The Seventh KEKB Accelerator Review Committee report

Introduction

The seventh KEKB Accelerator Review Committee meeting was held on February 25-27, 2002. The Committee welcomed one new member: Peter Kneisel from JLab. The Committee expressed their appreciation to outgoing member, Ron Sundelin for his hard work and wishes him well in his retirement. Appendix A shows the present membership of the Committee.

The seventh Committee meeting followed the usual format of oral presentations by the KEKB staff members and discussion by the Committee members. However, the because of the incredible success of KEKB operations, the Committee focused on the options for improving luminosity in the long term. The Agenda for the meeting is shown in Appendix B. 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.

Contents

1) Executive Summary

A) Foreword

KEKB has made excellent progress in the year since the last Committee meeting. The peak luminosity has increased to a new world record of 6.65 x 10^{33} $cm^{-2}s^{-1}$ (at this time last year it was 2.5 x 10^{33} $cm^{-2}s^{-1}$). The BELLE detector has accumulated 56 fb^{-1} compared to 13 fb^{-1} a year ago and published 23 papers in refereed journals. This is an extraordinary achievement, and required overcoming many issues during the year. In the two and a half day meeting, about one third of the talks dealt with present status of KEKB, and the remainder covered the plans for upgrading KEKB to a luminosity of 10^{35} $cm^{-2}s^{-1}$. The KEKB machine group had done an enormous amount of work, and is to be congratulated on the impressive results that have been achieved.

Summary

KEKB has made spectacular progress over the last year, breaking almost all of the previous worldwide luminosity records: highest peak luminosity: 6.6 x 10^{33} $cm^{-2}s^{-1}$, highest daily integrated luminosity: 329.5 pb^{-1}, highest 7 day integrated luminosity: 2.06 fb^{-1}, and highest 30 day luminosity: 7.56 fb^{-1}. These values are now above those obtained at PEP-II (maximum peak luminosity of 4.5 x 10^{33} $cm^{-2}s^{-1}$). The KEKB team has had to overcome a series of problems, both hardware limitations and tuning improvements, in order to reach this performance and they are to be congratulated on this excellent result.

The BELLE detector has now accumulated 56.3 fb^{-1}, compared with 72 fb^{-1} logged by BaBar. The BELLE detector is working extremely well and has had no major difficulties. Backgrounds are low, and losses during beam injection are generally small; this makes continuous injection acceptable to the detector. However, this will still require close collaboration between the BELLE detector group and the KEKB machine team. Overall, the BELLE collaboration is extremely pleased with the quality and quantity of the beam being provided by the accelerator.

The beam current limitations in the LER were obtained by installing additional solenoid windings (an additional 50% compared to last year). This completes the installation everywhere where it is reasonable. The last solenoids had a large effect and demonstrated the importance of finishing the task. Optimization of the machine parameters included moving the horizontal tunes closer to the half integer and improving the optics correction. A faster abort kicker also permitted an increase in the number of bunches from 1153 to 1223. At present the HER beam current is 822 mA (design value is 1.1 A); the LER beam current is 1333 mA (design value is 2.6 A) at peak luminosity.

Super KEKB was introduced. This is an upgrade of the entire KEKB facility with a goal of 10^{35} $cm^{-2}s^{-1}$. It would collide 10 A in the LER against 4 A in the HER, requiring major improvements to almost every system. Many details of this upgrade were presented during the meeting and are discussed below.

B) Comments

The committee would like to see a road map for the present KEKB that showed the planned hardware and procedure improvements, and the resulting luminosity improvement that may be expected. The graph of integrated luminosity that was shown was a lower limit and serves well as an estimate of promised performance, but does not serve well as a guide for decision-making (the KEKB Project Leader agreed, and later updated this graph). The Committee recommends that the KEKB Project Leader prepare a list of machine parameters for each year, that will indicate where improvements are likely to be needed and when.

The R&D required for Super KEKB should also be planned in parallel. This will help the KEKB Team to organize their work so that the limited KEKB manpower can be effectively used. It will also serve as input to the KEK directorate in making decisions about the Super KEKB parameters and schedule.

The decision to exchange the ring polarities, putting electrons in LER and positrons in HER, would minimize beam blow-up due to the electron cloud instability. However, the solenoids have now demonstrated that it is possible to control this instability, so the choice is not so obvious because the fast ion instability that affects the electrons has the potential of being even more dangerous, with extremely fast growth rates. The KEKB Project Leader is encouraged to evaluate both options for the ring polarities and to determine which seems the best. The impact of this choice on the injector should also be evaluated and, ideally, a solution found which can support both options.

The KEKB Project Leader predicted that the conservative lower limit for the monthly, integrated luminosity would increase to 9 fb^{-1}; the Committee agreed that this is the lower limit and that more may be obtained. The impression of the Committee is that the ultimate luminosity of the present KEKB is likely to be in the range (1.5 – 3) x 10^{34} $cm^{-2}s^{-1}$. The goal of the Super KEKB should probably be about 10 times higher than the ultimate luminosity of KEKB, so it is important to accurately estimate what might be achieved by continuous improvement of the present machine. The committee recommends that the Project Leader make a careful evaluation of the ultimate luminosity limit of KEKB, including those improvements that can be added to the machine without requiring a total rebuild (e.g. adding a few more RF cavities, providing continuous, two-beam top-up capability, etc.).

In parallel, the theoreticians should develop estimates of the integrated luminosity needed to study the different aspects of the Super KEKB physics so that the machine parameters can be matched to the physics requirements. The range of integrated luminosities of interest is from 1,000 – 30,000 fb^{-1}, although the highest range will be a challenge for the machine to reach.

This information will serve as input to the KEK directorate in making decisions about the Super KEKB parameters and schedule.

2) Findings and Recommendations

KEKB 2001-2002

A) KEKB overview

KEKB has made spectacular progress over the last year, breaking almost all of the previous worldwide luminosity records: highest luminosity: 6.65 x 10^{33} $cm^{-2}s^{-1}$, highest daily integrated luminosity: 329.5 pb^{-1}, highest 7 day integrated luminosity: 2.06 fb^{-1}, and highest 30 day luminosity: 7.56 fb^{-1}. These values are now above those obtained at PEP-II (maximum luminosity of 4.5 x 10^{33} $cm^{-2}s^{-1}$). The KEKB team has had to overcome a series of problems, both hardware limitations and tuning improvements, in order to reach this performance and they are to be congratulated on this excellent result.

The beam current limitations in the LER were obtained by installing additional solenoid windings (an additional 50% compared to last year). This completes the installation everywhere where it is reasonable. The last solenoids had a large effect and demonstrated the importance of finishing the task. In addition, some HER masks were replaced with a more resistant design and faster abort kickers were installed. A whole host of other minor, but important, hardware improvements were made in almost every system.

Optimization of the machine parameters included moving the horizontal tunes closer to the half integer, managing the tunes with a gated betatron meter, and improved optics correction. The faster abort kicker also permitted an increase in the number of bunches from 1153 to 1223. At present the HER beam current is 822 mA and the LER beam current is 1333 mA at peak luminosity.

In addition, several procedures that will improve the luminosity have been tested, but have not yet become standard operating procedure: continuous positron injection, which should raise the integrated luminosity by ~15%, and injection of 2 bunch per linac RF pulse, which has already demonstrated a 50% increase in injection rate.

Some improvements will be installed in the near future. There are some new operating modes which will become standard following machine development in March: continuous injection, 2 bunch injection of positrons, and 3.5 bucket spacing will increase the LER current to 1.5 A and the HER current to 0.9 A. After the summer shutdown in 2002, the bunch spacing will be reduced to 3 buckets, the HER beam current will increase to 1.1 A (design value) and the LER beam current will be increased up to the design value or as long as the luminosity is improved. The KEKB Project Leader predicted that the conservative lower limit for the monthly, integrated luminosity would increase to 9 fb^{-1}; the Committee agreed that this is the lower limit and that more may be obtained.

Super KEKB was introduced. This is an upgrade of the entire KEKB facility with a goal of 10^{35} $cm^{-2}s^{-1}$. It would collide 10 A in the LER against 4 A in the HER, requiring major improvements to almost every system. Many details of this upgrade were presented during the meeting and are discussed below.

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B) BELLE Status

The BELLE detector has now accumulated 56.3 fb^{-1}, compared with 72 fb^{-1} logged by BaBar. The BELLE detector is working extremely well and has had no major difficulties.

Losses during beam injection are generally small and this makes continuous injection acceptable to the detector. However, this will still require close collaboration between the BELLE detector group and the KEKB machine team.

The beam abort kickers have occasionally misfired, with each event causing up to 5 krad dose to the silicon vertex detectors. The silicon detectors have now received an integrated radiation dose corresponding to about one third of the expected lifetime. This detector will soon be replaced by a detector package that is about ten times more resistant to radiation damage. In addition, improvements to the electronics that triggers the abort kicker have made these accidents less frequent. This does not appear to be a problem at this time.

Overall, the BELLE collaboration is extremely pleased with the quality and quantity of the beam being provided by the accelerator.

The BELLE collaboration has started to evaluate the upgrades required to profit from the increased luminosity in KEKB. The designs involve a smaller interaction region beam pipe surrounded by four layers of silicon detectors (three in the present detector) and a small-cell drift chamber. There appears to be no major interference between the new machine components and the detector but this will need to be confirmed as the designs evolve.

C) Luminosity Boost

Since the last KEKB accelerator review committee meeting in February 2001, the peak luminosity has been increased from about 2.5 to 6.6 x $10^{33}cm^{-2}s^{-1}$. This remarkable achievement is also reflected in an increase of the integrated luminosity per day, which increased from 140 to 329 pb^{-1}/day, in the total integrated luminosity, which increased from 12 to 56 fb^{-1}, and in the beam currents, which increased from 0.7 A to 1.4 A in the LER and from 0.6 A to 0.9 A in the HER. All these improvements are remarkable and show how well KEKB has operated.

The increase in luminosity was due, in part, to an advantageous choice of the betatron tunes. The decision to change the vertical fractional tune from 0.08 to above the half integer has been very much worthwhile. Also, the very careful correction of the optical functions, which made it possible to bring the horizontal tune to only 0.014 above the half integer, has paid off in luminosity.

The increase in luminosity was also due to the increased beam currents that were possible after the electron cloud effect was suppressed by extending the total length of vacuum chambers with solenoid windings from 1300 to 2200 m.

Among the innovations that support increasing the luminosity, two should be mentioned in particular: (a) circumference control in the LER and (b) continuous injection. The committee suggests implementing a chicane for circumference control in the HER. The committee strongly recommends making continuous injection the standard mode of operation, since this can lead to more stable operating conditions and to a further optimization of parameters.

The operation of KEKB has been very efficient and regular with little downtime. However, injection into the HER is often difficult and time consuming after the HER beam has been aborted. The committee recommends that the reasons for these difficulties be investigated. The suspected culprits include tune and orbit drifts in the times when the feedback systems have no beam to act on, and tune shifts with intensity.

D) LER Blowup & Solenoid

Throughout the commissioning, the Electron Cloud Instability in LER has been one of the most important problems at KEKB, causing the vertical blowup in the positron beam size. To reduce the electron cloud density, a large number of solenoids with the field of 40-50 Gauss were installed in the year 2000, resulting in a clear improvement of the blowup threshold current in the single-beam mode. Installation of the solenoids continued in 2001 in several stages as was recommended by the last KEKB Accelerator Review Committee. It was completed in January 2002 with 2836 coils with bobbins and 5736 bobbin-less coils covering practically all the available space in LER drift sections (~95%).

The blowup was weakened after each stage of the installation, and careful tune-up of the collision resulted in steady growth of the KEKB luminosity over the year since the last Committee. The effect of the solenoids on the specific luminosity was recently confirmed by direct measurements with the solenoids on and off.

In spring and summer 2001, the effect of the solenoid was demonstrated in the gated tune meter data. This showed a variation of the horizontal and vertical tune shift along the bunch train caused by the electron-cloud. Machine studies dedicated to the interferometer measurement of the current-dependent vertical beam size in single-beam mode in the LER, confirmed the scaling of the blowup threshold and beam-size growth rate with the line density of the beam charge for the fill patterns with 4 and 3 bucket spacing.

The specific luminosity and the luminosity per bunch were improved after the 4th and 5th solenoid installation in September 2001 and January 2002. In the latest measurement of the beam size versus current in February 2002, no blowup was seen within the presently available current range of 1.3 A in the 4-bucket spacing fill pattern used for physics. An important indication of the improved situation with the electron cloud is that in this measurement, as well as in physics runs, the chromaticity setting was moderate (~4) compared with the high chromaticity settings (~8-10) used a year ago to suppress the beam size blowup, and which were believed to help in stabilizing a head-tail-type instability caused by the electron-cloud wake.

An urgent question remains of how much safety margin is provided by this apparent cure of the beam size blowup by the solenoid field. This should be answered by a dedicated study of the blowup thresholds for fill patterns with 4-, 3- and 2-bucket spacing; the Committee strongly recommends doing this study.

The effect of solenoids was also seen in the recent measurement of the coupled-bunch instability transient, triggered by opening the transverse feedback loop and recorded by the Bunch Oscillation Recorder. The observed growth rate was reduced when the solenoid is excited. Less clear is the mode spectrum change caused by the solenoid. This study provides plenty of data to be compared with the simulation and seems to be very interesting.

The 5% space remaining in the LER not covered by solenoids contains many BPM regions. It is suggested that one possible way to cover these regions might be to apply high voltages to the BPM buttons in such a way that they serve as clearing electrodes. In this way the coverage against the electron cloud problem may approach 100% of the circumference not covered by magnets.

Among other instabilities we note the low-frequency coupled-bunch instability (supposedly a resistive-wall type) causing operation problems due to the temporarily disabled low-frequency module of the transverse feedback and which should be cured when it is re-installed.

In view of the Super KEKB challenges, the Committee recommends enhancing the machine study program devoted to electron cloud studies and other collective effects, taking the full advantage of powerful diagnostics available at KEKB. More beam studies of the prototype antechamber-type vacuum chamber are also encouraged.

E) Antechamber prototype

The antechamber is expected to provide high conductance, a reduction of the power density on the vacuum chamber, and a separation of the photoelectron source from the beam space.

A prototype of an antechamber was constructed and installed in the KEKB positron ring to evaluate photoelectron reduction. It was made of copper and composed of three kinds of chamber: bend, quadrupole, and straight section chambers. In the straight section, the chamber had a tapered wall to absorb the synchrotron radiation. The vacuum group built and installed photoelectron monitors in the bend and straight sections to measure the secondary electron current. They compared electron currents in this antechamber with the current in the normal, single-cell chamber used now. In the bend section, it seems that the production rate of electrons in the antechamber is 1/6 to 1/10 of those in the normal, single-cell chamber. The reduction due to the solenoids is a factor of 9. In the straight section the reduction due to the solenoids is estimated to be a factor of 10. The measured electron current includes both photoelectrons and secondary electrons produced by the multipacting process. As the separation between the two kinds of electrons is not sufficient, it is difficult to estimate the photoelectron production in the antechamber. It is therefore unclear how effective the antechamber structure is in reducing the electron effect. The committee hopes that further experiments are carried out using the prototype antechamber to clarify these questions, as the antechamber (together with the solenoid windings) is one of the most promising ways to reduce the photoelectron effect.

F) Masks

The mask designs for KEKB have evolved with time over the life of the project. The designs are now on Versions 4 and 5. The present designs are well constructed and are working well. However, there are a few problems left to resolve; in particular, the grooves generated by errant aborted beams, and the HOM heating of nearby bellows and NEG pumps. There are solutions to these issues including rapid abort signals, beam-phase aborts, screens added to nearby NEG pumps, and changes of the length and material of the mask heads. These cures have been, or soon will be, implemented.

These masks are required to reduce the backgrounds in the BELLE detector. The BELLE group reports that the present backgrounds are acceptable to them, which is very commendable. Furthermore, these backgrounds are slowly being reduced with time due to the improved masking and sustained beam scrubbing of the accelerator.

The masking for the Super KEKB will be even harder than at KEKB. The committee recommends that an initial study of the collimation scheme be carried out.

G) High Current

At present, KEKB is operated with 4-bucket bunch spacing and up to 1.4 A beam current in the LER and 0.9 A in the HER. As much as 95% of the field-free circumference has been covered with solenoids. In this situation the beam blow-up due to the electron-cloud instability has completely disappeared. The presently installed RF system (16 ARES cavities in LER, 10 ARES cum 8 SC cavities in HER) still offers a comfortable reserve, because the system is run with less overvoltage than originally foreseen. The most severe problems with masks and absorbers have been solved by new designs (Versions 4 and 5), and also by a tighter beam-abort system (e.g. beam abort triggered by as little as 1° beam phase error).

It can, therefore, be expected that the installation of the full RF system (4 more ARES systems in LER, and 2 more ARES systems in HER, all constructed already) permit the full design currents of 2.6 and 1.1 A. This should enable KEKB to reach at least the design luminosity of 1×10^{34} $cm^{-2}s^{-1}$ in the coming year. If may well happen that the electron-cloud instability will cause problems again at only slightly higher current and/or reduced bunch spacing. Since a further extension of the solenoids is impossible, electrostatic clearing of at least some of the remaining 5% of space might be considered. In particular, the beam-position electrodes, which take some of this space, might be given a high-voltage bias for that purpose.

A number of miscellaneous problems and observations (such as damage of the masks by the dumped beam, 5-bunch spacing which had to be avoided because of the fortuitous excitation of a resonance in the detector beam pipe, extreme heating of bellows or NEG pumps just near the masks) give a warning that new problems may occur at every step of increased beam current. It seems advisable, therefore, to consider upgrading the performance beyond the design currents to be a continuous process, which should be systematically pursued during the coming years.

Super KEKB

H) Physics Motivation

The physics motivation for KEKB is divided into three phases. Phase 1, "Discovery of CP Violation in B System" requires an integrated luminosity of 30 fb^{-1}. This has already been completed, with BELLE obtaining a value of sin $2\varphi_1$ = 0.99 ± 0.14 ± 0.009 (BaBar has obtained a value of sin $2\varphi_1$ = 0.59 with the same error bars). This discrepancy should be resolved soon.

Phase 2, "Precise Tests of KM Scheme" requires an integrated luminosity of 300 fb^{-1}. This phase should be completed in the next few years with the present KEKB and PEP-II.

Phase 3, "Supersymetric Flavor Physics" requires an integrated luminosity of at least 3000 fb^{-1}. This is the regime that the Super KEKB should be designed to cover. The integrated luminosity per month is about 100 fb^{-1} at a peak luminosity of 10^{35} $cm^{-2}s^{-1}$, so an integrated luminosity of 3000 fb^{-1} would require about 3 years operation.

It will be important for the theoreticians to come up with estimates of the integrated luminosity needed to study the different aspects of the supersymetric flavor physics so that the machine parameters can be matched to the physics requirements. The range of integrated luminosities of interest is from 1,000 – 30,000 fb^{-1}, although the highest range will be a challenge for the machine to reach.

The physics capability of Super KEKB was compared to hadron colliders, particularly LHC-B. The committee recommends that the detector group (Super BELLE) define the physics goals so that the luminosity scope of Super KEKB can be specified. Should the physics scope of Super KEKB compete for the first years with LHC-B, or compete on only a few specific physics topics, or compete fully on all physics fronts including data statistics? The committee had a consensus that Super BELLE should be designed to compete fully with LHC-B.

I) Parameters

A set of basic parameters was given for the Super KEKB. The driving parameter is the luminosity of 10^{35} $cm^{-2}s^{-1}$. To reach this luminosity, the beams are designed to have very high currents (9.4 A in LER and 4.1 A in HER). In addition, the bunch length has to be very short (3 mm rms). The high intensity and the short bunch length combine to significantly enhance the effect of coherent synchrotron radiation (CSR), which may present a serious challenge. The reported conclusion that the total radiated power is negligible is based on the assumption that the CSR is well shielded by the conducting walls of the beam pipe. This is true provided that the orbit bend radius is constant, and that the beam surroundings are uniform. An improved estimate of CSR shielding may be in order, taking account of non-uniform orbit bends, and variable beam pipe cross-sections in a real machine.

More serious problems come from the CSR near fields, whose reactive component of the impedance is not well shielded, thus contributing to the broadband longitudinal impedance. Therefore, a careful feasibility study of the bunch length is recommended for Super KEKB.

Some of the issues associated with short bunch length, including how serious the HOM heating will become and whether there will be a CSR instability, can be studied in the present KEKB by lowering the momentum compaction factor. The committee suggests that such experiments be carried out.

In this design, the beams are assumed to be flat at the collision point. This means that a decision was made not to benefit from the potential gain of the round beam configuration. Although such a decision is reasonable because a round beam configuration requires a much more complicated lattice design, and no recent e^+e^- colliders have succeeded in obtaining this potential benefit, the committee urges further examination of this option so as not to prematurely forego its potential.

One of the key design features is to switch energies of the two beams, i.e. to store e^- in LER and e^+ in HER. This has the advantage of reducing the strength of the electron cloud instability, and it also shortens the filling time. However, the committee wishes to note that a down side is the potential for a serious fast ion instability in the LER. A preliminary estimate of the fast ion instability gives a growth time of 0.3 ms for 1 nTorr. Unlike the electron cloud instability, which can be cured by solenoid windings, the fast ion instability, once it occurs, is difficult to control. It is therefore recommended that the fast ion instability be examined more closely for Super KEKB. In particular, the committee recommends that some experiments should be carried out as part of this study.

J) Optics

The Super KEKB lattice design work has just started. At this early stage, no actual lattice was presented, but a design approach was described. The main emphasis in this design approach is the flexibility of this lattice. In particular, there is a wide range of variability in the momentum compaction factor as well as in the natural emittance. The committee agrees completely with this emphasis on flexibility, and urges the lattice effort in this direction. Another important issue will be that smaller values of both β_x^* and β_x^* are required, which in turn will impose more demanding chromatic correction, and/or tighter dynamic aperture. It is also suggested that the crab-crossing scheme be considered in the early lattice design.

K) Special Magnets

A first round of parameters for the interaction region magnets for Super KEKB have been determined from the lattice studies. The overall interaction region design looks promising. The crossing angle has been increased from ±11 mrad to ±15 mrad to allow better clearance for the magnets and vacuum chambers on either side of the interaction region. There has also been an initial look at the mechanical and magnetic designs needed for these magnets. The concepts are similar to the present designs used in KEKB, including septum quadrupoles as needed.

In order to reduce the β_y^*, the first quadrupoles must be moved closer to the collision point. Thus, the strength of these magnets must increase, and the compensation solenoid, which used to be in front of the quadrupole, must now be placed over the quadrupole. As with other recent insertion designs, overlapping coils should not be a problem.

One issue of concern is the heating of nearby vacuum chambers by synchrotron radiation at high beam currents. The beams exiting from the interaction region are strongly bent by being off-axis in the quadrupoles, and generate many kilowatts of power. These chambers have been an ongoing concern in the present electron-positron colliders and special attention must be paid for Super KEKB.

Furthermore, an initial semi-detailed vacuum design of the beam chambers at and around the collision point is important, particularly for the reduction of backgrounds in the new detector. The committee suggests a first round of investigation for these chambers.

L) QCS

The beta functions at the collision point must be reduced in order to produce the higher luminosity desired for Super KEKB. This requirement forces the final quadrupoles to be moved closer to the interaction point than those in KEKB. This also requires that the magnet strength be significantly increased, forcing the use of superconducting quadrupoles.

The design of these superconducting quadrupoles for the Super KEKB is well advanced. The design is an extension of that used for KEKB, but with higher gradients. The work done so far looks reasonable and is very detailed for this phase of the upgrade project. The committee recommends that further design studies include vacuum chamber and detector background issues as well as prototyping.

M) RF System

The upgrading of the RF system for 9.4 A (LER) and 4.1 A (HER) beam current is a major project. The total number of cavities and associated RF systems must be twice that of KEKB. There will be a total of 56 klystrons and the AC input power for the RF system and the associated infrastructure will be 73 MW.

In HER, the mixture of ARES and SC cavities will be maintained. One very desirable feature of this hybrid solution is the possibility to arrange the relative phases so that the ARES cavities deliver more than their share in beam power, while the higher voltage per superconducting cavity is used optimally.

In spite of the fourfold increase in power, it turns out that the basic design of the present RF system can be maintained, and most of the present existing equipment designs can be used with suitable modification. The main development issues concern the higher-mode dampers and couplers, but since many of these components have spare capacity already the improvements may often be limited to strongly reinforced cooling. The vacuum-pipe tapers between SC cavities will have to be eliminated. In addition, a program is aimed at improving reliability and reducing the crowbar trips. It should be noted, however, that the reliability of the present systems is already excellent now that the inevitable teething troubles have been overcome. The RF system fault rate is reported to be about once per day.

N) ARES

The main features of the ARES system of coupled cavities have been pointed out in previous reports. Their exceptionally high stored energy is already required in HER at the Super KEKB design parameters. Two types of input couplers have been tested up to 900 kW. This should already be marginally sufficient for super KEKB, but improvements will be made in cooling and in the use of low-loss alumina for the vacuum window. Of the two types of coupler-window assembly, one ("choke-type") has suffered two cases of window failure. The other type ("over-and-under cut") has performed satisfactorily and will be maintained.

The parasitic 0 and π modes of the two-cavity system (acceleration and storage) are extracted into an external water-cooled load that will be given increased cooling capability. Different SiC higher-mode absorbers (bullet-shaped and tiles) will be employed with enhanced water-cooling. In order to make the necessary detuning within the tunable range of the present tuner, the resonance frequency of the fundamental mode is planned to be lowered by machining the inner surface of the present ARES cavity.

All in all it appears that the ARES system offers an excellent basis for the required upgrade needed for the increased beam currents.

O) SCC

The 8 superconducting cavities in the HER have been operating reliably, with only minor problems, since their installation 4 in 1998 and other 4 in October 2000. Two cavities (D10-A and D11-C) have suffered from helium leaks at the indium joints; the cavities were taken off-line in January 2001 and October 2001, respectively, and re-installed after repair in August 2001 and January 2002. Only minor degradations in cavity performance were observed. The leaks did not represent a systematic weakness in the design, but could be traced back to problems during the assembly process. During these repairs, the voltage and the beam current were supported by the other cavities, which had been conditioned up to 2 MV, a 25 % margin over the operational goals.

Between April 2001 and February 25, 2002, the superconducting cavities have supported beam currents up to 870 mA in 1225 bunches with up to 380 kW of RF power transferred to the beam. The HOM power generated, and successfully damped in the ferrite dampers, has been up to 8 kW per cavity.

For the Super KEKB, the circulating current in the HER needs to be increased to 4.1 A. This increase requires large RF power levels to be transferred to the beam, and very high HOM losses at the cavities. The input couplers have to sustain 460 kW of incoming power, and the HOM power generated by the beam increases to 80 kW. The present ferrite dampers cannot handle such power levels. The route towards a technical solution has been identified:

a) Removing the tapered beam line sections between the cavities will reduce the loss factor of the dominant wide range HOMs, reducing the generated power to approximately 50 kW per module.

b) The damping material of choice would be SiC because of its higher thermal conductivity. This would provide better cooling capabilities and possibly reduce the surface temperature at the dampers to tolerable levels.

It has been recognized that the development of appropriate HOM dampers is essential for the superconducting cavities for Super KEKB; the committee fully endorses such R&D efforts to be carried out as soon as possible.

The input coupler power for Super KEKB increases from 380 kW (demonstrated) to 460 kW/cavity. The KEKB input couplers seem to have sufficient design margin, and incremental changes such as reinforced cooling and improved interlock protection might solve the increased demands on the couplers. Such investigations should also be started as soon as possible.

P) Crab Cavity

The development of the crab cavity system is continuing, and a full-scale superconducting prototype cavity has been tested. It has exceeded the design specifications by a margin of approximately 40 %, and had a coaxial coupler for frequency tuning installed in the beam line.

As has been mentioned in the sixth KEKB Accelerator Review Committee Report, the priority of this program is not considered extremely urgent since no dramatic degradation of luminosity due to the IP crossing angle has been observed. The committee was told that the crab scheme cannot be applied to the Super KEKB because of HOM power limits. However, the crab cavity is a very complex design, and no operational experience with a superconducting crab cavity in a collider is available yet. The committee recommends that the existing crab cavity be installed in the HER close to the superconducting cavities to study the high-current behavior. If the results are positive, the decision could be made to fabricate the full crab cavity system for installation at an opportune date to take advantage of the possible luminosity gain.

The crab cavity program continues with interesting technical developments, such as sputtered niobium on copper substrates, and manufacturing of thin copper bellows to be sputter coated with niobium. These might be of interest to a wider community. This demonstrates KEK management’s commitment to support SRF technology as one of the core competencies of KEK, and is strongly encouraged by the committee.

Q) Vacuum, Antechamber, Masks, Bellows, etc.

1. Antechamber

The total gas load in Super KEKB is estimated to be three to four times higher than the design value of the present KEKB. Enhancement of the pumping speed is important for the very high current and high gas loads produced, and an antechamber can provide a higher effective pumping speed. This enhanced pumping will be provided in the antechamber proposed, with NEG strips, localized NEG pumps, sputter ion pumps, and sublimation pumps all integrated into the design. The pumping slots proposed have RF shields that are not the usual slit type, but are the rectangular or hole type which are effective in minimizing HOM penetration. The KEKB vacuum group has considerable experience in NEG operation in the present ring, so the committee is confident that the slit structure in the new Super KEKB will be designed with low conductance for HOM penetration and high conductance for pumping.

An antechamber was proposed, which has a long, shallow side chamber along the beam orbit. The width of the side chamber is limited by the geometrical structure of the quadrupole and sextupole magnets. The magnets will not be changed; thus it is impossible to adopt the standard type of antechamber used in synchrotron radiation storage rings. In the standard antechamber, the beam chamber is separated from the antechamber by a thin neck, preventing the photons from escaping from the beam chamber. Photon irradiation in the beam space can be minimized and photoelectron production should also be minimized.

In the proposed antechamber with a shallow side chamber, all the photons irradiate the vacuum chamber, especially in the shallow side chamber. However, this chamber roughly doubles the distance between the source point of the synchrotron radiation and the first irradiation point (1300 mm to 2900 mm). Because of the vertical divergence of the synchrotron radiation, this increased length reduces the vertical synchrotron radiation power density by a half. As a result, the proposed antechamber gives a factor 4 reduction of SR power on the chamber that is 134 W/mm^2 to 30 W/mm^2, which is acceptable for copper chamber.

Experiments to reduce photoelectron yields were done in the synchrotron radiation beam line in the Photon Factory, and the results showed that a saw tooth structure is effective in reducing photoelectron production.

2. Photon stop

A slant type photon stop was discussed as an option. In Super KEKB, the bending radius is 16.3 m for the LER (e^-) and 104.5 m for the HER (e^+). The angle of incidence on the bend chamber is 3.2 degree in the LER. If the photon stop is installed in the LER ring 2.1 m downstream of the entrance to the bending magnet, the slant angle should be less than this value because the angle of incidence on the shallow-pocket antechamber is also less than this value. This type of the photon stop is successfully used in high-energy synchrotron radiation rings, so the design and operational experience in such machines is very relevant.

The photon stop option is closely correlated with an aluminum alloy chamber. The power density is too high to permit the high power radiation from abnormal orbits caused by magnet trips and operational errors to strike the aluminum alloy chambers. The aluminum alloy chamber and the photon stop are useful, and work well, only when the machine operation is correct and sound. The Super KEKB vacuum system should be designed to have sufficient margin to be stable against operational errors.

3. Wiggler

The synchrotron radiation power from the damping wiggler is estimated to be 27 kW/m in the wiggler vacuum chamber. The chamber in this section has cooling channels on both sides, and this power level is acceptable. There is a bending magnet section about 30 m downstream of the wiggler. The power density at this section increases to 50 kW/m because the angle of incidence increases going from the straight section to the arc section. The power density in this arc section is estimated to be 5.7 W/mm^2, so a special photon stop is not proposed because this power density is acceptable in normal operational conditions. The committee agrees with this assessment in normal, correct operation of the machines without any tripped magnets or other conditions with abnormal beam orbits. More attention should be paid to designing the vacuum chambers for an accidental beam orbit shift, when the synchrotron radiation may irradiate the un-cooled surface of the vacuum chamber.

4. Bellows

It is difficult to make a reliable RF shield that is capable of supporting the extremely high currents. Since the number of bellows is high, new bellows should be developed with an R&D program. The design presented, with longitudinally short slots and a double finger structure with thin cuffs of 0.1 mm thickness, seemed promising. In the design of the whole vacuum system, every effort should be made to reduce the number of bellows in the ring, though it is understood that bellows are necessary in some areas (e.g. the interaction region) to help in the installation process and to absorb mechanical deformation and thermal expansion. Designing the vacuum chamber to reduce the number of bellows would favor the adoption of an antechamber design based on photon stops, because the high current beams have less effect on the chamber temperature.

R) Facilities

For the Super KEKB, the increased currents in both rings require a dramatic increase of electric power consumption and cooling capacity. However, the estimated wall plug power of about 100 MW is less than that was required for TRISTAN, so it would be covered by the installed total power of 150 MW at the KEK site. Even though the power demands may not be evenly distributed among the five substations, this could be resolved by careful arrangement of the subsystems in groups, and/or connecting power cables between the substations.

The efficiency of the klystrons and energy recycling should be looked at carefully in order to reduce the operating costs. Even though this issue has been looked at before, an expert group should investigate this issue to see whether there are any new technologies that have become available.

Since the cost of new buildings can be a significant fraction of upgrading the RF and cooling systems, the committee recommends that the total cost of the project be minimized. This may lead to a change in the technical solution that provides the minimum cost (for example, a 2 MW klystron would take up less floor space than two 1 MW klystrons).

In general, there are no critical issues in the facilities and infrastructure for Super KEKB operations.

S) Monitors & Feedback

The beam position monitor system of KEKB has a resolution of about 1 μm. An analysis of both rings has shown that this very good resolution can also be obtained for the Super KEKB parameters. Also, the use of antechambers should not degrade the resolution since an appropriate detection frequency for the BPMs has already been found.

Operational experience has shown that the synchrotron radiation monitor is currently quite sensitive to HOM heating. Therefore, it cannot be used for the high currents of Super KEKB without some improvements. An innovative design using a mirror with a grazing incidence would reduce the direct heating due to the synchrotron radiation power to the KEKB values. An antechamber was proposed to reduce the strength of the beam-induced electro-magnetic field at the extraction window that would be a source of the HOM.

Currently, a transverse coupled bunch mode with a rise time of 1 ms is the strongest instability. It is compensated by a feedback with a damping time of 0.5 ms. If the particle types were switched for Super KEKB to avoid the electron cloud effect for the positron beam, then the fast ion instability for the electron beam in the LER will become the strongest instability. The vacuum pressure for today's operating currents is below 1 nTorr. A worst-case estimate of 5 nTorr for Super KEKB currents would lead to a fast ion instability rise time of 0.05 ms, requiring a drastic improvement of the feedback system which be not be technically feasible. A careful analysis should be carried out to determine whether the fast ion instability or the electron cloud effect is easier to deal with, and whether changing the ring polarities is the best option for Super KEKB.

The committee recommends that the recently removed low frequency feedback system be reinstalled in the HER to control the slow instability which is observed and, possibly, to stabilize injection after a beam abort.

T) Linac Upgrade

Continuously topping up the positrons reduces the importance of the positron filling time, which is then only relevant following beam aborts. The injector group has successfully tested the positron top-up mode in the last few months and this is expected to become standard operation this summer. However, in order to take full advantage of this technique, the top-up mode should be made available for both beams, which would require a bypass to be built around the positron converter. The committee recommends that the KEKB Project Team pursue this capability with a high priority.

There are two separate issues in the injector linac for the Super KEKB operations: the intensity upgrade and, if the ring polarities are inverted, an energy upgrade of the positron linac. Positron beams of 8 GeV with 1.2 nC would be required. There are two options presented for the energy upgrade scheme, both using a damping ring of 1 GeV to reduce beam losses near the detector following injection into the KEKB rings.

Option 1 is to replace 24 units of the existing S-band structures with C-band structures having twice the accelerating gradient. These would fit within the existing building and infrastructure. In this case, the new damping ring would also be necessary to reduce the positron emittance in the C-band structures. Option 2 is to re-circulate the 1 GeV positron beam from the damping ring back to Sector A for acceleration to 8 GeV. It requires an extra beam transfer line, a separate bending arc, and a target-bypass line, in addition to the damping ring.

For the intensity upgrade, the positron injection rate is to be increased from 1.5 mA/sec to 3.0 mA/sec for the HER, while the electron injection rate is to be increased from 3.0 mA/sec to 15.0 mA/sec for the LER. The capability for producing 5 nC electron bunches has already been demonstrated, since 10 nC bunches are routinely accelerated for positron production. For the positron beams, the capture efficiency must be doubled from 0.6 nC to 1.2 nC. Even though it is feasible to increase the focusing strength at the positron generator, there are other options such as increasing the electron energy at the positron converter or positron bunch stacking in the damping ring which should be investigated.

While both schemes are feasible, Option 1 has an advantage in reliability and the Option 2 seems to have an advantage in cost.

The Committee would like to recommend the use of C-band structures for a reliable injector to the Super KEKB if the construction cost is not excessive. Therefore, the committee recommends carrying out a detailed cost analysis for both schemes in the coming year.

U) Linac RF Sources

The C-band RF system for the injector would be consistent with the line of development of SPring-8 SASE FEL Project (SCSS), and the linear collider(JLC). The exact frequency would be slightly different (5712 MHz, exactly twice that of the present S-band linac, has been chosen for KEKB to allow staged installation of the new systems), and the structures themselves would be different from SCSS and JLC. However, the RF sources and modulators could be very similar and it would be valuable to obtain operating experience at this frequency. The committee therefore supports the use of C-band, 5712 MHz, for the Super KEKB Injector upgrade.

The preliminary design of the C-band RF source for the e^+ beam energy upgrade to 8.0 GeV has already been developed. The strategy of combining 2 klystrons and 2 modulators to form a single RF source unit seems reasonable. It is possible to decrease the total capacitance by 30% to get a 2 μs flat top on the pulse.

The use of available, existing components for this new RF source is also quite reasonable. Examples are using the existing C-band 50 MW klystron to be the final amplifier, using the existing 200 kW C-band klystron to be the sub-booster amplifier, and using temperature-controlled rectangular waveguide (WRJ-5 or 6) as the driveline phase reference.

It is important to fully evaluate the phase stability tolerances of the C-band RF sources.

V) Damping Ring & Beam Transport

The Damping Ring is needed for both linac upgrade Options (C-band and recirculated S-band) to reduce the beam emittance and energy spread to the required small values. An Energy Compression System (ECS) and a Bunch Compression System (BCS) are necessary for positron injection into the Damping Ring from the linac and into the C-band linac structure from the Damping Ring, respectively. The zero-order fundamental parameters for the Damping Ring and the Bunch Compression System have been developed. The preliminarily designs of the Damping Ring and Beam Transport systems seem reasonable.

Obviously, further studies are needed: the committee identified the following areas:

- The effects of machine errors on the dynamic aperture of the Damping Ring;
- The possibility of stacking more linac bunches into the Damping Ring bucket to increase the pulse charge and provide a higher injection rate into the Super KEKB-positron ring;
- The effect of nonlinearities on the design of the Energy Compression System and the Beam Transport system.

W) Control System

The decision to join the EPICS collaboration has lead to an efficient front end of the KEKB control system. Also, the strategy of basing the control system as much as possible on commercially available components, and outsourcing much of the programming, has worked very well. For simplification, the same control system is used for KEKB and for the PF-AR. All in all, the KEKB operating system is working very effectively, and the successful integration of simulation software like SAD seems to have lead to very helpful capabilities.

Some of the old TRISTAN CAMAC field busses have been used for KEKB. In spite of the fact that they work well, developing new systems with CAMAC is problematic, because designers are becoming rare and components are often no longer available. The committee therefore recommends moving slowly away from CAMAC technology for obsolescence reasons, and not to use it for the new systems of Super KEKB. If a digital RF feedback should be needed, CAMAC components would not be used for technical reasons.

X) Beam Dynamics

At present, the main thrust of the beam dynamics studies at KEKB is to understand the electron cloud instability, and its impact on the machine luminosity. One of the main limitations of the KEKB luminosity was the blowup of the LER vertical beam size during collisions, which limits the presently achieved vertical beam-beam parameter in HER to about 0.04. This effect has been regularly observed during the past two years, both by interferometer and from the current dependence of the specific luminosity.

Before the 4^{th} installation of solenoids in September 2001, the LER current limit for the physics runs was set slightly above the threshold of the LER blowup in the single-beam mode and, at the beginning of the luminosity runs, the increased vertical beam size could be attributed either to the electron cloud instability, or to the beam-beam effect, or to the interplay of both of these effects. However, even now that LER current of 1.3 A is below the single-beam blowup threshold, bringing the beams into collision results in an increase of the vertical beam size in LER.

One possible way of explaining this effect is to consider the combined action of the coherent beam-beam interaction and the machine impedance. For KEKB LER, the electron cloud is believed to dominate the transverse machine impedance budget, and the vertical instability threshold is lower than the horizontal.

Linear theory predicts a head-tail type instability in a system of colliding bunches. This instability, in combination with the strong non-linearity of the beam-beam force which provides a decoherence mechanism for the growing bunch oscillations, is a candidate to explain the experimentally observed “heating” of the vertical beam size during collisions, which occurs below the threshold of the single-beam instability.

The simulation made for KEKB seems to confirm this hypothesis. Although the first simulation of the combined effect of the electron cloud and beam-beam involves some simplifications (e.g., the colliding bunches are now sliced into transversely rigid Gaussian disks), the instability growth and saturation can already be seen. The indication that the synchrotron tune spread may cure the growth in the beam size seems to be very important. Further work in this direction, with more realistic “soft” strong-strong models, is strongly encouraged.

Concerning the LER blowup in single-beam mode, the past year brought more confidence in the simulation results of the electron cloud buildup in LER. The thresholds obtained from the head-tail instability model with the simulated cloud densities are in good agreement with experimentally observed LER blowup thresholds; their variation with the momentum compaction factor and the effect of the machine chromaticity are also explained by this model.

Recent simulations of the electron cloud buildup in the antechambers with and without solenoids predict stability of the Super KEKB beams with the solenoids, however the safety margins are not wide. Refinement of these calculations may be in order, given the importance of the result.

Another important issue where the simulation can help in understanding the real situation with the electron cloud is to explain the experimental results on the spectra and growth rates of the coupled-bunch instability in LER. The committee recommends that these studies be pursued.

Appendix A

KEKB Accelerator Review Members

Andrew Hutton	JLab	Chairman
Alexander W. Chao	SLAC	
Eugene A. Perevedentsev	BINP	
Masanori Kobayashi	KEK	
Won Namkung	Postech	
Fleming Pederson	CERN (excused)	
David Rice	Cornell (excused)	
Wolfgang Schnell	CERN	
John Seeman	SLAC	
Peter Kneisel	JLab	
Georg Hoffstaeter	DESY	
Wang Shuhong	IHEP	

Appendix B

Agenda of Seventh KEKB Accelerator Review Committee

February 25	(Monday)	
9:00-10:00	Executive session	
10:00-10:15	KEKB overview	K. Oide
10:15-10:35	Belle Status	F. Takasaki
KEKB 2001-2002		
10:35-10:55	Luminosity Boost	Y. Funakoshi
10:55-11:15	LER Blowup & Solenoid	H. Fukuma
11:15-11:35	Antechamber prototype	K. Kanazawa
11:35-11:55	Masks	Y. Suetsugu
11:55-12:15	High Current	K. Akai
12:15-13:30	Lunch	
Super KEKB		
13:30-13:50	Physics Motivation	M. Yamauchi
13:50-14:10	Parameters	Y. Ohnishi
14:10-14:30	Optics	H. Koiso
14:30-14:50	IR Design	Y. Funakoshi
14:50-15:10	Special Magnets	M. Tawada
15:10-15:30	QCS	N. Ohuchi
15:30-15:50	Break	
15:50-16:10	RF System	K. Akai
16:10-16:30	ARES	T. Kageyama
16:30-16:50	SCC	T. Furuya
16:50-17:10	Crab Cavity	K. Hosoyama
17:30-18:30	Executive session	
18:45-20:45	Reception	
February 26	(Tuesday)	
8:30- 9:00	Executive session	
9:00- 9:40	PEPII status	J. Seeman
9:40-10:00	Vacuum, Antechamber, Masks, Bellows, etc.	Y. Suetsugo
10:00-10:20	Break	
10:20-10:40	Facilities	Y. Ohnishi
10:40-11:00	Monitors and Feedback	H. Fukumu
11:00-11:20	Linac Upgrade	T. Kamitani
11:20-11:40	Linac RF Sources	S. Fukuda
11:40-12:00	Damping Ring and BT	M. Kikuchi
12:00-13:00	Lunch	
13:00-13:20	Control Systems	T. Katoh
13:20-13:40	Beam Dynamics	K. Ohmi
13:40-18:00	Executive session	
18:00-20:00	Working dinner	
February 27	(Wednesday)	
8:30-11:00	Executive session	
11:00-11:30	Interaction with KEKB staff members	
11:30-12:00	Closing	