The Fourth KEKB Accelerator Review

Introduction

The fourth KEKB accelerator review Committee was held on March 8-10, 1999, about one year after the third Committee meeting held on March 5-7, 1998. The membership of the Committee is shown in Appendix A.

This fourth meeting consisted of a number of oral presentations by members of the KEKB project and discussion by the Committee. The agenda is shown in Appendix B. The Committee wrote a draft report on the basis of discussion during the Committee meeting and the report was then improved and finalized by e-mail communication among the Committee members.

Contents

Executive Summary

The fourth meeting of the KEKB Machine Advisory Committee was held on March 8–10 (see Appendix A for the attendance list, Appendix B for the three-day program). On March 8 and 9 the project staff presented the current status of the machine, with committee members touring KEKB and the injector linac the first day. The Committee had time to discuss the various items brought up during the meeting in a closed executive session and to reach agreement on the opinions given in the following report.

Professor Sugawara, Director-General of KEK, opened the meeting by highlighting the major research projects of the lab and describing the important role of the KEKB project in the overall research program.

The project leader, Professor Kurokawa, then gave an overview of KEKB. This asymmetric electron-positron collider project was completed at the end of 1998 and had within the last two months successfully stored and collided intense beams of electrons and positrons for the first time. All the major components were in place and working at close to design specifications. Given that only one year ago the complicated and extensive vacuum system was not even close to ready–due to the default of one of the manufacturers–project completion with almost no delay of the original schedule was a remarkable achievement.

Another major project was also completed on time: the upgrading of the injector linac to 8.6 GeV electron and 3.5 GeV positron energies. The Committee expressed admiration and praise to the project leader and his team for this accomplishment.

The debugging and commissioning phase has now started. In the 8 GeV ring, 240 mA of electrons (design 1.1 A) has been stored, while over 300 mA of positrons (design 2.6 A) has been stored in the 3.5 GeV ring. Both beams were brought into collision with beam-beam effects roughly corresponding to expectations. Storage lifetimes between thirty minutes and several hours were observed, as expected from the residual gas pressure in the vacuum system. Vacuum conditions are slowly improving with time as the vacuum chambers are cleaned up by synchrotron radiation desorption. Nothing in the behavior of the rings so far has displayed any unexpected or unforeseen problems.

A commissioning team was formed from members of the linac team and the KEKB group. In the course of the two-day presentations many new and refreshingly young and highly motivated members of this commissioning team reported on their work. The head of the commissioning team, Professor Oide, gave more details on the commissioning process. The lattice functions of the rings were measured to be close to the design values. With the beam sizes at the interaction point (values of beta functions) approximately twice the design values, the beam-beam effects (deflection and beam-beam bremsstrahlung) were close to the predicted numbers. The radiofrequency systems (ARES and superconducting cavities) worked smoothly as designed.

The positron injection rate (0.4 mA/s) and the injection stability were somewhat below expectations. Some sources of instability have been identified and upgrades are in progress. The Committee strongly encourages these efforts. In the future the injector linac will have the additional tasks of supplying 2.5 GeV electrons to the Photon Factory and to the Accumulator Ring while serving as the 8 GeV electron and 3.5 GeV positron injector for KEKB. The Committee approved of the creation of a Task Force, headed by Professor Kihara, Director of Accelerator Laboratory, to address the problems of delivering beams to four different users. The Committee recommends that this Task Force also evaluate whether the long-term need for improving the positron injection rate justifies building a low-emittance accumulator ring.

In the following special linac upgrade talks, the immense scope and the success of this project became clear and were applauded.

Dr. Seeman from SLAC gave a report on the PEP II B-factory in the United States, a similar collider built at SLAC with time schedules close to those of KEKB.

The KEKB rings display beam instabilities which could be controlled with the existing feedback systems up to the largest currents reached so far. It will be important to identify and analyze these instabilities in the commissioning process, so that additional remedies can be prepared if the existing stabilizing feedback systems prove insufficient at the highest currents.

A very important area of analysis is that of the background conditions at the interaction point. At present, the backgrounds are too large for successful and safe detector operation. Most of the background is probably due to injection, but radiation due to insufficient vacuum in the interaction region is also a concern. A special detector, the BEAST, is being used to track down causes for the excessive radiation background and to evaluate the effectiveness of remedies like movable collimators and radiation masks, which have been installed for just this purpose. It is hoped that by April 1999, the BELLE detector can be moved into position at the interaction point and that the overall system of storage rings and particle detectors can be tested together.

The initial complement of RF systems for both storage rings is installed (about 50% of the final set of accelerating cavities) and working perfectly. This will make storage of up to 50% of the design currents possible, a process more than adequate at this stage of the commissioning. The remaining ARES cavities and superconducting cavities, together with their RF power sources, will be ready for installation when they are needed. The smooth and proper functioning of these highly complex systems deserves special mention and praise.

The extensive beam instrumentation and controls for the operation of the KEKB storage rings are almost faultless, and have helped greatly in the rapid commissioning of the machines. The causes for occasional computer crashes need to be identified, but such problems occur in other major installations and are not uncommon.

In conclusion, the KEKB Machine Advisory Committee was most impressed by the perfection of the design, construction, and commissioning of this new, large facility. No technical or design errors are apparent. The commissioning team and the project leader are highly motivated. A timely conclusion of the commissioning process and a successful start-up of the high energy physics research program with KEKB should be expected.

Findings and Recommendations

A) Overview

The construction of KEKB, a five-year project costing 380 × 10^8 yen, has been completed within two months of the date projected in the original, aggressive schedule—a major achievement of which the entire project staff can be proud.

During 1998, the linac upgrade was completed, increasing the maximum energy from 2.5 GeV to 8.6 GeV by adding new accelerating sections and installing SLED cavities. The positron yield was also increased by a factor 20. The new linac was successfully commissioned, as were the new transfer lines. The linac has been operating successfully since June and has been available to support the KEKB ring commissioning.

The initial complement of RF systems—both superconducting single-cell cavities and the ARES coupled cavity systems—was completed, tested, and installed. They have been operating since December with virtually no problems, an incredible achievement considering that both cavity systems were new developments.

The interaction region of KEKB is, by its very nature, extremely complex because of the large number of constraints that must be satisfied. The superconducting final focus quadrupoles are a good solution. They were completed in 1998 and their fields were measured in their final operating configuration in the presence of the BELLE detector solenoid field. Many non-standard magnets were also designed, produced, and installed on time.

Commissioning of the rings started at the beginning of December, and despite a couple of hardware problems (LER dipole coil cooling passages blocked, vacuum event in the interaction region), progress has been extraordinary. This was helped by having a single, cohesive commissioning group, headed by Professor Oide, and by operating the linac, transfer lines, and both rings from the same control room.

Beam was stored for the first time in the HER within 13 days of first operation and in the LER within four days of first operation. The first collisions occurred only 12 days later. These are outstanding results, indicating that the construction and installation were not only rapid, but also accurate. Virtually all of the diagnostics and software that were needed for commissioning were also available right from the start, which contributed to these successful results.

The beam currents have been increasing as commissioning proceeds (243 mA in the HER, >300 mA in the LER) and the vacuum has been cleaning up following the predicted relationship. The only major problem was the vacuum incident in the IP caused by synchrotron radiation burning through the vacuum chamber. The vacuum group has made an excellent recovery from this setback. They have already redesigned the vacuum chamber with increased cooling, and the new chamber is promised from the manufacturer with only a two-week turnaround. This problem is a part of the general problem of synchrotron radiation and particle loss in the interaction region, which will need to be addressed in order to achieve physics-quality collisions.

The linac is scheduled to operate as the injector for the Photon Factory and the Accumulator starting in June, while continuing to support the commissioning of both KEKB rings. A Task Force headed by Professor Kihara has been set up to address the problems inherent in delivering beam to four rings with widely different requirements. The Committee encourages this team in its endeavors; it will not be an easy problem to solve, and the physics program of the laboratory depends upon their success.

The schedule for completing the rings (RF, diagnostics) is appropriate; the proposed roll-in date for the BELLE detector (April 19) seems tight but not impossible, although the backgrounds may not be as low as ultimately desirable.

The incredible progress since the last Machine Advisory Committee is a credit to the laboratory director, Professor Sugawara, the project leader, Professor Kurokawa, and the entire project staff.

B) Commissioning

KEKB commissioning is progressing very well. The commissioning team under the direction of Professor Oide is strong and has the appropriate breadth of experience. The rapid accelerator progress is to be highly commended.

The ring vacuum system seems sound and the pressure levels are processing as expected. The beam position monitor system is working well for this phase of the project. The HER has achieved 243 mA and the LER >300 mA in about 1000 bunches each. Both levels are very respectable. The diagnostics and controls are in good condition.

The Committee agreed with the plan for addressing the beam issues which have been identified by the commissioning staff. There are approximately 110 accelerator shifts remaining until the April 19 installation date for the BELLE detector. The detailed plan for using them must be worked out during the run, but care must go into scheduling activities, as the time will go very rapidly and unexpected events will happen. A prioritized list should be made and followed, but less important tasks should also be given some time. As much simultaneous two-ring work should be done as possible to maximize vacuum scrubbing and the operational burn-in or systems check-out time.

Little work, so far, has been done on dispersion and coupling correction. We concur with the commissioning team that these are important issues to be addressed soon. Going to the design beta functions at the interaction point is important, as issues of ring acceptance, beam lifetime, injection, and backgrounds may appear. We suggest trying both the design horizontal and vertical beta functions soon. We also suggest measuring the dynamic aperture of both rings to check if the harmonic content of the interaction region quadrupoles has an adverse effect.

Injection efficiency is an issue with the LER. Time should be allocated to understand the background implications of injection and to identify which possible future upgrades are the most promising. Measuring the momentum acceptance of the rings may illuminate issues with injection.

As multi-bunch instabilities affect the peak current stored in the LER and also the quality of the colliding beams, significant time should be allocated to instability studies. The proposed cures presented at the last meeting for the PEI instability should be reviewed so that beam tests along those lines may be done during the next month.

A significant amount of time is planned for vacuum scrubbing. A large fraction of this time may be used effectively for simultaneous activities such as colliding multiple bunches, background studies, or watching orbit drift.

C) Linac and Beam Transport Lines

There has been great progress on the linac upgrade program from 2.5 GeV to 8.0 GeV in a short period of time. Also, there are two stand-by units available for 0.6 GeV extra beam energy. Last year at this time, electron beams turned the J-section, and the beams were further accelerated to the full energy. On the other hand, positron production and acceleration to 3.5 GeV was also successfully carried out on time for the KEKB commissioning. We congratulate the Injector-Linac Group for their dedicated hard work.

For positron production, electron beams of 10 nC are used for positron beams of 0.6 nC with energy spreads of 0.125% and emittance of 2.5×10^{-4}. The performances obtained up to now are very close to the design values. However, the same linac will have to serve four different assignments, and its operating modes are to be changed frequently, especially during the period of KEKB commissioning. The beam characteristics must be reproduced quickly, and with great accuracy. Since some components or subsystems are twenty years old, their reliability should be checked very carefully. Operational experience shows that the subharmonic buncher system should be upgraded immediately. The Committee congratulates the Injector Group for their dedicated work to identify these weak components. This work will pay off rapidly in improved injection conditions for KEKB.

The RF-systems generally require long-term conditioning to be reliable. There are a few brand new subsystems such as new accelerating sections and SLED cavities. It will take time to reach a stable state with constant running of the machine. Therefore, the Committee believes that the initial problems will be overcome soon.

The beam transport lines of the 8 GeV electron and 3.5 GeV positron beams were constructed and used for the initial KEKB commissioning. The beam transmission efficiencies were reported as 100% for electrons and 80% for positrons. There is room for improvement in the positron beam-transport efficiency by further matching of the beam optics. It may require better diagnostics and the installation of beam dumps at the end of the transport lines. This should allow confirmation of the beam characteristics before and after the beam energy collimators and also near the injection points prior to beginning injection into the rings.

The Committee strongly agrees with the plan of the special task force team for the injection mode study headed by Professor Kihara.

D) Lattice and Orbit Analysis

Good progress has been made in the analysis of the lattices of the HER, the LER, the linac and the transport lines. This is encouraging especially because of the very short time since the start of commissioning. There are a few apparent lattice problems facing the commissioning team, but these problems will be resolved as the commissioning effort continues.

Among the issues currently being addressed, the LER vertical optics is found to be off from the design. The vertical tune is off by about 0.2, and occasionally large deviations were observed in vertical beta and dispersion functions. Efforts are in progress to identify the possible error sources, including beam-based measurements and additional magnet measurements. It is suggested that the beam-based diagnostics tool using the response matrix technique be adopted and applied to the LER. This tool has been applied effectively in other laboratories and is available.

The beams were observed to have substantial coupling. The minimum tune split was found to be as large as 0.04 after a minimal decoupling effort was made. The Committee considers the decoupling work important because of its impact on the collision studies and looks forward to the results of further decoupling using the available skew quadrupoles.

A singular value decomposition technique has been applied to the linac and the LER to identify any jitter sources. The Committee is impressed by this work, which is a completely new application of a theoretical approach due to John Irwin at SLAC. As a result of this effort, the SLED cavity at the end of the Linac A sector was identified as a source of jitter which, when corrected, resolved the problem. Also, a few LER beam position monitors were found to be particularly noisy. This is an excellent diagnostic tool. Its applications should be further explored and applied, especially when the beam intensity increases, as this technique might allow the detection and diagnosis of any collective beam modes.

Of particular concern are the orbit drifts in the KEKB rings. The vertical orbits were found to exhibit a long-term drift of about 1 mm over a ten-hour period and a short-term drift of 0.1 mm in ten minutes. Efforts were made to identify the possible cause of these orbit drifts. The Committee feels this effort is very worthwhile and should be continued. These orbit drifts, however, are a serious impediment to other operations, and have hindered the commissioning progress. It is therefore suggested that, in addition to the effort to identify the cause, a practical approach be taken to find a way to feed back on them regardless of the cause and remove them as an operational concern as soon as possible. This will require that the BPMs in the interaction region be made less sensitive to HOMs and/or synchrotron radiation.

Studies of the interaction region lattice are discussed elsewhere in this report.

E) Instabilities

No single-bunch instabilities were expected at the design current and none were seen. The 10% increase in bunch length which was observed is in agreement with predictions.

Although no commissioning shifts have yet been dedicated to the study of coupled transverse multi-bunch instabilities, there is already substantial evidence of Fast Ion Instability (FII) in the HER (e-) and Photo Electron Instability (PEI) in the LER (e+).

Without feedback, multi-bunch instabilities limit the injected current in the LER to about only 0.7% of the design current (~18 mA) for bunch separations of five buckets or less, and about 2 to 4% of the design current for bunch separations of ten buckets or more. Much higher thresholds are expected from the fairly well known resistive wall and cavity HOM–induced transverse coupled bunch instabilities. The variation of thresholds with bunch spacing is in qualitative agreement with the expected short-range wake of the PEI.

Without feedback, multi-bunch instabilities limit the injected current in the HER to about 10% (80–114 mA) and the maximum current is dependent on the filling pattern. The head-to-tail intensity profile and bunch oscillation amplitude along the bunch train are compatible with what is expected from the FII.

So far the transverse multi-bunch feedback systems (with an estimated damping time of 1–2 ms) have been successful in eliminating the coherent signals and raising the injected current to 240 mA in the HER and more than 300 mA in the LER.

The single-pass BPM system with memory boards is expected to be commissioned shortly and will enable detailed studies of the growth rates of PEI and FII as well as a confirmation of the expected damping rates of the feedback systems. Since the PEI growth rate is expected to be very fast in the LER (150 μsec or 15 turns with significant uncertainty) and is faster than the design damping rate of the feedback systems, these studies should be pursued with high priority. Measured growth rates will make it possible to predict whether the instability can be cured with the existing feedback systems or whether an upgrade of the feedback systems (more power, gain and/or more kickers) or other cures (solenoid) will be needed.

The FII in the HER is less critical because the growth rate is slower, and it is not expected to be much faster in the future as the vacuum improves due to synchrotron radiation scrubbing. However, the combination of the fast multi-bunch feedback and the memory boards will provide excellent tools to study it in detail.

These studies will involve temporarily switching off the feedback systems with high stored currents, and will therefore involve a certain risk of suddenly losing a large fraction of the beam. Thus it would be preferable to pursue these studies prior to detector installation, unless it can be demonstrated that collimators can concentrate the losses away from the IR.

Longitudinal coupled bunch instabilities have not been observed and are not expected at the presently stored currents, but a feedback system is available if and when it is needed.

Recently, an unexpected rapid increase in pressure (not linear with current) has been observed in the PEPII LER above a threshold of about 400 to 800 mA. This is believed to be associated with beam-induced multipactoring (which was first observed by O. Gröbner in the ISR at CERN about 30 years ago). Fortunately for the KEKB LER, this threshold goes up with reduced bunch spacing and may therefore be much less of a problem in KEKB than in PEPII.

F) Interaction Region

The interaction region has been completed in the past year according to the design. It has sound accelerator physics input and engineering and was implemented very well. The integration with the detector BELLE has also been done well.

The radiation shielding near the interaction region is being upgraded. This shielding will remain an issue for a while, even with BELLE installed, because the beam currents and injection rates will increase.

The superconducting quadrupoles at the collision point were constructed in a timely way and have excellent field harmonics. However, the cryostat, and thus the quadrupoles, move with time and with the BELLE solenoid forces. These motions will affect the beam orbit in this very sensitive portion of the ring. The studies of these motions have been very thorough so far and we suggest continued investigations.

In general, the alignment of all the quadrupoles in the interaction region is crucial, and review of the sensitivities and the observed alignment should be made.

The special steel quadrupoles near the interaction point are difficult magnets to design and manufacture. We were shown that several of these magnets have, or may have, field harmonics which may reduce the dynamic aperture of the rings. We support the continued tracking studies to investigate the effects on the dynamic aperture and for designing and constructing better quadrupole magnets if needed. Dynamic aperture studies with the beam are encouraged. Furthermore, beam studies designed to observe the motion of these quadrupoles with beam current through vacuum chamber forces are suggested.

In light of the recent vacuum event, further studies of the radiation fans of the two beams in the interaction region should be carried out. Such studies would show whether there are other vacuum chambers exposed to radiation heating during manipulations of the beam during beam-beam studies, background studies, or poor orbits made by errant trim dipole correctors.

The fine tuning of local coupling and dispersion in the interaction region introduced by the detector solenoid and global ring errors requires special adjustment "knobs" in the control system. Similar "knobs" are needed to adjust the beam waists and skew at the collision point. We suggest trying these knobs on the beams during the next month, as testing them with BELLE will be more difficult.

G) Collisions

The first beam collisions in KEKB were observed on January 26, 1999. Further studies have observed beam-beam deflections in both the horizontal and vertical planes and have seen a luminosity signal in the forward detector of about 10^{30} cm^{-2} sec^{-1}. This was done with single bunches and approximately the design charges. These results are highly encouraging and congratulations are in order for the commissioning team. This rate of progress bodes well for the future.

The method to scan the horizontal beam size by using the LER RF phase is very clever and interesting. We have a concern that at high currents this technique may be difficult, since the vertical beta function enlarges significantly over the longitudinal separation length used. It may also be affected by parasitic crossings with every bucket filled.

Beam studies with the design betas at the collision point are highly recommended to observe any accompanying beam problems. Many issues may be driven by these changing betas, including backgrounds, orbit drifts, chromaticity changes, injection losses, and beam-beam limits.

We encourage studies of single bunch collisions to maximize the single bunch luminosity, both before and after the installation of BELLE. These studies are aimed at increasing the beam-beam tune shifts to their maximum values, finding the optimum beam currents, beam emittances, interaction region betas, and beam lifetimes. With single bunches the integrated backgrounds in the detector components will be minimized.

We also encourage significant multi-bunch collision studies in the next month so that effects of beam-beam parasitic crossings, injection complications, specific luminosity with many bunches, head-tail RF loading issues, and luminosity monitor calibration and beam-gas background subtraction may be studied. Further studies of the techniques to put the beams into collision, longitudinally or transversely, should be carefully tried with the correct bunch spacing to see if there are issues which may affect BELLE. Multi-bunch collisions are required to produce significant luminosity for BELLE, but multi-bunch studies have the potential for significant radiation damage.

All of these accelerator studies must be organized in a logical sequence to maximize beam time usage.

A close-in low-angle scattering monitor is suggested which allows very fine detection of subtle beam-beam changes and is used to optimize interaction region parameters.

The interaction region magnets generate some magnetic coupling of the two rings. Continued work to reduce these couplings is encouraged, since many magnet changes will be required to adjust and squeeze all the luminosity from the KEKB interaction region.

H) Backgrounds

We commend the efforts to begin measuring, understanding, and reducing machine-induced detector backgrounds from the start of KEKB commissioning. The BEAST detector is well conceived and many of its elements are contributing. We encourage the BEAST group to commission the recently installed silicon strip detector, and also to measure the dose and spectrum at the radius of the CsI calorimeter. It may be useful to shield large-radius detectors against radiation from far upstream sources coming down the tunnel, to simulate the shielding provided by the BELLE flux return. We also encourage the BEAST group to consider the KEKB distributed loss monitors as a tool for understanding the sources of backgrounds. It should be investigated whether the machine loss monitors are dominated by synchrotron radiation, particularly in the interaction region, and they should be shielded with lead if necessary.

The Monte Carlo simulation of backgrounds is relatively complete. However, the GEANT simulation of the beam line should be extended to include all of the high-beta quadrupoles on the incoming beams, not just the QCS quads. We also recommend that the TURTLE simulation be done with a realistic pressure profile—which would probably have a higher pressure in the arc regions than the IR—and with measured or estimated gas species composition. At PEP-II, the analogous changes doubled the calculated backgrounds.

A very useful experiment is to measure the increase in measured backgrounds when a NEG pump is heated up while the beam is circulating. This produces a localized pressure bump dominated by hydrogen, with an amplitude that can be measured by local ion pumps or cold-cathode gauges, and with a length that can be calculated from known conductances. The increase in background from the localized bump can also be calculated in the simulation. A relatively precise comparison between data and Monte Carlo can be performed, for a variety of gas-source locations around the IR and the whole ring.

The integrated dose at the radius of the silicon vertex detector to date is 65 krad, to be compared to the estimated detector lifetime of 200 krad. This is dominated by injection, particularly in the LER. The problems may increase when the beta functions go to the design values, and injection will be complicated by switching between KEKB and the Accumulation Ring and the Photon Factory programs.

The machine and detector groups must give high priority to learning how to inject with much lower dose to the detector. We suggest that a task force of people from the linac, beam-transport, ring, controls, and background groups develop a program of machine experiments to understand the injection dose and develop procedures for clean injection.

Time-resolved beam-loss monitors should be developed to determine whether the losses occur in the first few turns (transverse betatron motion), the first few synchrotron oscillations (longitudinal motion), over the damping time, or with some other time scale.

Collimators in the ring or in the injection line may help. Switching between a lattice optimized for injection and a lattice optimized for luminosity and stored-beam backgrounds may also reduce the injection dose. Tuning of injection would be much simpler, less interfering, and produce less dose to the detector if there were a tune-up dump and analysis station just before the ring injection points. In the long run, a positron damping ring could greatly improve positron injection.

The measured dose from stored beam is stated to be 0.01 and 0.04 mrad/sec/nTorr/mA for the HER and LER respectively at the silicon detector radius. Since the LER current needs to be about 2.5 times the HER current to equalize the tune-shifts, at equal vacuum the LER dose would be 10 times higher than the HER dose. For a flat 1 nTorr vacuum at full current of 1 and 2.5 A, this extrapolates to 100 krad and 1 Mrad from the HER and LER in a running year of 10^7 seconds. The Committee was shown very little on how the stored beam dose was estimated, and it is very important that the analysis be carefully checked, and further data be gathered.

It is noted that there has been almost no attempt to tune the machine for minimum detector backgrounds, so there is reason to hope that these numbers could be reduced. Beam time needs to be devoted to steering at the interaction point and collimator setup.

At 10 ampere-hours and 1 A, the HER pressure would be 30 nTorr according to the background group, and the HER arc pressure would be 200 nTorr according to the vacuum group. These groups need to understand how their assumptions are different. The LER pressures are even higher. In any case, it is clear that a lot of scrubbing (many hundreds of ampere-hours) will be required to reduce the pressure to the nTorr level with ampere currents. Since beam-gas backgrounds from dynamic pressure are quadratic with beam current, if the scrubbing is done quickly (i.e., with high beam currents) the dose to the detector could be very large. We commend the effort to understand the vacuum in the interaction region, and to install more pumping if necessary.

It is vital that communication between the accelerator control room and BEAST (and soon BELLE) be excellent. Some BEAST signals are already available to KEKB; it must become standard practice to keep them live at all times and pay attention to them. Such communication must also exist for whatever background monitors are installed with BELLE.

Before the BELLE roll-in, mechanisms must be in place to control the radiation dose to the detector. The minimum would be real-time signals (available even when BELLE is not taking data) for the operators to monitor and minimize. Preferable would be automated systems to limit the injection rate and dump the stored beam, as employed at CESR and PEP-II. These measures do limit accelerator operations and the ability to freely do any possible machine study, but in the long run lead to a successful experimental program as operators learn to limit the dose delivered to the detector. The sooner this becomes the mode of operation the better.

Finally we firmly recommend that as much time as possible be spent on background studies between now and BELLE roll-in on April 19. The current status is not good for the prospects of a long-term BELLE run, but this is based on very preliminary data and no attempts to properly place collimators and otherwise tune the beam for background reduction. If it is not possible to greatly improve the backgrounds, BELLE may need to contemplate rolling in without a full vertex detector.

I) Magnets, Alignment and Power Supplies

The Magnet Group has done an exceptional job over the last few years. A total of 3364 magnets (not including spares) of 35 different types were fabricated and measured. All magnets satisfy the exacting optics requirements. In addition, detailed studies of the field distributions have been undertaken as well as of proximity effects between the quadrupoles and correctors. This is far beyond what is usually done and will serve the project well. Every magnet was subjected to full-power tests and measurements. However, this did not prevent an insidious problem from creeping into the LER dipole coils. Of the 276 coils, 31 were improperly capped during the epoxy potting process, allowing a small quantity of epoxy to enter the cooling channels, creating a thin film which initially had no effect on the water flow. However, the film flaked off during operation, eventually causing a blockage. The response from the magnet group was fast and effective, with rapid diagnosis of the problem and effective corrective action completed.

One problem still needs attention. The C-type steering magnets have a sufficiently large stray field that they affect the other ring in places where the two rings are close to each other near the crossing points. New types of magnets (H type) will be designed and installed. Interference between the rings needs special attention. A temporary solution may be the use of soft iron shielding between the rings near magnets with a leakage field to channel the field away from the other ring.

The magnets and other components were installed in the ring on a very rapid schedule and, judging by the commissioning results, with great accuracy. More than 3000 magnets of different varieties were installed and aligned, and all this work was well done in a six-month period. Congratulations! The Committee was surprised at the continuing sinkage of the tunnel in the South Arc, but agreed with the solution adopted to deal with the problem. All in all, this was an exceptional effort.

The Committee recommends to pay attention to permanent control of drift, movement, and vibration of the final focus lenses.

More than 2200 power supplies have been produced, tested, and installed in an extremely short period. The stability requirement for field ripple is very high, of order 10^{-5}. At present, only the field ripples for QC1LE and QC2RE do not satisfy the specification and require further work. In addition, the currents for the steering magnets (St and Sx) has a thermal drift which will be corrected by improving the temperature stabilization of the power supplies.

J) Vacuum

The main concern about the vacuum system in the last meeting of this Committee was the delays in production and delivery of many kinds of vacuum chamber. Now all of them are installed, pumped down, and working very well, especially in the arc sections of both the HER and LER.

Dynamic pressures, the pressure normalized by beam current, and the photo-desorption yields decreased in both rings with the integrated photon doses as expected. The beam-scrubbing process in the commissioning stage progressed according to expectations. The total amount of gas molecules desorbed, mainly by photon irradiation, is within a factor of 2 of the estimate, so the NEG pumps have been activated as scheduled.

To get the vacuum in the nano-Torr region with ampere-beam storage, over 500 A-hr operation is estimated to be necessary for HER and 1000 A-hr for LER.

Micro dust trappings are observed in HER. Judging from the experience at the Photon Factory and other electron storage rings, when the electron beam current goes up to 400 mA or more, the dust trapping will decrease gradually, so it is not expected to be a serious problem. Of course, slow, careful venting is required with a micro filter in the venting line.

Though the Committee commented on the inherent weakness of the Helicoflex gaskets in the last meeting, they seem to be stable in practice. In the beam cleaning process, m/e spectra of 18 (H_2O), 32 (O_2) and 40 (Ar) were observed, which are typical gas species in air leaks. The residual gases should be analyzed carefully and continuously during long-term operations, to ensure that the Helicoflex gaskets do not degrade with time and thermal cycling.

Some bellows, gate valves and NEG pumps heated up as beam was accumulated. Since the temperature rise seemed to be proportional to the square of the beam current, HOM loss may be the dominant cause. Careful monitoring of the temperature of such components is required, and the data should be plotted against the product of the peak charge and the average charge to enable accurate predictions of the problems when the rings are at full power. Beam related heating was also observed in the interaction region; the vacuum pressures rose and caused high background. Though the vacuum group believes that the pressure rise came from irradiation of synchrotron radiation from the QCS magnets, heating due to HOM loss should also be taken into account.

Many of the vacuum chamber in the interaction region have complicated structures. One of them was connected using a “magic flange”, a component that the Committee had been skeptical of, but which has proved very successful.

In the commissioning stage, strong synchrotron radiation caused a vacuum leak and pressures in about half of both rings increased, in some parts up to almost atmospheric pressure. This was caused by the area monitor study at the interaction point. A newly produced vacuum chamber will be improved with a water channel for better cooling and by adding thermocouples for monitoring.

The vacuum pressure in the interaction region should be improved in order to reduce background bremsstrahlung, which is one of the noise sources. Hydrogen and methane are the dominant residual gases in the interaction region. Though the hydrogen gas load is greater, the pumping speed of the NEG pumps is higher for hydrogen, and since in addition it has a low Z number, hydrogen is not a concern. Less methane is released, but the NEG pumps cannot pump it, so methane is the dominant residual gas at the interaction region. The adoption of sputter ion pumps was proposed for pumping methane but sputter ion pumps do not have a high pumping speed for methane. One recommendation is that turbomolecular pumps be arranged at the pumping port of the sputter ion pump, in parallel with pneumatically operated valves controlled by an interlock system.

The interlock system for the vacuum system did not work very well because the pressure set points were too high to prevent air from rushing in. Such a high pressure setting is directly due to the poor reliability of the vacuum gauges. The vacuum safety system has not been considered or discussed fully for high current, i.e., for stored beams in the ampere range. Intense synchrotron radiation will hit the vacuum chamber if one or more magnet power supplies fail accidentally. Reliable vacuum sensors and an operating scheme are not available now. Both should be prepared before higher-current commissioning.

In the design of the interlock systems, the vacuum interlock and the beam abort system should be integrated. The operating time constants of the relevant components have to be discussed carefully. The cold cathode gauge has poor performance over the wide range of vacuum measurement. Because there are many important components, including superconducting RF cavities, not only cold cathode gauges but also hot cathode gauges and small sputter ion pumps are recommended as a trigger for the vacuum interlock system.

K) RF System

The production, installation, and commissioning of the RF system for the LER and the HER has proceeded on schedule and is well on the way, having already accumulated more than 1000 hours of successful operation. This is an impressive achievement for such a challenging system. The Committee wishes to congratulate the efforts and successes of the RF group.

Out of a total of 24 ARES cavities produced so far, 22 have been RF conditioned to power levels between 180 and 240 kW, compared to the design cavity dissipation power of 150 kW. The typical total conditioning time was two weeks.

In the LER, the 12 ARES cavities installed have stably provided 4 MV and a total beam power of 175 kW at 200 mA beam current. The maximum HOM power extracted was 0.2 kW per cavity at 300 mA beam current. Six ARES cavities have been installed in the HER and operated at 1.8 MV to deliver a total of 200kW beam power at a beam current of 210 mA.

Four superconducting cavities have been installed in the HER, and have operated stably for more than 1000 hours to provide a total of 6.2 MV and a total beam power of 680 kW. For short periods, the superconducting cavities have been operated at 2 MV each, and have delivered more than 200 kW each to the beam.

The high-power tests of the fully assembled superconducting cavities have shown an even higher voltage capability, 2.6–3.1 MV. For most cavities the dynamic heat load is between 20 and 33 W at 2.0 MV each, and the static heat load is between 27 and 30 W. One cryostat developed an insulation vacuum leak from liquid helium vessel to increase the static heat load to 67 W. Therefore, the total heat load for four cavities at 2 MV each is 250 W (100 W dynamic and 150 W static load). Since the available refrigerator power is 6 kW, there is plenty of margin for expansion to crab cavities when needed (see below).

The following table summarizes the performance of the ARES and the superconducting (SC) cavities in the HER/LER at the present time, and also shows the parameters needed to reach full beam current.

	HER		LER	
	Now	Full current	Now	Full current
ARES cavities installed	6	12	12	20
ARES cavity voltage	0.31MV	0.5 MV	0.33 MV	0.5 MV
HOM per cavity	0.2kW	1.2 kW	0.2 kW	7 kW
ARES beam power per cavity	30 kW	250 kW	15kW	250kW
SC cavities installed	4	8	0	0
SC cavity voltage	2 MV	1.5 MV	–	–
SC HOM per cavity	1.5kW	5kW	–	–
SC beam power per cavity	200 kW	250 kW	–	–

The complete RF system is operating very stably at 99% reliability with parameters close to the final requirements as shown in the table. Since these are extremely complex systems that have been developed by KEK on a tight schedule, this performance level is exceptional.

The prognosis for reaching the full-current RF requirements is very good in view of the off-line high-power test results conducted on the HOM loads, windows, ARES cavities, and SC cavities. The plans for the production of the remaining units appear sound and timely.

Development of the crab cavities has been progressing. Four crab cavities will be required in the future to deflect the beams to provide head-on collisions for maximum luminosity. The present design has a $\pm$11 mrad crossing angle.

The crab cavity project is presently in the R&D phase. This year the most important step has been a successful test of the squashed niobium prototype with a model center conductor for the fundamental mode extractor. The design field was reached at a Q of 10^9. A second model conductor with T-stub support is under fabrication. The conceptual design for the cryostat is progressing. The infrastructure for the clean room and high-pressure water rinsing is underway. Much work remains to reach a complete system of four crab cavities. This is an important effort and the Committee recommends that it be continued.

L) Beam Instrumentation

There were three excellent presentations on the KEKB beam instrumentation systems—an overview as well as presentations on the BPM and synchrotron radiation systems.

These systems have been well thought out and implemented, and have contributed significantly to commissioning successes so far. Plans for improvements also seem to be appropriate and progressing well. There was some concern about occasional BPMs which appear to give erroneous readings, due perhaps to radiation effects or stray fields. It is critical that BPMs at the interaction region be thoroughly checked and calibrated. There are plans to halve the time required to obtain a complete orbit measurement (from four seconds to two) by doubling the front end processing power.

The Committee particularly wishes to recognize the impressive accomplishments with the SR interferometer. The pictures are beautiful, and the work is truly a "tour de force." Congratulations!

M) Bunch Feedback Systems and Related Diagnostics

All the transverse multi-bunch systems (LER and HER) have been successfully commissioned, they work well and have been very successful in eliminating the coherent multi-bunch signals as well as dramatically increasing the stored current.

The growth/damping rates are expected to be measured soon by means of the associated large-size memory boards. These are important for identifying the source and nature of the instabilities as well as for making predictions and plans for higher current: whether more gain, power, or kickers are needed at high current in the LER. While these boards have been used in BEPC to study transverse instabilities, the ability to start the instabilities from a small amplitude by switching the feedback system off enables a much more detailed study of the modes, because small amplitude growth rates can be measured. Without feedback available, only the saturation mode pattern can be observed.

Slow changes in BPM position are now being eliminated by a circuit to cancel the DC offset prior to the ADC. While the two-tap filter in principle can do the same, the DC offset enables a more efficient use of the limited dynamic range of the 8 bit ADC. Alternatively a slow, local closed-orbit correction system could be implemented.

The longitudinal multi-bunch feedback system has not yet been commissioned, but is not yet needed either.

N) Control System

During the course of two days of presentations, an impressive array of data was presented by many groups on all aspects of the various accelerator subsystems. Much of this data—both raw and analyzed—was presented in the form of screen images of control room displays. It was apparent that the control system has made a significant contribution to the highly successful commissioning of KEKB. This has been made possible by the integration of SAD, an accelerator modeling tool already used at TRISTAN, and Python, an object-oriented scripting language, within the EPICS toolkit. The controls group is to be congratulated for having paid attention to these high-level tools from the outset. All too frequently such capabilities are available only long after the time of maximum need—commissioning. Still, the need for applications is unending. It was estimated that the same number of high-level programs remain to be written as have been written to date. Fortunately the tools to facilitate this work are already in place.

Not unexpectedly, and not more than for comparable systems at the same stage of development, the control system has encountered a number of problems. Some of these have already been addressed, and it is gratifying to note that in at least one instance the solution came from the world EPICS community. The controls group is encouraged to continue using the EPICS community and its network as problems are identified. Frequently someone out there has solved a similar problem. Most troubling is the unduly high number of IOC crashes being experienced. CEBAF experienced a similar symptom, but those problems have been fixed in the version of EPICS in use at KEKB. It appears, however, that a new set of problems may have surfaced. Still, the proposed upgrade to the latest version of EPICS (v3.13.1) will do no harm, since a "Beta" version is in use at present. The good news—or is it the bad?—is that the frequency of crashes is such that a diagnosis should be possible, and present indications are that the problem is hardware-related. It is important for the commissioning team to allow time for the controls group to learn as much as possible after each IOC crash. The diversion of accelerator time will be well rewarded. It appears that this is already happening.

The presentations suggested many areas where the controls group should be able to contribute to more efficient, reliable, or productive operation. Automation of the linac mode changes is an obvious candidate (provided adequate beam instrumentation is available). The controls team should be represented on the injector mode task force led by Professor Kihara. The possibly suggestive observable precursors to the recent vacuum event, all archived by the control system but not noted or correctly interpreted by the commissioning team, seem a candidate for some artificial intelligence analysis. It would have taken a sophisticated human observer indeed to note the anomalous behavior and guess the outcome. Some proposed slow feedback systems might also be implemented in software, as should implementation of the "knobs" (for local coupling and dispersion as well as for beam waists and skew at the interaction point) described in the "Interaction Region" section of this report. The controls team should be having fun for some time.