The Fifteenth KEKB Accelerator Review Committee Report

March 8, 2010

Introduction

The Fifteenth KEKB Accelerator Review Committee meeting was held on February 15-17, 2010. Appendix A shows the present membership of the Committee. Trevor Linnecar, Flemming Pedersen, and Wang Shuhong were regrettably unable to attend this meeting. In addition, Mike Billing, from Cornell, replaced Dave Rice who 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 Committee was as always impressed by the high standard of the talks, both the technical content and the presentations themselves. This year however, the quantity of work that was presented was outstanding as the KEKB group had, in a single year, taken an idea for a Nano-Beam version of SuperKEKB and brought a specific design to a really advanced state. 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.

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A) Executive Summary

The performance of KEKB improved considerably over the last year as new skew sextupoles were installed and used to optimize the beam-beam collisions. The peak luminosity that has been achieved with crab crossing is now 2.11 x 10^{34} $cm^{-2}s^{-1}$, significantly more than the previous record without the crab cavity (1.76 x 10^{34} $cm^{-2}s^{-1}$).

The Belle detector has reached its goal of accumulating a total integrated luminosity of 1 ab^{-1}. This is an extremely important achievement as this was the target that had been defined for the KEKB project. The Committee congratulates the KEKB and Belle groups for this wonderful achievement. The detector accumulated 105.4 fb^{-1} in 2009, compared to 98.2 fb^{-1} in 2008, 86 fb^{-1} in 2007 and 145.4 fb^{-1} in 2006. The Belle detector has published, or submitted for publication, a total of 324 papers in refereed journals (294 as of the last meeting). This year the main focus of the physics program has been on Y(1S), Y(2S), Y(3S), and Y(5S) running. The focus is now shifting to process aggressively all of the data and to test the prototype components for Belle II, the new detector for SuperKEKB.

A major focus of the Review was the SuperKEKB Upgrade. Last year, the Accelerator Review Committee had recommended "the machine design work concentrate on the low emittance option for the next few months, with a focus on identifying any possible showstoppers." The KEKB group followed this advice and has made great strides in the design of a low emittance option (Nano-Beam), to the point where it is now considered to be the baseline design. So far, no showstoppers were identified by the KEKB group, and the Committee agreed with this assessment.

The Nano-Beam option also addresses a major concern – the cost of the facility. The new design reduces the construction cost from around \$560M to \$390M (\$1=90 yen), a significant cost saving. In addition, the operating costs are expected to be lower, addressing another concern of the funding agency.

A great deal of component R&D was carried out over the last few years and most of this R&D was applicable to both designs. However, the focus over the last year has been the Nano-Beam option, trying to identify any possible showstoppers. This work has provided the detailed underpinning of the Nano-Beam design and has permitted the KEKB group to adopt the Nano-Beam design as the preferred option.

The Committee unanimously supported the decision to make the Nano-Beam option the baseline. Having said that, the Committee recognizes that a considerable amount of work is still required to complete a consistent design, and recommends establishing a parameter team to ensure that all of the systems are compatible.

B) Recommendations

The Committee has made recommendations throughout the different sections below. Highlights of these recommendations are summarized here.

KEKB

1) The Committee recommends preparing a prioritized program of machine and detector studies for the final KEKB run.

SuperKEKB

2) The KEKB Group should create a parameter team to develop and approve a consistent parameter set for SuperKEKB. The team should have participation from each group to ensure a fully integrated design for the machine.
3) The KEKB and Belle Groups should formally create a joint working group to optimize the interaction region and the machine-detector interface. The first topic to be decided is the rotation of the Belle detector. The second topic to be studied is how to understand and minimize the detector background.
4) KEK management should ensure that the resources needed for the Nano-Beam studies are made available (staffing, computing). The most important issue is the established shortfall in staff during the construction period (~30 people) and in the operating era. In this context, the Committee recommends exploring collaborations with universities, industry and other laboratories world-wide.
5) The change to the Nano-Beam design has strongly increased the work in the magnet and power supply area. This is an area where staffing is a major issue which needs to be resolved, perhaps by industrial partnerships. The Committee recommends that the number of different magnet designs be minimized.
6) Since the vertical beam size is so small in the Nano-Beam design, all of the transverse instabilities should be fully evaluated and mitigation strategies developed. In addition, a solution should be developed for damping vibrations of the interaction region components and/or the beam to maintain luminosity.
7) The continued use of the older analog RF low level controls on the existing stations should be evaluated for compatibility with the new digital systems, which are currently only proposed for the new stations.

C) Findings and Comments

1) KEK Roadmap and SuperKEKB Upgrade

Professor Suzuki presented the road map for the KEK Laboratory, which consists of a multi-pronged approach to accelerator-based science. J-PARC will soon become a world leader in long baseline neutrino studies, and has already initiated materials science studies using neutrons and muons. The upgrade of KEKB using the low emittance option will study CP asymmetry and new sources of flavor mixing in the quark sector. The physics from SuperKEKB will be complementary to that which can be obtained from LHC. KEK is involved in LHC physics experiments and is designing the crab cavities and the superconducting insertion quadrupoles needed for the LHC Upgrade. SuperKEKB will play a large role in these preparations, both in the physics aspects and developing the technologies. KEK will remain involved in preparing for energy frontier experiments at ILC and is playing an extremely active role in the ILC R&D, both in the S1 and S2 superconducting module program and the low-emittance frontier with the ATF. KEK will also remain in the forefront of photon physics with the Photon Factory and later a cERL. There is also an idea for using KEKB as a photon source (KEK-X) that would have extremely interesting photon energy reach.

2010 is a decisive year for KEK as many projects are vying for an upgrade: the power upgrade of J-PARC; the upgrade of KEKB to SuperKEKB; beginning the cERL project; continued involvement in ILC during the Technical Design Phase; and finally the involvement in the ILC program. This is an extremely heavy load and at some stage it will be necessary to prioritize. The outlook for SuperKEKB is extremely positive, with construction expected to start in JFY2011 with a four-year construction time. The total construction cost envisioned by the funding agency is $300-400M and the operating cost should not significantly exceed the present annual operating budget of $60M.

2) KEKB Status

One year ago, the luminosity with the crab cavities was still less than had been obtained without the crab cavities, and no remedy for this had been found. In the last year, the idea that the limitation was due to chromatic errors in the coupling compensation was developed. A set of compensating skew sextupoles was built, installed and commissioned, resulting in a significant step forward in luminosity (15%). The KEKB group is to be congratulated on finding the cause of the luminosity limitation and the resulting world record for luminosity of 2.1×10^{34} $cm^{-2}s^{-1}$. This is significantly larger than the maximum luminosity obtained without crab cavities, finally realizing the gain expected from this system. Since the tune-up time available for optimizing the new knobs has been somewhat limited, more luminosity may still be possible.

A major milestone was reached in November when the total integrated luminosity finally reached 1 ab^{-1}, the KEKB operational goal established when the project was initially funded. This is a wonderful achievement and the Committee congratulates the KEKB and Belle teams who have worked so hard for so long to achieve it.

A factor in increasing the integrated luminosity was the achievement of simultaneous injection into the LER, HER and Photon Factory. This required a complex set-up with a fast event generator and is a significant step forward in preparing for SuperKEKB.

Machine development has been devoted to evaluating hardware for SuperKEKB as well as demonstrating new techniques. Since there is only one more short operations run planned before dismantling KEKB and preparing for SuperKEKB, the time needs to be planned wisely. The Committee recommends preparing a prioritized list of machine activities for the final run.

3) Belle & Belle-II

The Belle detector worked well during the last run and activities are now focusing on a grand reprocessing of all of the data. In addition, new readout electronics that will be needed for the expected faster data rate of SuperKEKB are being tested in the detector. This is an extremely positive development that should be continued. The required development time needed by the Belle detector should be folded into the prioritized list of activities during the final run.

A brief outline of the physics case for SuperKEKB was presented. The Committee recommends that this case be strengthened and, more importantly, made crisper. In the coming year, it will be necessary to convince politicians and government officials of the importance of building SuperKEKB, so the arguments need to be aimed at non-experts.

4) Simultaneous Injection

The Committee would like to extend their congratulations to the injector group for the success of simultaneous injections of different beams to three rings in 50 Hz top-up mode (20 ms). It has taken many years of thorough planning and careful step-by-step execution. First, the dual-bunch positron injection in 2003 and top-up injection in 2005 improved the efficiency of filling the KEKB rings. Starting with the by-pass transfer line to the Photon Factory, about 1000 devices were improved or modified. In addition, beam diagnostics, a fast control scheme and the fast event system with pulse-to-pulse reprogramming, have been implemented. Finally, the group achieved the remarkable milestone of completing the "Event-based Control System" in April 2009. It will be essential for the Super-KEKB operations due to the expected short beam lifetime. Again, they have done a remarkable job very well.

5) Operation Experience of Crab Cavity

A detailed account of the operational performance of the crab cavities since their installation in KEKB in 2007 was presented. The cavities have been essential to achieving the world record luminosity in KEKB. In spite of their complex and delicate design, the operation has been remarkably stable, with an acceptable overall performance over the years. Most recently the cavities have been operated with beam currents of 1250 mA in the HER and 1700 mA and in the LER. The trip rates have been improving with time, coming down to values of about 0.1/day for the LER and about 0.8/day for the HER.

The design parameters were shown to remind the Committee of the many critical components in the crab cavities. The HOM load dampers have operated reliably beyond their design power levels. The sudden breakdown of the piezo-actuator has not stopped the operation of the LER since the low level feedback can compensate for this failure. Unfortunately, the reduction of the maximum cavity voltage after installation in the LER, as reported to a previous MAC, has never been recovered. Lowering the operating temperature and RF conditioning have been without success, and this problem remains a subject of concern. More recently an oscillation at high beam currents has (again) been observed for unknown reasons.

The Committee congratulates the KEKB team for the important contribution it has made with the crab cavities to accelerator science and technology. As the crab cavities are no longer needed in the Nano-Beam scheme, it is satisfying to hear that they will be used in the future for machine studies at CERN in the context of the LHC luminosity upgrade.

6) Nano-Beam Scheme for SuperKEKB

The KEKB staff has performed a careful investigation over the past year comparing the High Current option for SuperKEKB as well as the Nano-Beam scheme. Many accelerator physics and engineering topics were covered. Many of these topics were needed for both schemes. After looking at overall issues such as minimizing operating costs, minimizing construction costs, optimizing accelerator physics issues like CSR with the bunch length in both rings, and reducing the needed beam-beam tune shift for full luminosity, the team has now converged on the Nano-Beam scheme for the construction of SuperKEKB.

The Coherent Synchrotron Radiation (CSR) effects are much less important with 6 mm long bunches compared to 3 mm long bunches. The needed beam-beam tune shifts have been reduced from 0.3 to 0.09. The machine parameter optimization is ongoing and will likely stabilize over the next few months as studies continue. Many engineering tests of the new components have been successfully completed over the past year.

There are several key issues to resolve influencing the overall design. 1) The accelerator staff should confer with the high energy physicists from Belle as to whether longitudinal electron polarization is needed at the interaction region. 2) The accelerator staff should come to a final conclusion with the detector collaboration concerning the energy operating ranges of SuperKEKB, e.g. should SuperKEKB be capable of running at a much lower energies, e.g. the tau-charm threshold, or whether extensive scanning of the Upsilon resonances will be needed. 3) Rotating the detector on its support would help the optical and mechanical design of the accelerator. The pros and cons of this rotation should be discussed with the collaboration and an optimized solution found.

Several injection issues should be resolved. A phase space plot of the stored and injected beams at the injection septum needs to be made to ensure all the injection parameters are chosen adequately. An accounting of the injection rates, charge per pulse, and the injected beam emittance should be tabularized in a systematic fashion for the Nano-Beam scheme including requirements for the low emittance gun and damping ring.

Finally, the overall interaction region design is still in flux and additional concentrated work is needed to converge on the optimal accelerator physics parameters there.

7) Machine Parameters

The Nano-Beam scheme for the SuperKEKB collider will be a challenge from the perspective of beam parameters. There are many new and innovative concepts that need to be brought to fruition. The target luminosity for the Nano-Beam scheme is 8×10^{35} $cm^{-2}s^{-1}$ with beam energies of 4 and 7 GeV. The energy asymmetry has recently been lowered to reduce the synchrotron radiation power of the high-energy ring and to make the beam currents more equal.

The beam currents in the Nano-Beam scheme are significantly lower than in the High-Current scheme, but still are a factor of two larger than for KEKB. This increase in current is being addressed in detail, as many improvements to the RF system, ring impedances, vacuum duct design, and feedback systems are needed.

The bunch spacing will be two buckets in SuperKEKB requiring an upgrade in bandwidth of the bunch-by-bunch feedback systems.

The low horizontal emittances and, especially, the very low vertical emittances, will be a challenge to commission, tune, and maintain during collisions. Specialized tuning techniques need to be developed and correction schemes optimized.

The beams are very small at the interaction point. Collision feedbacks and correlated beam readout diagnostics need to be designed to complete this crucial operational function.

The quadrupole lattices for the rings were shown and large steps have been taken toward completion. Many aspects have been studied. Work is ongoing to optimize the dynamic aperture and the IR parameters. One of the next phases is to determine the allowed magnet field tolerances, component alignment tolerances, and power supply specifications. These studies include the requirement to tune the machine after construction during commissioning.

There is a plan to run KEKB in May and June of 2010 to provide Belle with more selected particle physics data and to do crucial accelerator physics experiments aimed at SuperKEKB. The committee recommends that a detailed plan for the time usage of the KEKB accelerator run in May and June 2010 be made soon so that all the essential studies get done during this crucial time period.

8) Beam-beam Simulation

Dependence on beam-beam simulation will increase with time. Beam-beam simulation is a critical effort for SuperKEKB. One early result so far predicts that one must insist on the hourglass condition that beta > sigmax/2 phi. Simulation shows that the luminosity decreases sharply when the value of beta/(sigmax/2 phi) exceeds 1. Another important prediction of the simulation is that the crab waist does improve luminosity, but only by about 20%.

These beam-beam simulations, particularly for the Nano-Beam scheme, require a large amount of computing power. It is suggested that KEK management addresses the issue of computing power as soon as possible, given the expectation that these simulations will become increasingly more important for the design effort.

Further studies are required to address the following aspects, among other things:

- Confirm the feasibility of injection while colliding.
- Benchmark against DAFNE.
- The tolerance on the y-z tilt of the beam due to optics or the y-z banana effect due to wake fields. The intentionally long bunches in the Nano-Beam scheme will tend to make this worse.
- The operation of the beam collision feedback system at the IP will require input from beam-beam simulation.
- Beam-beam collisions occur only among a small number of particles. Statistical fluctuations will be large, causing beam-beam diffusion. This effect may need analysis and simulation efforts.

9) Systematic Study of Nonlinear Dynamics

In order to achieve the design parameters for the SuperKEKB collisions, a sophisticated IR lattice is needed. The present LER IR lattice solution provides for needed small beta-y* and Local Lattice Correction at the expense of a large beta-beat along the IR: there are 3 maxima of beta-y ~ 2.5 km on either side of the IP.

The study of nonlinear effects in the LER included simulation of the nonlinear dynamics up to 4th order using a Budker INP code, with the aim of enhancing the dynamic aperture.

The included nonlinearities were: strong chromatic sextupoles of Local Lattice Correction, chromatic sextupoles of the arc, quadrupole fringe fields, bending magnet fringes (to 3rd order) and the kinematic terms.

Although the sextupoles of both types are arranged in pairs with a –I transformation in between, the compensation problem arises from the finite sextupole length, which leads to non-cancellation of the nonlinear terms; the residuals start from the 4th order. But in this lattice the quadrupole fringe terms are actually dominant (by a factor of ~5) over the former. The kinematic term is dominated by the IP section with beta-y* = 0.27 mm.

Before optimization, the vertical dynamic aperture limitation was primarily caused by the quadrupole fringe field nonlinearity (mainly coming from the final focus); the 4th order residuals from the sextupole pairs were the second most important. Actually two terms affect the result: the 4th order vertical nonlinearity limits the vertical dynamic aperture while the horizontal dynamic aperture was limited by the 4th order nonlinear coupling to the vertical degree of freedom. Adding the quadrupole fringe field did not seriously reduce dynamic aperture sizes because they added a positive amplitude-dependent tuneshift to reduce the negative amplitude-dependent tuneshift from the sextupoles and thus moving the tune off the half-integer resonance. As for the kinematic term, its influence on the dynamic aperture was small.

The compensation of the quadrupole fringe terms was done by placing octupole correctors at either end of the quadrupole (local compensation) and finding their strengths so as to (approximately) compensate both vertical nonlinearity and nonlinear coupling terms. Depending on the position in the lattice, a single compensation octupole or an octupole combined with the quadrupole over the entire length could do the job (needed K3 ~ K1**2). Computation of vertical amplitude-dependent tuneshift and nonlinear coupling amplitude-dependent tuneshift provided a fast and accurate indication of the compensation. The compensation proceeded for each of the strongly contributing quadrupoles; the resulting widening of dynamic aperture is: >10-fold in y, >3-fold in x. Actually, at this stage it was important to demonstrate the principle and capability of the technique.

For compensating the residuals from a sextupole pair, the trick is to add two more weak sextupoles with the same sense as in the above procedure and to find optimal strengths using the same indication as for the quadrupole fringes. This work for the LER IR lattice is now in progress.

The next steps are the joint optimization of the on-momentum and off-momentum dynamic aperture, i.e. widening the momentum acceptance, the global optimization of the entire machine lattice and compensating all known errors for a lattice. Except for the last item, this path has been taken for the Frascati-SLAC design for SuperB lattice.

The Committee recommends further use of the compensation techniques to optimize the SuperKEKB lattice and suggests development of pre-computed recipes for experimental optimization of the dynamic aperture and momentum acceptance.

10) Fringe Field of Solenoid

The large Piwinski angle adopted in the Nano-Beam option of the SuperKEKB collider leads to an unusually large tilt of both beam orbits by ±41.5 mrad with respect to the Belle solenoid axis. In combination with a very small vertical emittance, this necessitates an extension of conventional accelerator physics approaches to reveal the effects that were believed to be negligible in previous machines, e.g. more accurate orbit position evaluation, nonlinear transverse dynamics and quantum excitation in the solenoid fringe field.

With a trapezoid model of the solenoid fringe field, the 4^{th}-order nonlinear canonical transformation of the transverse dynamical variables has been derived to the 1^{st} order in the solenoid field strength, and implemented in SAD. Estimation of its effect on the dynamical aperture is now in progress.

Next, the quantum excitation of the vertical emittance has been evaluated in the solenoid fringe field by the relevant modifications to the SAD code. The new contribution turned out to be so important that the rotation of the IR with respect to the Belle solenoid axis has been re-optimized, resulting in the presently adopted ±41.5 mrad beam entrance angles. As a by-product of this activity, a corrected calculation by SAD of the beam orbit accounting for the radiation effects resulted in a revision of the wiggler section lattice. Remarkably, the new features when applied to the present KEKB optics appeared to be unimportant, but they are critical for the SuperKEKB parameters!

The Committee recommends further improvements/revisions of the particle dynamics calculation techniques critical for the Nano-Beam, e.g. as follows: 1) Find the acceptable amplitude of the vertical orbit bumps which are essential in the coupling/vertical dispersion correction. 2) Check if the vertical bends in the IR Local Lattice Correction are compatible with tolerable vertical emittance excitation. 3) Implement in SAD the direct quantum excitation of the vertical motion that may appear to be non-negligible in the lattice sections with very large beta-y, etc.

11) Lattice Design

The SuperKEKB design has shifted from a high current scheme to a Nano-Beam scheme. This is a good shift in the sense that the design burden is now more evenly shared among all design considerations, and the design as a whole becomes more optimized in terms of technical challenges. In particular, the Committee wishes to support the design strategy to save crab waist as a further upgrade possibility and not as an essential part of the design that is required already on Day 1. It also welcomes the fact that with a Nano-Beam scheme, the requirement of operating extremely close to a ½ integer tune is much more relaxed. The Committee considers Nano-Beam to be a more robust scheme than the high current option.

An impressive amount of work on lattice design addressing the Nano-Beam scheme was done in the short time since the last review. The SuperKEKB team has demonstrated a solid ability to deal with a demanding list of difficult lattice design issues.

For the Nano-Beam scheme, a significant part of the burden of proof is shifted to the efforts for lattice design and dynamic aperture. Knowing the long list of difficult issues facing the lattice design ahead, it is suggested that every effort be made to make the lattice design requirements as simple as possible.

Although much progress has been made in a short time, the lattice issues remain extremely demanding for the Nano-Beam scheme. For example, more work will be needed on the following issues:

- Further optimization of chromaticity correction, optimization of the local chromatic sections, and ways to control chromatic coupling effects.
- What is the optimal choice of magnet apertures? Can they be smaller for the nanobeams? This is a major cost issue.
- Tolerances on field errors and alignments particular to the small x-y coupling.
- IR optics (small beta*, large beta_max, correction scheme, solenoid orientation angle, tapered solenoids).
- Crab waist implementation (although not necessarily on day 1; the option must be kept in lattice design).
- Momentum aperture (optimize for Touschek lifetime).
- Dynamic aperture (required for injection).
- Energy variation (how do solenoids and permanent magnets vary when beam energy is varied?).
- Polarized beams? (Make sure this is NOT needed. Otherwise, this will drive the design in a strong way, so it has to be determined early – cannot retrofit.)

Collision feedback system for vibration effects has to be integrated into lattice design.

The workload is extremely heavy. Much more work on lattice design will be needed.

In passing, the Committee wishes to comment again on the very small vertical emittance that is the key to the Nano-Beam scheme. When the vertical emittance is small, some effects that are usually negligible will require renewed attention. A few examples come to mind:

- Radiation at solenoids and wigglers and other fringe fields (thanks to Oide's work).
- Vertical beam orbit alignment and jitter, and collision feedback system.
- Quantum noise due to opening angle of synchrotron radiation (a small effect if it contributes < 1 micron to vertical beam size in the arcs, but this should be checked).
- Banana beam tilt in y-z plane (steady state distortion) due to lattice optics and/or transverse wake fields.

There could be more effects to be added to this list. The Committee encourages the SuperKEKB team to stay alert to other such effects.

12) <u>IR Overview</u>

A schematic overview of the design for the interaction region (IR) was shown including the detector, vacuum chambers, superconducting magnets, permanent magnets, and supports. The design is converging but there are many topics to refine. The designs of the superconducting quadrupoles (5) and permanent magnet quadrupoles (3) are maturing, but further evaluation is ongoing. A prototype of the permanent magnets is proceeding.

Leakage fields from the superconducting quadrupole into the aperture of the opposing beam chamber needs additional study, as the fields are not pure multi-poles and they change with position along the beam line. Compensation with normal windings on the opposite vacuum chamber will not be an easy task.

The chromaticity correction of the IR quadrupoles is a crucial need for the overall dynamic aperture of both rings. Work at the KEK and BINP laboratories is going on to find the optimal correction. This work should be supported and carried out in a timely manner.

The accelerator design would gain significantly from the rotation of the Belle detector about a vertical axis of a few tens of mrad. The difficulty for the detector collaboration to carry out this rotation should be investigated.

As was recently addressed by original research in the KEKB accelerator group, the anti-solenoids to compensate the detector solenoid need to have a soft field transition along the beam path to minimize vertical emittance growth of the beams due to non-linear terms in the transport matrix. Thus, the overall solenoid compensation scheme needs to be revisited.

The number and location of the diagnostics in the IR need further work to determine the best location and needed capabilities.

The overall design needs a completed specification of the beam aperture for magnets and beam duct design. The required studies should include the closed orbit distortions, the beam-stay-clear required for adequate lifetime, the injected beam clearances, and lost particle issues for detector backgrounds.

Keeping the small beams in collision will be difficult especially in the vertical plane. Algorithms and the hardware to provide feedback need to be designed and analyzed.

Finally, the beams are very sensitive to the vibration of the IR quadrupoles, as the beta functions there are by far the largest in the rings. Recent measurements of the existing vibrations of the components and tunnel in their region were done and clearly showed the need to mitigate this effect. A scheme of passive and active damping of quadrupole vibrations in the IR should be pursued.

13) <u>IR Magnets</u>

The IR magnets consist of 5 superconducting main quads, 3 permanent magnet quads, 2 superconducting compensation solenoids and 32 superconducting correction coils. The superconducting strands and cables are under development for various prototypes. The superconducting compensation solenoids cancel the Belle solenoid fields. Since there is no iron core in the superconducting quadrupoles, superconducting correctors placed around the adjacent vacuum chamber compensate the leakage fields from the quadrupoles. However, these correction coils also produce a field at the center of the quadrupoles. The impact of these fields should be evaluated carefully. The permanent magnet quads are made of SmCo and, because they do not need cryostats, allow the BPM's and vacuum pumps to be as close as possible to the interaction region. The permanent magnets require constant temperature to maintain proper field uniformity. The group will carry out the required R&D and build prototypes this year to keep the project on schedule. The Committee encourages beam simulations with the measured fields.

14) <u>IR Vacuum Chamber and Assembly</u>

The new interaction region layout of the Nano-Beam scheme was presented. Starting from the boundary conditions imposed by the detector and by the magnetic insertion elements, the vacuum system has to be entirely redesigned. The insertion magnets will have a warm bore vacuum chamber attached by bellows to the cryostats. Proposed positions for beam position monitors, vacuum bellows and pumps were shown on the schematic layout. The nearest pumps can be placed at a distance of approx. 2.5 m from the IP. The operating pressure with this configuration has been estimated to be in the range of 10^{-4} to 10^{-5} Pa. In a dedicated test with the Belle Detector, an artificial pressure increase of this order of magnitude did not result in an increased background rate. Nevertheless, this must be considered to be an exceptionally high pressure for an interaction region.

The central part of the IP chamber can be shielded from direct synchrotron radiation from the last bend. An updated estimate of the power levels shows that the adjacent beam pipes in the cryostats receive around 0.5 kW each and hence need to be water-cooled. It is proposed to integrate the cooling ducts in the thin wall of the pipes in order to minimize the loss of space. The central cylindrical Be-beam pipe of the interaction point is attached to the gradually opening branching pipes, where the LER and HER beams merge together or separate. An important cross section variation is seen by the beams, creating a local impedance, which has been evaluated in a later presentation (see impedance estimation). A reliable estimate of the HOM power dissipated in the central beam pipe has not been presented, but it could well exceed the contributions from synchrotron radiation.

A very common problem with the design of IP vacuum systems is the 'fight' for space. The space for machine components and for vacuum pumps inside the detector is extremely tight. As a consequence, assembly and the required precise positioning of beam position monitors are extremely difficult. The Committee encourages the KEKB team to continue the design work and to search for innovative solutions, leading to an optimization that can only be the result of an iterative design approach between all systems. A specific concern is the high pressure in the interaction point due to the lack of pumps. Again, this is not a unique problem for KEKB. It should be recalled that solutions exist for integrated ion pumps operating in the field of a solenoid, e.g. getter pumps integrated in the beam pipe and cryo-pumps.

With respect to heating of the vacuum chambers, the Committee expresses doubts concerning the proposed water-cooling scheme that may result in either impractical or unreliable flow conditions. A change of the proposed scheme may have implications for the cryostats and hence nontrivial design implications. The Committee also recommends studying the solutions for this problem utilized by other laboratories, such as Cornell and SLAC.

15) <u>Machine-Detector Interface</u>

There has been considerable effort spent studying the effects of synchrotron radiation and particle backgrounds in the detector. This is a very important first step. Direct illumination of the central beam pipe is not a problem although future work needs to include scattered radiation and the means for reducing this effect if it proves to be problematic.

Extrapolation of the backgrounds from an increase of the IR beamline pressure by a factor of 100 to 1000 is quite difficult. The present studies have shown that masking will be very important and detailed simulations of the masking will need to follow the evolution of the IR optics design. Machine studies measurements of backgrounds in the detector with IR pressure bumps will be a very important calibration for the background and masking simulations.

Space within the machine-detector interface has been shown to be at a premium. To allow for as independent accelerator- and detector-hardware development as possible, care should be taken to clearly define the physical volumes within this space, which are the domain for a) the accelerators only, b) the detector only and c) where hardware for both will co-exist. In addition to determining beam pipe cooling requirements and the implementation and the routing of cooling lines, some thought should be given as to whether temperature regulation will be needed for the beam pipe cooling. This may be particularly important for the beam pipe through the permanent magnet quadrupoles and stabilization of BPM positions.

The Committee suggests that, if it is not in place at this time, a joint machine-detector interface design team be established as soon as possible. At other laboratories, this approach has been critical during the design, installation, commissioning and early operational phases of similar projects. We suggest that this group should have a representative from both the accelerator and detector sides, who are at a high level administratively to influence the design efforts and resources from both sides. From the accelerator the Committee would suggest that this team include members who have the following specializations: IR optics design, vacuum, operations, radiation-monitoring and controls/accelerator instrumentation. From the detector we would suggest team members be included who can represent the following areas: background simulations of synchrotron radiation and particles, the vertex detector, the central tracking chamber, other major detector systems as needed, and the DAQ system. The charge of this group is to forge a common vision, design and plan for the machine and the detector interaction, which optimizes the overall interaction between the accelerator and detector and to oversee the installation and initial phase of operations. Some of the specific tasks of this team are to address remaining questions such as the background levels for the detector, potential radiation damage of machine and detector hardware, the machine-detector angle, vacuum and beam-pipe properties (including accelerator & detector installation), cooling, access to and redundancy of components, radiation masking and monitoring, diagnostics for operations, the ability of the detector systems to handle the higher trigger and background rates. The team should also look carefully at solutions to these problems that have been employed at other laboratories. Ideally it is best if the solutions that are found are ones that all sides can "live with."

Particular concern in the talks has been raised because the anticipated higher beam pipe vacuum pressures due to the synchrotron radiation deposited, poor vacuum chamber pumping, as well as much poorer beam lifetime from losses due to beam-beam and Touschek scattering. While it is the case for many detectors that a higher pressure in the center of the detector may result in scattered beam particles impacting the vacuum chamber walls outside of the detector (reducing the detector background), this will need to be analyzed carefully for any IR optics design and choice of masking. This is a very critical issue for the overall accelerator and detector designs!

The effects of the electron-clouds within the detector should be analyzed, paying attention to the sources of the electrons, their transport and impact sites. If the anticipated densities along the beamline are significant, consideration should be given to the scattering of electrons and positrons from the electron cloud and its potential for altering the dynamic aperture from non-linear modifications of the focusing-functions in regions of large beta.

It may be possible to benefit from the higher deposited synchrotron radiation in the interaction region. It has been observed that high synchrotron radiation dose levels and the right vacuum chamber surface material (one example, aluminum) after sufficient time to beam process the vacuum and lower the secondary emission yield of the surface, will result in a synchrotron radiation stripe that will act as a getter. This is often referred to as "wall pumping." As an example, at high currents and in the arcs of CESR, this represented a significant increase in vacuum chamber pumping (~50 l/s/m) and resulted in lower beamline pressures. This effect should be estimated for the IR designs. A plan for vacuum chamber conditioning during the beam current ramp up during commissioning should be formulated and include the effects of radiation deposition in, and the long term damage to, the detector (esp. the SVD) and nearby accelerator components. It might be particularly useful if the initial round of commissioning and beam processing could take place with the detector electronics powered down.

The Committee concludes the importance of a coordinated machine-detector effort must not be underestimated. The correct understanding and modeling of detector backgrounds in the presence of new accelerator and detector components is paramount to being able to achieve the goals of SuperKEKB.

16) Vibration Measurement

For the Nano-Beam design, requirements to the LER/HER orbits' offset at the IP are unusually severe, especially in the vertical direction where an offset of about 10% of sigma-y = 56 nm may degrade the high-luminosity performance and whereas a sigma-y/2 offset is unacceptable. Hence special care must be taken for the minimization of lattice magnet vibrations and for an active, fast compensation of the collision offset with the orbit feedback.

In order to update and improve the characterization of the tunnel vibrations for KEKB machine components that are to be inherited by SuperKEKB, a new series of vibration measurements at KEKB have been performed mainly in the summer of 2009. The measurements were undertaken with the superconducting quadrupoles of the final focus, Belle solenoid and ring magnets turned off. Magnets, their supports and the tunnel floor were tested with acceleration sensors at many locations around the ring, with particular attention to the IR region, at different times during the day. The vibration amplitudes and power spectra were recorded and analyzed in comparison with the 2003 data.

The conclusion is that at the IP the KEKB tunnel vibrates at 0.3 Hz horizontally and at 3 Hz vertically. In addition, the magnets and QCS support system vibrate at 8 Hz. The measured spectra roll off considerably in the frequency range 10–100 Hz. The correlation between vibrations of different positions is reported to be negligible.

The vibration amplitudes of the IR magnets are much smaller than the size of the colliding beams in the KEKB, that is ~2 μm vertically and ~100 μm horizontally, but comparable with SuperKEKB, where sigma-y = 56 nm. The tunnel floor vertical vibration is ~70 nm for frequencies >1 Hz; other components have even larger amplitudes. The contribution to the vibration amplitudes from the He flow is to be measured when the machine is running in May.

Since beta-y > 2.5 km in the final focus quadrupoles, their uncorrelated vibration amplitudes are converted roughly 1:1 into the vertical collision offset, while the contributions from other magnets' vibrations are less important. So a special study of the IP orbit response to each magnet vibration is in order for the more accurate assessment of the total collision offset caused by magnet vibrations.

In such a situation countermeasures are indispensable, e.g. in two possible areas: 1) Special attention must be given to the mechanical design of the QC1 – QC2 support systems, where the frequencies of the principal mechanical resonances should be tuned above 10–30 Hz and all possibilities to damp the mechanical response should be employed. 2) A fast IP-orbit feedback system must be designed.

The Committee recommends the scheduling of an R&D study and the construction of a prototype for the fast IP-orbit feedback system so it may be tested with beam as soon as possible.

17) Injector Upgrade Overview & Positron Source

The Injector Group plans to provide 4 GeV, 8 nC/bunch (= 4 nC x 2) positron beams to the LER, by introducing an L-band capture section with either a flux concentrator or a superconducting solenoid, followed by a 1 GeV Damping Ring. In the flux concentrator scheme, the L-band sections would be displaced in a parallel beam line to allow the electrons to bypass the concentrator. With the superconducting solenoid, the electron path does not need the long target bypass but instead transits the solenoid. The focusing effect of the solenoid on the electron beam should be evaluated. The flux concentrator scheme is under development with collaboration with BINP, but there seem to be more advantages to the superconducting solenoids. The final choice should be decided by comparison of prototype test results of both schemes.

In order to achieve positron energy of 4 GeV, a second C-band section is required after the damping ring. For the L-band capture, the group has developed 40 MW klystrons and accelerating sections of 10 MV/m. The damping ring is an essential part of producing low-emittance positron beams. On the other hand, a photocathode RF gun is being developed for intense low-emittance electron beams. The Committee strongly encourages the necessary R&D activities to support the damping ring construction.

18) RF Gun

The argument for an RF gun for the production of low emittance electron bunches as the most cost-effective solution was certainly clear. The interest in having a cathode surface with the longest possible lifetime seems to point to copper as the cathode material. However, the committee thinks that it is very optimistic to expect the cathode to survive more than several weeks with the emission of 1 nC bunch charges even assuming the presence of 10^{-9} to 10^{-8} Pa vacuum levels. So the gun structure should be designed to allow for the easy, rapid changing of cathodes.

Increasing the quantum efficiency for a copper cathode will lower the incident laser power, reduce long-term damage to the cathode, and therefore raise the cathode lifetime. The idea for increasing the efficiency by reducing the wavelength of the laser to approximately 200 nm is reasonable for a test. The plan to produce the highest accelerating gradient from a ½ cell normal conducting S-band RF cavity also is a reasonable design to consider.

The committee sees this effort as important for the SuperKEKB project and for RF gun research for the accelerator community at large. It recommends careful assessment of the resources and effort require for this study: the design of the copper RF structure with sufficient pumping to maintain the necessary ultra-high vacuum, the selection of a laser (locked to the RF frequency), the design of the laser's optical systems, the design of the RF coupler, the selection of the needed RF source and power amplifier, and sufficient diagnostics to measure the cathode's performance both during initial testing and operations. The committee also suggests that the effort for this project not be underestimated, as experience from other laboratories has shown developing expertise in RF photo-cathodes requires significant time and resources.

19) Damping Ring

The design of the positron damping ring is innovative and fits nicely within the scale of the linac and the site constraints of KEK laboratory. Careful engineering details were shown including the lattice, magnet designs, vacuum duct design, and injection extraction. The circumference appears longer than other similar damping rings in the world owing to the reverse-dipole bending scheme of the lattice. The budget of the accelerator components of the damping ring is about 30 M$ which should be adequate for the task. The committee discussed whether the design could be simplified to reduce the size of the ring in order to reduce the cost of components and the overall size of the new tunnel and overhead support building.

The accelerator physics aspects of the damping ring were discussed and all the major topics were covered in detail. The outstanding issue the committee saw was reducing the harmonic multi-poles of the magnets, which was shown to reduce the dynamic aperture of the injected beam. Further work is needed on the dynamic aperture and magnet specifications of the damping ring.

The requirement to be able to inject up to 8 nC charge per bunch seems to the committee to perhaps be larger than needed. This charge will likely only be needed if many new systems work perfectly and there are many fills from scratch of SuperKEKB. In the top-up mode during collisions, the SuperKEKB rings will need and want far smaller bunch charges to keep the currents constant.

20) Beam Transport, Injection, Extraction from DR

Simulations show that the positron beam produced by an electron beam of 10 nC at the L-band capture section is more than 10 nC. However, the beam is so large that it requires an Energy Compression System for injection into the damping ring. Assuming 80% efficiency for injection to the damping ring with a momentum spread of <1.5%, an 8 nC positron beam would be produced in the damping ring. Because of radiation safety concerns, the group plans to start operation with 4 nC, 120 MeV beams. For extraction, a double kicker system is to guarantee that the two bunches are placed on the same trajectory. A bunch compression system is employed to obtain 0.5 mm long beams just after extraction from the damping ring. At the end of the linac, an ECS system is also required for the transfer line to the LER. The group plans to study detailed electron trajectories in this new arrangement. The Committee fully endorses the planned simulations and prototype R&D.

21) RF Overview

The performance specifications for the Nano-Beam version SuperKEKB, while less demanding of the RF system than the high-current version, are nonetheless significantly more demanding than those of the existing KEKB. In particular, beam power in the LER is increased by nearly a factor of three, due to the increase in beam energy and current, while circumferential voltage is increased by only 5%, leading to a substantial increase in beam loading. In the HER, beam energy is reduced by 12.5% while current is increased by 87% and the circumferential voltage is decreased by more than a factor of two. Beam loading in the HER becomes very severe. A straightforward extrapolation of the existing system would require unfeasibly large input coupling and cavity detuning frequencies larger than the revolution frequency. The last condition would result in unacceptably rapid growth of the -1 mode instability.

The RF team has been exceptionally creative, reconfiguring existing equipment with only modest additions to meet these stringent new requirements.

In the LER, removing two ARES cavities and adding 8 klystrons creates a system of 18 ARES cavities, each with its own 800 kW klystron. In this configuration, each station can comfortably supply the needed voltage and power with a readily achievable input coupler, while maintaining a sufficient reserve and instability growth times that are manageable with existing feedback and damping systems.

An even more challenging situation in the HER is very elegantly handled by invoking the concept of "reversed-phase operation", in which four of the ARES cavities are removed, all remaining ARES cavities are provided with individual klystrons and some of the superconducting cavities are switched to the opposite side of the crest of the RF wave. All remaining cavities can then be operated at higher gradients, with much reduced beam loading demands, including instability issues, detuning angles and input coupling. This implementation, which works because of the high beam loading, is preferred over a scheme using 14 ARES cavities without superconductivity, which would also work, partly because the existing SC cavities and cryogenic system can be used essentially unchanged, but mostly because use of SC technology reinforces KEK's world leadership in that technology. The non-SC solution is preserved as a back-up scheme.

The doubling of the beam current means that the phase transient driven by the abort gap of 500 ns would be twice as large as the presently accepted 3-5°. This will be straightforward to handle by reducing the abort gap to 200 ns and using faster abort kickers. KEK has been a leader in developing the fast (< 10 ns) kickers required by the proposed ILC damping rings.

While this plan meets operational requirements, reliable implementation will require the deployment of the advanced digital Low Level RF control circuitry being developed by KEK and its industrial partners, in parallel with most other accelerator laboratories around the world. Hardware design is nearly done and the first system will be installed and tested later this year. The only proposal that is of some concern to the committee is the suggestion that some of the RF systems would continue to be operated with the old analog LLRF control. The reliability and simplicity of operation achieved by a having a common system seem worth the additional 10 Oku-yen.

The design of the RF system for the damping system is also underway. The basic ARES cavity design will be used, but stripped of its storage and coupling cavities, which are not needed because the stored current is so much less than that of either of the Main Rings.

The committee wishes to compliment the RF team for the very innovative and efficient way in which they have met all the RF requirements of SuperKEKB!

22) ARES Cavity

The reconfiguration of the RF system for the ARES cavities to one klystron per cavity has already been described. With the exception of increased HOM power, the operating characteristics of the cavities in the LER are essentially unchanged, and continued successful operation is a reasonable expectation.

Multipacting in the coaxial section of the input coupler has been observed in about 10% of the ARES cavities in use in KEKB. To eliminate this concern for the higher power operation of the couplers for SuperKEKB, fine circumferential grooving has been applied to the inside of the outer conductor, and successfully tested and used in actual KEKB operation. In addition, the increased input coupling factor required for SuperKEKB has been demonstrated in low power tests. High power tests are scheduled for April, and installation of the new coupler on an operational ARES cavity for May

The HOM waveguide loads will still have a 50% margin to their design limits. The Grooved Beam Pipe (GBP) loads will have a 30% margin with respect to their measured performance limit at 1200 W. Nonetheless, the higher power GPB loads being designed for the Damping Ring accelerating structure can be used here, if needed.

23) <u>Superconducting Cavity</u>

The feasibility of "reversed-phase operation" of the superconducting HER cavities is critical to the RF system plan for Super KEKB. Only by using this technique can the new RF demands be supported by existing hardware without major changes. By analysis and careful test, the KEKB RF group have examined the issues and determined that none of them will prevent implementation of this concept; synchrotron tune, beam loading response, controllability, bunch length and transient trip response are all either unchanged, or if changed are acceptable and controllable. Tests included support of a luminosity run at 1200 mA delivering 300 kW/cavity to the beam. The only unusual event was a rise in cavity voltage on a reversed-phase cavity during a beam energy change. A thorough investigation demonstrated that this was to be expected, and that the range of possible excursions at the nominal operating point is well within the tolerable operating range of the superconducting cavities.

HOM dampers will have to be improved to deal with beam currents in excess of 2 A, but this should be achievable with straightforward extensions of the existing design. Design concept tests were successful and prototypes are being constructed for further proof.

Although the existing input couplers will meet the RF power requirements of SuperKEKB, further development of couplers for higher power is ongoing.

24) <u>RF Accelerating Structure for DR</u>

The ARES accelerating cavity, relieved of its coupling and storage cavities for use in the damping ring, needs to be dimensionally adjusted to correct for the frequency changes caused by those removals. Changes in cavity diameter must be accompanied by rotation of the input coupling loop to achieve the correct coupling factor at the right frequency. This design and analysis task has been completed, and the geometry is settled.

HOM power will be handled by replacing the SiC tile-loaded GPB with directly cooled SiC bullets in a winged chamber capable of handling 5 kW. Analysis has identified the optimal position and angle for the bullets, subject to the mechanical constraints imposed by beam pipes and flanges. The fact that the cavity is provided with a single slug tuner creates a slight asymmetry in the fundamental electromagnetic accelerating mode and some leakage of fundamental power into the HOM load. The effect has been thoroughly investigated and the maximum effect is less than 2% of the load thermal rating. High power tests are planned to take place soon.

Investigations of higher order modes of the complex RF structure have been carried out, and the most troublesome mode, at 11.75 GHz, has a comfortably long growth time of 30 ms.

25) <u>Vacuum</u>

With the Nano-Beam scheme as the new base line for the SuperKEKB, several important design parameters have changed for the vacuum system. In the LER the lower beam current of 3.6 A and the increased arc bending radius of 71 m give a reduced power load to the vacuum chambers. In the HER the lower beam energy of 7 GeV combined with the reduced beam current of 2.6 A result in a considerable reduction of the synchrotron radiation load on the vacuum chambers. The longer bunch length also lowers the HOM power. Compared with the present machine the new parameter set is still very severe but, nevertheless, opens up several new design options. Therefore, copper beam pipes, as they were shown to the last MAC, are no longer the only choice but, depending on the location in the machine, aluminum and other materials could be used. This widens the choices for design, manufacturing and procurement of the vacuum components.

It is proposed to install newly designed beam pipes and other main vacuum components for the LER and for the HER arcs. Some of the existing equipment like ion pumps will be reused. It is proposed to replace the NEG pumps since they have a limited capacity. A new design for the pumping ports, bellows and other components will reduce the global impedance of the rings. A strong reduction of the global impedance budget results from the use of beam ducts with an antechamber. This design would in principle no longer be required with the reduced synchrotron radiation load but it provides a low impedance. It is proposed to maintain the vacuum chamber aperture from the high current design (94 mm) so that chambers fit into existing and reused magnets. A decision on this point is still open.

The electron cloud will remain an important consideration in the new design. Therefore, all the measures previously studied and proposed for the high-current version like antechamber, surface coatings, solenoids, clearing electrodes, and a grooved surface will be used for the design of the new vacuum system. The threshold for single bunch instability defines an electron density of $1x10^{11}$ m^{-3}, which has been taken as the design value for the LER. The estimated electron densities in the arcs exceed the threshold for instability by about a factor of 50. The main contribution (~93%) comes from drift spaces and steering magnets. It is proposed to use all of the various established measures to come below the threshold. The most promising solution consists of a combination of solenoids in the drift spaces, grooved surfaces in bending and wiggler magnets, and possibly TiN coating for the copper chambers. For an aluminum chamber, a surface TiN coating remains indispensable. The best results have been obtained with specially designed clearing electrodes. Unfortunately, this solution is very delicate and expensive. Longitudinal grooves are by comparison much easier to produce specially with an extruded aluminum pipe. This solution will be evaluated with a test chamber during the next run.

Among the outstanding issues are the design of special components and a decision on the cross section. Is proposed that the beam ducts for the HER will use the same components as the LER. The schedule shown to the committee includes a total of about 2000 beam ducts between 2 and 6 m long that have to be manufactured and installed. This will require well-established procedures for manufacturing, baking, vacuum testing, solenoid winding and installation.

The committee is impressed by the considerable progress that has been made since the last MAC and specifically, since the change to the new base line. It must be recognized that for the vacuum system it has essentially been a new starting point in the design that requires a fundamental reorientation. For this reason some of the choices presented to MAC my not withstand a critical scrutiny. Among the most obvious items is the traditionally very tight interrelation between magnet and vacuum systems. The committee recommends a combined effort between magnet and vacuum groups to arrive at a common design.

A decision on the aperture and vacuum chamber cross section is urgently needed.

The choice of the vacuum chamber material is important since it has wide-ranging consequences from material properties to procurement and manufacturing. With limited resources, it may be preferable to adopt one common solution for both rings. The committee believes that the basic design concepts have all been validated and are ready to be chosen. The means to mitigate the electron cloud are a specific example.

The new design and layout of the insertion is in a first stage of iteration. To advance the design, the committee recommends a combined effort between machine and detector specialists.

26) Magnets

The presentation of the main ring magnet system was very well organized; its overall description of the current scope of work seemed quite complete. In the latest optics design for the LER and HER, a very large number of new magnets will be required: the lengths of the dipole magnets for both rings become nearly the same length, and more wiggler magnets with shorter poles, more bend magnets, quadrupoles, sextupoles and steering correctors are needed for the approximately 30% more HER cells. A larger capacity water cooling system is required for the added heat load and almost all of the magnets will need to be removed, refurbished, tested, have magnetic field measurements performed, their support base-plates replaced, the magnets and stands replaced, be surveyed, connected to power supplies and tested. While some of the power supplies may be reused, specifications for many have changed; some will certainly need to be replaced or upgraded, new power supplies (and building space) are needed for the additional magnets in the optics, and the cable plant will at least need servicing and likely replacement or upgrade. With the construction of new magnets out of different runs of steel and using different dies, the magnetic characteristics will be different, requiring the different magnet families be placed in common magnet power supply strings – likely adding to the number of magnets to be constructed.

Removal and reinstallation schedules will be constrained by the vacuum system work, the requirement to not disturb certain accelerator components and systems (e.g. the RF cavities) and the need to stage the disassembly and reassembly to make use of the accelerator tunnel as a storage site for magnets, while not being refurbished, tested or measured. Having proper tools and fixtures for moving magnets and surveying them may also impact the schedule positively. For example, perhaps special lifting fixtures, which can straddle one beam line to pluck a magnet from the other beam line, or a transport fixture, which does not require significant repairs to the floor for operation, might be useful in reducing delays to the schedule.

Improvements to survey and alignment were described and the committee feels these will be very important for the placement of accelerator elements. While the simulation of placement errors for optical elements in the final lattice layout needs to be completed, experience in other laboratories underscores the importance of accurate alignment and mechanical stability of magnets in order to approach single-beam emittance coupling values of 0.3-0.4%. The study of vibrational modes in the magnets and their supports and their relative motion with respect to the floor, the ground and the other ring's components is critical for the understanding and operation of position and collision alignment feedback loops. For these endeavors the magnet group and feedback group need to be in close communication.

The committee recognizes the large effort required by the magnet group in the current design of the lattice. The Committee's first recommendation is that a closer connection between the lattice design group and the magnet group be established to allow magnet hardware considerations to be taken into account in the optics design. For example, any effort made to standardize magnets and reduce the number of different types will have a significant impact on the magnet system workload. A few possible ideas to explore are: 1) The present design has the LER and HER dipoles almost the same length; could they be the same? 2) Is it possible to reuse a combination of the present HER and LER dipoles alternately in either the HER or LER cells by allowing the cell symmetry to be broken? While it is unavoidable to build new magnets for SuperKEKB, the benefits of reducing this effort need to be a consideration in the optics design.

As the effort for recreating the magnet layout for SuperKEKB is massive, the committee also recommends that adequate resources (personnel, financial and space) be provided to accomplish the task. If this is not done effectively, the magnet workload could become the critical path for the project's schedule.

27) Beam Diagnostics

A comprehensive survey of diagnostic needs for the SuperKEKB has been initiated. The Committee commends this effort.

A button electrode has been designed for the SuperKEKB BPMs with a small diameter of 6 mm. The prototype is being tested at KEKB. The signal-to-noise ratio of the superheterodyne detector has increased from 61 to 88 db after several recent improvements.

The BPM accuracy requirements are presently simply copied from those of the KEKB. All system designs follow from this assumption. It is strongly recommended that the diagnostics requirements specific to SuperKEKB be defined as soon as possible. These requirements cannot be fully specified until the lattice is fixed. However, as the lattice firms up, they should be provided to the diagnostic team in a timely manner so that the subsequent design work on diagnostics systems can proceed without delay. Iterations for the design requirements are then expected as the lattice design progresses in time.

The fast ion instability growth rate is estimated to be 0.3 ms for the HER. The electron cloud instability growth rate is estimated to be 0.5 ms for the LER. The growth rates of various longitudinal instabilities are generally found to be slow, although the LER is still envisioned to require a longitudinal feedback system. These growth rates form the present basis for the design of the transverse and longitudinal feedback systems. However, more work is needed to sharpen up on the predictions of these instability growth rates, and as that happens, the feedback systems design should evolve.

Vertical beam size measurement using an interferometer is at the limit of the interferometer resolution. Reflection mirrors, although much more relaxed than in the high current scheme, will require some serious design work. A prototype will be tested on KEKB. A straight-radiation X-ray monitor for vertical beam size measurement is considered with resolution ~5-10 micron.

An interesting idea of a beamsstrahlung monitor is being considered. It is estimated that there should be a large number of beamsstrahlung photons that can be used to measure beam collision sizes.

It is planned to monitor the multi-bunch operation by providing a pilot bunch at the end of a bunch train. The Committee suggests considering the possibility of double pilot bunches, one ahead and one behind a bunch train, because the difference between these two pilot bunches can give information on effects such as ions, cloud electrons, and wake fields.

Collision optimization is assured by a feedback system around the IP. It is suggested that a more careful evaluation of the Nano-Beam configuration be performed for this feedback operation—in particular, whether this system will only feed back on the vertical beam offsets or it is also capable of feeding back on the horizontal offsets, and in either case, what are the (possibly complicated) beam responses as functions of beam offsets.

It is suggested that a means be provided to monitor BPM vibrational motion relative to its nearby quadrupole center.

28) <u>Impedance Estimation</u>

For a number of SuperKEKB LER vacuum duct components, evaluation of loss factors and longitudinal impedances has been carried out using the GdfidL code. For a bunch length of 3–10 mm a reasonable longitudinal wake length of 0.1 m (for the loss factor) and 5 m (for the longitudinal impedance) was computed.

In the comb-type bellows (1000 units) the loss factor is computed as a function of the bunch length, in the above-mentioned range, showing 2.2 V/pC at 6 mm, while all of the curve lies below the present KEKB level. However, a couple of trapped modes were discovered with the frequencies above cut-off. The synchrotron radiation masks on the outer sidewall of the antechamber gives a negligible contribution; the same is true for the perforated screen covering the NEG side of the antechamber and for the flange connections.

The following reported loss factors are so far evaluated at the 6 mm bunch length only. 16 movable masks with taper sections on both ends give 3.7 V/pC, being the largest vacuum component. From the 2.2 km round resistive pipe we have 1.7 V/pC for Cu or 2.3 V/pC for Al. BPMs and the bunch-by-bunch FB BPM have been designed especially for the high-current SuperKEKB option and thus their contribution to the loss-factor budget is small, as is the contribution from the crotch IP chamber, both with 20 mm and 30 mm diameter joints. However, a vertical beam displacement in the IP duct excites many trapped TE modes; their impact on stability of the 2503-bunch beam is planned for further study. All those components so far evaluated (together with the ARES cavities) contribute ~18 V/pC to the loss-factor budget, which results in ~900 kW HOM power loss at 3.6 A current in the LER with the Al duct, and somewhat less (~880 kW) with the Cu chamber.

The next items planned include estimation of other components such as injection section and interaction region, using the obtained impedances for evaluating beam instability increments (specifically, from bellows and movable masks), and calculation of loss factors and longitudinal impedances of the HER components.

The Committee recommends speeding up the evaluation of the loss-factor/impedance contributions which are as yet unknown in order to provide reliable specs for the LER RF design which has to have sufficient allowance for the HOM power loss.

Smallness of the vertical emittance strengthens the limits on the coherent vertical instabilities of any kind; therefore the Committee puts the emphasis on timely evaluation of all important transverse impedances with the priority on the novel components, e.g. clearing electrodes or grooved walls envisaged for reduction of SEY, where the preliminary results indicate a serious enhancement of the kick factor caused by the misalignment of the groove direction. The wake-fields should be incorporated into the tracking simulations for the ring to evaluate the impact of the wakes on the transverse (esp. vertical) distribution.

29) Beam Abort System

The concept of the beam abort system for SuperKEKB is described. The beam abort system must have a fast rise time to cope with the abort gap of <200 ns which has been required by the design. A list of the design parameters of the abort system was shown. The proposed system consists of a fast, pulsed kicker with a water-cooled ceramic vacuum chamber. The extracted beam traverses first a thin Ti window, followed by a Lambertson magnet. The extracted beam passes through air and is absorbed in the dump block. In order to reduce the power density on the titanium window, it has been proposed to orient the window at 45° with respect to the beam. As a further step to cope with the high beam density in the SuperKEKB, it is proposed to add a pulsed quadrupole in front of the window that defocuses the beam as it sweeps across the extraction window. The power supply for the kicker magnet has the requested 120 ns rise time. The Committee was shown results from a test with a 1 mm Titanium window exposed to the KEKB beam. The preliminary results confirm that the window can withstand the SuperKEKB beam currents, but without a satisfactory safety margin.

The Committee encourages the KEKB team to continue with the detailed design and to improve the safety margin. The window thickness as well as choice of material, e.g. a stronger titanium alloy or beryllium, could be optimized. It may also be possible to add another pulsed magnet, which has a ramped deflecting field during extraction, and to move the window downstream of a defocusing quadrupole to further "fan out" the bunches. The Committee also suggests looking into the coated ceramics used in CESR and LEP. The Cornell coated ceramic chamber was capable of passing a 40 nsec rise-time deflecting magnetic field. Perhaps an adaptation of this design would be applicable.

30) Control

The control system for SuperKEKB is envisioned to be EPICS based, as it is in KEKB. The KEKB control system is currently being upgraded to a more recent EPICS version. This involves upgrades of the IOC, which allows EPICS to be embedded in various devices, as well as upgrades in OPI host computers and the network switches. The old CAMAC field buses are mostly to be progressively replaced. Ethernet-connectable modules will replace the magnet power supply interface. For SuperKEKB, the application programs will also be updated, with the interface with the applications provided by linking a person from the hardware group with someone from the control group. It is envisioned to provide additional manpower by collaborations with commercial companies and foreign laboratories.

Continuing along the path of the present KEKB upgrade route is a reasonable and necessary approach in preparation for the SuperKEKB. To speed up the process, it is suggested that inputs from various hardware groups be sought anticipating the operation of the SuperKEKB and that these inputs be integrated into specifications for the control system in a timely manner.

Some "software" support will likely be needed during the creation of EPICS control panels for the hardware groups, which have major component changes. This may be necessary since those groups will be undertaking a large number of tasks in the design, production, testing, and installation of new hardware, and at the same time have a large number of related control panel changes. When looking across working groups, it will be the ones with the greatest workload who will also have the greater number of software modifications. So in an effort to bring the workload into more of a balance, these groups with the greater amount of work should be provided with software support from the control group or elsewhere.

31) Facility and Infrastructure

The presentation for the scope of work for the facilities and infrastructure was well organized and relatively complete. Although it does need to be updated to reflect the present design for the accelerator, the conclusions will not likely be fundamentally different from those presented: Additional space will need to be located temporarily for storage of components removed from the accelerator, for modification, construction and testing of components and permanently for additional infrastructure such as new magnet power supplies, added cooling and electrical capacity.

The committee agrees with the general conclusions for the requirements for temporary and permanent space for facilities and for the increase or upgrade of the cooling and electrical infrastructure. The effort in this capacity needs to be linked to the various groups that it supports (e.g. vacuum, magnet and power supply) before estimates can be finalized for the needed support facilities and services. The lack of a clear up-to-date plan can complicate or delay the implementation of the overall project schedule.

32) Schedule / Budget / Human Resources

The overall R&D and construction schedules for SuperKEKB were shown, and the details discussed. The plan is for a 3.5 year construction time starting mid-year in JFY2010. The overall schedule looks well thought out and complete. It appears to have a good chance of being able to be carried out if the funding is provided as proposed. There is some uncertainty, however, because the funding profile for each year is not really known.

The overall budget as shown at first look seems to be adequate although tight with little margin to complete the project. However, as the accelerator tasks are better defined, the budget details need to be worked out in more depth. Contingency planning for unforeseen events should be built into the budget or if the funding versus year is not as requested.

The tightest part of the schedule is the removal and reinstallation of the tunnel components including the magnets, supports, and vacuum beam ducts. The planning for the schedule for these activities should be taken to the next level of sophistication to resolve potential conflicts with resources. Interferences with other laboratory resource needs should be determined and taken into account.

If the SuperKEKB funding arrives as planned, the number of people available to design and plan the project is too small. A staff of about 82 people is needed for SuperKEKB at the peak of construction. With the present staffing it is anticipated that there will be about 48 people available at the time. Thus, 34 new people need to be redirected or hired to construct the project on time. Where these people will be found is a subject of ongoing discussions. A laboratory wide strategy for staffing would help with this issue.

Finally, the cost of controls and diagnostics, e.g. beam position monitors, appears to be higher than can be accommodated. A reduced scope plan or new technical solutions should be investigated.

Appendix A

KEKB Accelerator Review Members

Andrew Hutton	JLab, Chairman
Mike Billing	Cornell (replacing Dave Rice)
Alexander Chao	SLAC
Warren Funk	JLab
Oswald Gröbner	CERN (retired)
Trevor Linnecar	CERN (unable to attend)
Won Namkung	Postech
Flemming Pedersen	CERN (unable to attend)
Eugene A. Perevedentsev	BINP
David Rice	Cornell (unable to attend)
John Seeman	SLAC
Wang Shuhong	IHEP (Unable to attend)
Katsunobu Oide	KEK, Ex Officio Member
Kazunori Akai	KEK, Secretary, Accelerator
Haruyo Koiso	KEK, Secretary, Accelerator

Appendix B

Agenda of the 15th KEKB Accelerator Review Committee

February 15-17, 2010
In the meeting room on the first floor of Building No.3, KEK Tsukuba, Japan

Date / Time	***Subject***	***Presenter***
Feb. 15 (Mon)		
8:30 - 9:00	Executive Session	
9:00 - 9:20	KEK Roadmap	A. Suzuki
9:20 - 9:50	KEKB Status	Y. Funakoshi
9:50 - 10:20	Belle & Belle-II	T. Higuchi
10:20 - 10:40	Simultaneous Injection	K. Furukawa
10:40 - 11:00	Coffee Break	
11:00 - 11:20	Operation Experience of Crab Cavity	Y. Yamamoto
11:20 - 11:40	Nano-Beam Scheme for SuperKEKB	H. Koiso
11:40 - 12:20	Machine Parameters	Y. Ohnishi
12:20 - 13:30	Lunch	
13:30 - 13:50	Beam-beam Simulation	K. Ohmi
13:50 - 14:05	Fringe Field of Solenoid	K. Oide
14:05 - 14:50	Lattice Design	A. Morita
14:50 - 15:10	Systematic Study of Nonlinear Dynamics	E. Levichev
15:10 - 15:30	Coffee Break	
15:30 - 15:50	IR Overview	M. Tawada
15:50 - 16:10	IR Magnets	N. Ohuchi
16:10 - 16:30	IR Vacuum Chamber and Assembly	K. Kanazawa
16:30 - 16:50	Machine-Detector Interface	M. Iwasaki
16:50 - 17:10	Vibration Measurement	H. Yamaoka / M. Masuzawa

Feb. 16 (Tue)		
8:30 - 9:00	Executive Session	
9:00 - 9:20	Injector Upgrade Overview & Positron Source	T. Kamitani
9:20 - 9:40	RF Gun	T. Sugimura
9:40 - 10:00	Damping Ring	M. Kikuchi
10:00 - 10:15	Beam Transport, Injection, Extraction from DR	N. Iida
10:15 - 10:35	Coffee Break	
10:35 - 10:55	RF Overview	K. Akai
10:55 - 11:10	ARES Cavity	T. Kageyama
11:10 - 11:25	Superconducting Cavity	Y. Morita
11:25 - 11:40	RF Accelerating Structure for DR	T. Abe
11:40 - 12:20	Vacuum	Y. Suetsugu
12:20 - 13:30	Lunch	
13:30 - 14:10	Magnets	M.Masuzawa
14:10 - 14:50	Beam Diagnostics	H. Fukuma
14:50 - 15:05	Impedance Estimation	K. Shibata
15:05 - 15:25	Coffee Break	
15:25 - 15:40	Beam Abort System	T. Mimashi
15:40 - 16:00	Control	T. Nakamura
16:00 - 16:20	Facility and Infrastructure	M. Ono
16:20 - 16:35	Schedule / Budget / Human Resources	K. Akai
16:35 -	Executive Session / Report Writing	
Feb. 15 (Wed)		
8:30 - 11:00	Executive Session	
11:00 - 12:00	Close-out	
12:00	Adjourn	