The Third KEKB Accelerator Review

Introduction

The third KEKB accelerator review Committee was held on March 5-7, 1998, thirteen months after the second Committee meeting held on January 23-25, 1997. The membership of the Committee is shown in Appendix A.

This third 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 third meeting of the KEKB Accelerator Review Committee took place March 5-7, 1998, 13 months after the second meeting (January 1997). At the time of the second meeting the completion of the project construction was estimated for October 1998, but it was pointed out that only on a very aggressive schedule could this be done. Now, 13 months later, October 1998 looks more assured, and the KEKB staff must be congratulated on the enormous progress they have made during the last year. There are still some worries left about the timely completion, stemming mostly from the late delivery of some vacuum chambers and components, after one contractor has slipped badly in their contractual obligations with respect to the delivery schedules. But through continuous and detailed follow-up and control by members of the KEKB team, this situation may now be under control. There are also many smaller components still under construction (e.g., moveable collimators, special smaller IR magnets, injection kickers), but completion of all this for first beam trials in October 1998 does not seem to be unreasonable.

Most of the bigger components like machine magnets, RF accelerating units (superconducting and of ARES type), control system, power supplies, monitor systems, beam feedback systems, etc., are on schedules which are safely compatible with an October 1998 turn-on. Particularly the injector Linac upgrade and commissioning program needs to be mentioned, where full injection capability into the two KEKB rings is now imminent (3.5 GeV and 8 GeV, respectively).

Also very noteworthy is the fact that the large magnet of the BELLE detector together with its two compensating solenoids and the superconducting interaction region quadrupole magnets have simultaneously reached full design currents and fields.

At this stage of the KEKB construction it obviously does not make much sense to suggest any hardware changes, but there was also very little that the Committee members felt necessary to suggest. Two recently discovered and analyzed potential beam instabilities were discussed by the Committee members to some extent. The fast beam-ion instability (FBII) could in principle trouble the high-energy electron ring HER. But the rise times of the FBII seem to be in the range of 1 ms, where the transverse feedback system in place might be able to take care. The photoelectron instability (PEI) with estimated rise times as low as 150 microseconds is potentially more dangerous for the low-energy positron ring LER. A number of expected cures were discussed should this instability ever occur. But the Committee members agreed with the project leader that although intense studies of this instability and some preparation for possible action at some future time are recommended, no hardware changes are indicated at this moment.

A similar attitude prevailed with respect to the relatively low positron injection rates, which might want to be improved by a small damping/accumulator ring at some future date. Alternate solutions (e.g., simultaneous filling of more positron bunches) should continue to be studied, should their need become apparent in the future.

Plans for commissioning KEKB were intensely discussed. The advantage of having the BELLE detector in place for better background analysis and a more realistic scenario of magnetic fields near the interaction point IP was appreciated by all Committee members. The more radiation-sensitive parts of the detector like the vertex chamber and the forward/backward calorimeters should be installed at some later time after turn-on when a better understanding of machine behavior has evolved and the danger of radiation damage to the more sensitive detector parts has been reduced.

Overall, KEKB is in good shape and one can look forward to a timely and successful turn-on.

Findings and Recommendations

A Magnets

Almost all bends, quads, sextupoles, octupoles, wigglers and steering magnets except IR quads have been or will be ready at KEK by the end of this March.

Most of magnets have been or are being measured at KEK or at the manufacturers. The measured results show that the rms amplitude for bends and quads is within 3 to 6 x 10-4 and for steering magnets within 1 to 2 x 10-3, so that the excellent quality of the magnets meets the KEKB requirement.

The KEKB team has studied the potential problems with using backleg windings on the dipole magnets for horizontal orbit correction due to hysteresis effects, which was addressed by the Committee in the last Review meeting. The primary study results show that this effect is about 5 to 6 x 10-4 depending on the main coil current. The potential damage of the backleg power supplies caused by a trip of the main bus supply should also be examined.

B Power Supply

Over two thousand power supplies are required for the magnets of KEKB. They are all in production. A limited number of large power supplies are being recycled from TRISTAN. Apart from these, all the medium power (25 kW) and small power (300 W) units are switched-mode types with 20 kHz and 100 kHz switching frequencies respectively and are correspondingly compact. The electromagnetic compatibility related to radiated and conductive emission of switching noise has been checked and found to be in agreement with industrial standards.

The performance with respect to current ripple (1, 2 and 50 ppm for large, medium and small supplies respectively) and current stability (15, 15 and 50 ppm) and setting errors (30, 25 and 50 ppm) are quite satisfactory. A further factor ten reduction in field ripple (at 100 Hz) is invoked due to eddy-current shielding by the copper vacuum chamber. Since the eddy-current shielding may be less in the special IR quadrupoles, field-ripple in these locations should be checked. A high level of reliability and easy maintenance as well as compact construction are distinct design features. A separate DCCT permits monitoring the output current independently from the regulation system.

The schedule foresees completion of delivery by the end of June, installation till the end of July and complete readiness by the end of September.

The Committee is completely satisfied with the situation concerning power supplies, and wishes to express its appreciation of the excellent work.

C Vacuum

The principle of the layout and the manufacturing quality of the components which have been delivered up to now seem to be more than adequate, as the achieved base pressure after baking is better than anticipated. Also from first experiences of PEP-II, the value of 10-6 molecules/photon for desorption yield is confirmed. Thus the design average pressure of about 10-9 mbar should be reached after a conditioning time of about one month.

There is considerable delay in the delivery of vacuum chambers for the arcs of the both rings and straight sections. The Committee share the concern about this delay and the possible consequences on the overall time schedule. The overall installation schedule should be optimized under the changed conditions. The Committee recommends considering installing longer vacuum sections with all the necessary parts (including cabling, water cooling and so on) to make sure that the assembly meets the design with respect to dimensions and tolerances and that all parts are at hand. It is also recommended to make sure that a sufficient number of spare parts is available in case of failure or necessary modifications.

Given the inherent weakness of the Helicoflex gaskets and the high failure rate during initial installation, the use of alternate gaskets should be investigated. Also, the torque on the bolts should be increased to ensure metal-to-metal contact of the flanges, and spring (Belleville) washers should be used. These measures will help to minimize vacuum leaks created by thermal cycling of the chambers (expected to be about 1000 cycles per year).

The Committee appreciates that the design of the very complicated vacuum system around the interaction region has been completed. However, there is concern whether the scheduled production date can be met. The installation of a longer vacuum section would also allow to test pump down and leak test procedures.

D RF System

The RF system is fully developed, tested, and in production. In particular, prototypes of both cavity systems, ARES and superconducting, have been tested at full power and with substantial beam in the TRISTAN AR.

The effects of beam gaps on the voltage seen by each bunch have been evaluated, and are acceptable.

The RF system is to be installed and commissioned in two stages. For the first stage, the necessary voltage for 10 mm rms bunch length and 0.01 minimum synchrotron tune will be provided, which corresponds to at least 3 MV in the LER and 6 MV in the HER. This stage will limit the beam currents to 50 to 70% of the nominal values in the LER and HER, respectively. In this stage, 12 ARES cavities will be installed in the LER and another 12 ARES cavities, combined with 4 superconducting ones, in the HER.

In the second stage, 22 ARES cavities in the LER and 12 ARES cavities with 8 superconducting cavities in the HER will permit full luminosity and a maximum synchrotron tune of 0.02. In both rings, a two-to-one range of voltage variation is foreseen, in order to vary the synchrotron tune. The system is being designed so that the circulating beam survives an accidental trip of one RF station.

At this time, eight ARES cavities have been assembled. Five of these have been conditioned to full power. All four superconducting cavities required for commissioning are under construction. The low-level control and tuning systems have also been designed and tested. It is planned that the first complete RF station will be assembled in April, and all stations required for commissioning will be ready in October.

Current efforts to further reduce the superconducting cavity trip rate through ozonization, improved beam line pumping, coupler bias, and addition of thermal transition region outgassing capability are all worthwhile.

The superconducting crab cavities, which may or may not be required, could be used to create head-on bunch collisions in spite of the beam crossing angle. These cavities, which are not planned for installation prior to turn-on, are in an advanced state of development. A first full-scale prototype has reached a very noteworthy surface field of 31 MV/m, compared to the required operating value of 21 MV/m. The questions of optimum external Q and of tolerances in phase, amplitude, and beam alignment have been studied, although the effect of differences in amplitude between a pair of cavities may need more evaluation.

Considering that the RF system is potentially one of the more difficult parts of a B-factory, the Committee wishes to congratulate the KEKB team for their outstanding achievements in this area.

E Masks and Collimation

An initial study of masking and collimation calls for two pairs of horizontal and vertical collimators in each of the two rings. The plan is a good start. In the horizontal plane the betatron and energy collimators are combined. This arrangement should be checked for unwanted compromises. The impedance issues of these collimators are being studied and will likely not be negligible. The thermal protection of these collimators should be studied in the event that the abort system does not completely remove an errant stored beam.

The transverse position settings for the collimators will be chosen to protect the interaction region from the injected beam. After the beam is stored the collimators are likely to be moved closer to remove particles which spill from the coasting beam so they do not interfere with BELLE. The movement of these collimator jaws should be automated to maximize collision time and minimize errors.

Finally, the collimators in the Tsukuba straight section which will help minimize BELLE backgrounds have not been fully designed. Planning for this near collimation system should continue and location options left open as long as possible.

F Beam Abort and Dump

The beam abort and dump for errant beams are needed to protect accelerator components such as the collimators and the interaction region, and also as a radiation safety device. The design should be completed soon so that the hardware can be constructed, installed, and tested for commissioning in October.

G Control System

Since adopting the EPICS toolbox as the basis for the KEKB Control System, there has been considerable progress in integrating the existing controls experience at KEK and developing new bus architectures for connecting the hardware. The arrangement with the contractor (MELCO) appears to be working well with five people working at KEK for software development and linkperson support.

The system overview addresses some previous concerns of the Committee with a separate development area connected to the operations network via a gateway workstation. The IOC computers are upgraded from the previous version and now use a Macintosh PC chip on an IME board (FORCE Power Core 6750 with a 233 MHz MPC750 chip). EPICS has already been ported to this environment. The on-board memory is 64 Mbyte, which should avoid the problems of memory fragmentation which has been observed at Jefferson Lab.

The three timing synchronization circuits appear to have been well thought out and are under construction.

The ARCNET Magnet Power Supply Control System is an excellent development by the KEK group. The system allows for easy interchange of power supplies while maintaining the addressing information and supports automatic re-connection to the IOC.

The lack of a central database for configuration management is a weakness of the EPICS toolbox, and the KEK group has done an excellent job of integrating the ORACLE relational database into EPICS. The concept appears to be sound and is progressing well.

The focus should now be on defining the high-level applications that will be needed, especially for the interaction region, which is significantly different from TRISTAN.

H Radiation Protection

The extremely high currents in the B-Factory (1.1 A electrons and 2.6 A positrons) make it necessary to properly evaluate the radiation risks. There are two different areas: the injection line, where masks and collimators must be used to define the beam emittance; and the ring itself, where several different phenomena create beam loss. In both these areas, the analysis has been carried out thoroughly and completely.

In the transport lines, the positions of the collimators and masks have been carefully selected to limit the losses to areas that already had sufficient shielding or, in the case of the bend close to the AR South Experimental Hall, to an area where additional shielding can be added easily. The Committee believes that the additional steel and earth are sufficient to make the injection lines safe.

In the Main Rings, the loss rates have been calculated by adding up the losses during injection, stable beam operation, and beam aborts. The assumptions made appear to be valid and complete. The beam abort dumps near FUJI have been designed with concrete protection as this is the place where the losses are highest. The positioning of the masks and collimators avoids places which are close to the site boundary and appears to be effective at localizing the losses in the rest of the ring. Losses in the straight sections require additional shielding and the calculations indicate that the proposed Arch Shields will be adequate when installation is complete. For the rest of the ring, the calculations of particle loss show that it will be necessary to block the unused portion of holes in the air-conditioning, cables and waveguides and to provide a concrete maze at the bottom of each emergency exit.

If all of these tasks are completed, the Committee believes that these tasks will bring the radiation level on site and at the site boundaries within the regulatory limits.

The other sources of radiation problems, ozone and NOX production as well as airborne radioactivity, were not presented in detail.

I Feedback and Instrumentation

Multibunch Feedback Systems

The design of the multibunch feedback systems and its control hardware is healthy and hardware fabrication is progressing on schedule. Also the related diagnostics system (tune monitors, bunch current monitor, mass storage for studies) are progressing on schedule. Certainly the studies on the AR ring were useful in confirming the concepts and choices. The choice of the DA_NE type low Q cavity for the longitudinal kicker looks good both in terms of shunt impedance, ease of fabrication and cooling.

As already experienced during the AR studies, the access to bunch by bunch and turn by turn data will certainly be extremely useful to diagnose instabilities during commissioning, in particular as far as the FBII (Fast Beam-Ion Instability) and PEI (Photoelectron Instability) are concerned.

The target damping rates appears adequate to deal with the classical instabilities (driven by HOM and resistive wall) but marginal or insufficient to deal with the expected growth rates from FBII and PEI.

It might be worthwhile to investigate ways to increase the damping rates in case this might be needed to deal with the PEI. One limitation is kicker, which might be overcome by additional kickers and amplifiers. A more fundamental limit is imposed by the one turn delay from PU to kicker. This limit could (if needed) be pushed by a factor of two or four by installing multiple systems with PU and kickers separated by 1/2 or 1/4 turn thus reducing the PU to kicker delay by a factor of two or four and increasing the damper sampling rate from once per turn to two or four times per turn.

Such techniques are commonly used in stochastic cooling feedback systems. The inconvenience and extra cost of such systems is caused by the need to transmit the correction signal with sufficient velocity across one or two arcs.

Beam Position Monitor

Effects on the BPM button calibrations due to welding distortion have been estimated to be acceptable, but this should be verified by measurements.

The plan to provide single-turn position measurement by bringing cables up into local service buildings is workable, but would be a nuisance if needed frequently or for prolonged periods. Plans should be made for how to go about adding single-turn capability, should it be necessary.

Four single-turn sets of electronics are planned. The Committee recommends the addition of four additional sets of single-turn electronics on each side of the IR to facilitate threading injected beams through this sensitive region.

Synchrotron light monitor

This is an ingenious and well-executed system.

IR beam feedback and monitors

The planned system appears capable of keeping the beams well centered on each other. Details were not presented concerning how the button signals will be analyzed, error sensitivity, and the effects of whether the two beam signals are in phase or out of phase with each other. An alternative plan for using BPMs in the regions where the beams are separated was also presented.

J Linac Upgrade, Beam Transport Line and Injection System

Linac upgrade

The Committee was impressed by the significant progress in the Linac upgrade since the last review meeting. Almost all the hardware for the upgrade has been built with the required quality and planned schedule. The commissioning of the upgraded existing sections from section 1 to 5 was completed successfully, meeting the design accelerating gradient of 20 MeV/m. The Committee would like to congratulate the KEKB team on having the first 1.5 GeV beam from the extended new sections A, B, J-arc and section C with a bunch charge of 2 nC and 100% transmission through J-arc, which occurred during this review meeting.

The extended and upgraded existing Linac will be joined with the old Linac in March and the entire

KEKB injector is scheduled to be commissioned in May and June, 1998.

The KEKB Linac is well equipped with a full set of beam instrumentation, such as BPMs, bunch monitors, wire scanners, wall current monitors, and emittance and energy measurement devices. This instrumentation worked very well with good precision and reliability in the initial commissioning.

The Committee would like address the following points to which the KEKB team should pay attention in the upcoming commissioning:

- In the recent beam tests of the upgraded, existing Linac, the normalized emittance was increased by a factor of about 3 to 5 compared to design, at bunch currents in the range 1 to 10 nC. This serious emittance growth should be studied in detail and suppressed by orbit control. The energy spectrum and energy stability should be optimized at the same time.
- The achromaticity and isochronicity of the J-arc should be measured by, for example, modulating the energy of the incoming beam by about ±0.5% at~1 Hz rate, looking at the transverse position difference at the exit of arc for achromaticity, and looking at the time of arrival for isochronicity. The method is very sensitive because differences are being measured, not absolute values.

Beam transport line

The new beam transport lines both for electrons and positrons from Linac to KEKB rings are being constructed. Most of the components, such as magnets, power supplies, beam instrumentation and others have been, or are being, fabricated and measured. Their quality and schedule should meet the requirements of the KEKB project.

Injection system

Since the last review meeting the KEKB team has done a lot on the kicker system. In R&D on ceramic chambers, the power loss due to eddy currents and the power dissipation by image currents have been tested and calculated. Because the power dissipated in the ceramic chamber is of the order of ~1 kW, the water cooling structure has been studied and tested. In this respect, the Committee would like the KEKB team to be attentive to the cooling efficiency, the reliability, and the impedance issues of the ceramic structure.

Since the last review meeting, the KEKB team has seriously considered a decision to build an accumulator/damping ring to increase the positron injection. A preliminary design of a 1 GeV damping ring to damp the positron beam emittance was presented which would improve the emittance by a factor of 10 to 2.9 x 10-8 m. The Committee would like to recommend that the

KEKB team consider other ways of increasing the injection efficiency of the positron beam into the LER ring, for example, by increasing the electron/positron conversion efficiency (e.g., higher-energy positron production) and/or by using an accumulation ring.

K Interaction region

The interaction region design has advanced significantly in a year. Several key systems have been delivered and all the critical components have been ordered. The interface issues with BELLE have been resolved, and collimation studies started. Construction is in full swing with completion scheduled for early fall 1998.

The successful full-strength test of the interaction region superconducting quadrupoles in the BELLE solenoid field is a very significant achievement. The Committee congratulates the interaction region group. However, the possibility of beam induced quenches in the superconducting quadrupoles should be studied, and measurements of the vibrations of these magnets should also be performed.

The designs of the remaining magnets located near the interaction region have been finished, and the magnets are on order. The construction of these magnets should be monitored closely, as the time to complete, test, and install them is short.

Similarly, the design of the vacuum system near the interaction region has been completed and the chambers ordered, but again the allowed construction time is short. Tests of the recently built "magic flange" should be completed in the near future.

Several accelerator physics issues still need study. The required application codes for interaction region commissioning should be specified soon so that they will be ready this fall. The vertical closed orbits of the beams through the detector due to the solenoid fields should be evaluated and a correction scheme specified. Techniques to monitor and adjust the local vertical dispersion and coupling in the interaction region should also be developed. A plan to bring the beams into collisions was shown. A very inventive eight-electrode position monitor system is to be used to monitor beam-beam deflections. A question of nearby HOM power interfering with the electrode signals was raised. Locations have been reserved for collimators upstream of the BELLE detector. The planning and simulations for these collimators should be an ongoing activity. To complete these studies, we suggest that more theoretical manpower be allocated to the interaction region group to resolve all these issues in a timely fashion.

Once again, the Committee congratulates the interaction region group on their significant progress in the past year.

L Instabilities

Two instabilities are of particular concern: the fast beam-ion instability (FBII) and the photoelectron instability (PEI).

FBII

The FBII is estimated to have a growth time of 1 ms with 500-bunch train and 100-bunch train gaps. With this growth rate, the feedback system can suppress the FBII. The present state of understanding of the FBII effect has progressed significantly since a year ago, particularly from the experiments at the AR and at the PAL, and from the subsequent data analysis. It is still suggested that close attention be paid to the commissioning of the PEP-II HER to observe if they have the FBII effect and, if so, what are the results of their studies. It has been suggested that quadrupole modes might also be excited by beam-ion coupling. This instability can potentially have a growth rate similar to the dipole mode growth rate, and yet it cannot be cured by a normal feedback system. This mode of FBII should be studied for the KEKB. If it becomes an issue, its effect on the beam gap scenario should be evaluated.

PEI

The state of understanding of the PEI has improved substantially compared with a year ago. A lot of work has been done during the year: the secondary emission yield coefficient has been measured; an experiment at BEPC has been performed and data analyzed; three simulation codes are now in agreement; and the PEI growth rate at the Photon Factory has been simulated successfully. The result of these improvements has led to a simulation tool which has become more trustworthy compared to a year ago. Using this tool, it is estimated that the growth time is about 150 microseconds in the absence of external fields. This is potentially a very serious problem. The proposed solution is to introduce a solenoidal field of 30 gauss along the beam trajectory. However, to bring the growth rate to a level that can be controlled by the existing feedback system, 90% of the circumference must have the solenoidal field installed, while only 46% is possibly available. As a backup solution, it was suggested that it may be possible to install permanent magnets in part of the space and bring the fraction of the circumference covered to 71%.

The Committee regards the PEI a potentially serious issue. However, it does not consider any redesigning of the LER vacuum components appropriate or beneficial at this stage of the project. Instead, the Committee suggests that the construction and commissioning proceed as planned, and to respond only if and when the PEI indeed becomes a problem during operation. Before that time, the following additional preparatory steps should be taken:

- perform simulations to make sure that permanent magnets are a solution to the PEI problem; design a diagnostic procedure (including the use of the superior data acquisition system available in the feedback design) which allows one to identify the PEI quickly and effectively in case there is a suspicion that it is occurring during operation;

- look for other operation parameters which can lower the PEI strength, e.g., lowering bunch intensity, increasing bunch spacing, higher chromaticity, beam train gaps, etc.;
- study the effect of beam-induced microwave on photoelectrons with the view that they might destroy the coherence and therefore reduce the growth rate. As an extension of the study, one might consider sending RF power down the pipe as an electron-cleaning agent;
- pursue further on additional methods to combat the PEI. This is in case the presently envisioned solutions (solenoids and the permanent magnets) are not eventually available or are not sufficient.
- consider the possibility of increasing the feedback strength (adding amplifiers and kickers and, if necessary, multiple systems across arcs) if the PEI does occur and the solenoid field is not sufficient. The hardware and machine space implications should be examined.

M Commissioning

The KEKB commissioning plan is well advanced. The tasks have been organized into a logical sequence and reasonable, minimum times have been estimated for each task. The times required may be shorter for some items and longer for others.

The Linac commissioning is also well advanced. The J-arc and associated linacs have just completed commissioning, both very nice achievements. The Committee appreciates that the Linac and ring groups have now combined to form an effective commissioning team.

The KEKB ring commissioning list should now have some backup procedures added to the tasks so that the required software and hardware will be ready when needed. Also, the proposed background studies with the BELLE detector should be planned in advance as there are two very different groups involved. The commissioning plan should be as flexible as possible, as the two rings will commission at different rates due to different hardware and accelerator physics issues. An initial plan should be developed in case one ring is ready before the other, say by a month or more.

The installation of BELLE early but desensitized to early commissioning backgrounds without the Silicon Vertex Detector (SVD) and backward and forward calorimeters is a very reasonable plan. The recording of some early BELLE data is also useful to help commission the on-line and off-line software of the detector.

The present commissioning staff will be thin if two rings are commissioned at the same time. The possibility of adding personnel should be investigated, including people from the detector and hardware groups.

The decision when to install the BELLE SVD and calorimeters in 1999 should take into account the impact on the rate of ring commissioning.

The Committee believes that KEKB commissioning is well planned.