

None.

21. Ring Commissioning

The strategies for commissioning the LER and HER rings for SuperKEKB were presented. So far, the commissioning planning has concentrated on Phase 1, scheduled to start sometime between January and March 2016. At that time, the injector should be able to provide 0.6 to 1.0 nC bunches of electrons and (undamped) positrons at 50Hz. Thus, an ampere of beam can be stored in a few minutes in anticipation of an ultimate beam lifetime of comparable duration.

The damping ring commissioning period in 2016 is about 3 months. Detailed plans have been made and were presented.

The Phase 1 commissioning plans for LER and HER include injection tuning, basic tuning (tunes, orbits, aborts, RF), vacuum scrubbing, detector backgrounds, collimator setting, orbit feedback, optics tuning, emittance tuning, abort system, data logger, CSS alarm system, beam current increases, beam instability studies, and bunch-by-bunch feedback systems.

For SuperKEKB Phase 2 commissioning in 2017, the plan includes, in addition, IR optics, low IP beta functions, collision controls, establishing luminosity, luminosity feedbacks, lifetime controls, and luminosity optimization aiming at $1 \times 10^{34}/cm^2/s$.

Belle II and SuperKEKB teams have agreed on the design and implementation of a slow control system to exchange information about the beam conditions, luminosity, vacuum conditions, and real time run status.

The BEAST II hardware will be installed in summer 2015 in time for Phase 1 background measurements. A running period of one week will be dedicated to BEAST II during Phase 1. For commissioning Phase 2, BEAST will be reconfigured to fit into the VXD volume inside Belle II. Two weeks are currently dedicated to BEAST studies in Phase 2.

The dithering system for IP beam collision control, which includes the coils, control circuit and functional simulation, is currently being delivered to KEK through an international collaboration. The dithering system can provide up to 100 Hz of excitation of the local orbit bump in the x-plane. From simulations, the orbit difference can be controlled to be better than 10 um for a frequency span up to 100 Hz wide.

Continuous injection is the operation mode to mitigate the beam lifetime of "several minutes." A mismatch of the injection bump and the transient effect of an empty gap between filling bunches might perturb the colliding point causing reduction of luminosity. This would be an interesting topic to pursue during Phase 1 tuning.

The SuperKEKB accelerator team has been working with staff members at other laboratories on mutually beneficial studies. Some of these groups include Cornell (non-linear beam dynamics), Wayne State (beamstrahlung monitor), SLAC (IP feedback, dither simulations, optics, beam dynamics), LAL-Orsay (fast luminosity monitor), INFN-Frascati (feedbacks, optics, lifetimes), and FNAL (beam-beam interaction).

Recommendations:

R48: A complete list of Phase 1 ring commissioning tasks in time order should be developed to ensure that the needed hardware and software is available when needed.

R49: Determine the optimum RF commissioning plan for the rings so that only the minimum RF is powered to support the near term commissioning schedule to reduce operating power costs and extend klystron lifetimes.

R50: Determine the maximum beam current that can be stored in each ring without the need for the abort system, so that early commissioning can proceed without the complication of the abort triggering and kicker system, if it is advantageous.

Appendix A

KEKB Accelerator Review Committee Members

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

Appendix B Agenda of the 20th KEKB Accelerator Review Committee

February 23 (Monday)		
08:30 - 09:00	Executive Session	
09:00 - 09:15	Welcome address	M. Yamauchi
09:15 - 10:05	Overview of Ring Construction Status and Schedule	K. Akai
10:05 - 10:35	Belle II Construction and Schedule	I. Adachi
10:55 - 11:35	Beam Dynamics Issues	D. Zhou
11:35 - 12:15	Optics Issues	A. Morita
13:30 - 14:00	Interaction Region Mechanicals Overview	K. Kanazawa
14:00 - 15:00	IR Superconducting Magnets	N. Ohuchi
15:00 - 15:25	Beam Background and BEAST	H. Nakayama
15:45 - 16:25	Magnet	M. Masuzawa
16:25 - 17:05	Vacuum: Progress and Troubles of Upgrade Works	K. Shibata
17:05 - 17:45	Status of RF System	T. Kobayashi
February 24 (Tuesday)		
08:30 - 09:00	Executive session	
09:00 - 09:10	Linac overview	K. Furukawa
09:10 - 09:30	Alignment	T. Higo
09:30 - 09:50	Gun review	M. Poelker
09:50 - 10:30	Electron gun and transport	M. Yoshida
10:50 - 11:30	Positron generation	T. Kamitani
11:30 - 12:10	Linac Commissioning	M. Satoh
13:30 - 13:40	Abort System:	M. Kikuchi
13:40 - 14:00	Status of Damping Ring, Beam Transport	M. Tawada
14:00 - 14:40	Beam Diagnostics	H. Ikeda
14:40 - 15:10	Control	H. Kaji
15:10 - 15:40	Ring Commissioning	Y. Funakoshi
15:40 - 18:00	Executive Session / Report Writing	
February 25 (Wednesday)		
08:30 - 11:00	Executive Session / Report Writing	
11:00 - 12:00	Close-out	