REVIEW COMMITTEE REPORT ON SPEAR3 LATTICE UPGRADE

August 11, 2004

EXECUTIVE SUMMARY

A review of the planned SPEAR3 Lattice Upgrade was held at SLAC/SSRL on August 11, 2004. The review committee members were: S. Krinsky, Chair (BNL), D. Robin (LBNL), C. Steier (LBNL) and H. Wiedemann (SLAC). The committee was charged to review the technical aspects of the conceptual design and to evaluate whether it provides a suitable plan to develop the capabilities of SPEAR3 for utilization of small-gap, in-vacuum x-ray undulators. In addition to optimizing the brightness of the new undulators, it is of key importance to maintain the quality of the existing sources as well as the high level of operational reliability, stability and performance achieved to-date. The committee was asked to consider what additional work is needed: (1) before issuing a request for quotes (desired time frame being September 2004); and (2) before placing the final order (desired time frame being January 2005).

The analysis carried out thus far and presented at the review is impressive and goes far toward establishing the validity of the design. We see no show stoppers. However, the computer simulations and experimental measurements do indicate that the implementation of the low beta chicane has the potential of having a significant impact on injection efficiency, lifetime and maximum single bunch current. To facilitate an informed decision on the project, we believe additional work is needed to better quantify the effect of the modifications on the ring performance. The SSRL project team has the expertise and tools necessary to complete the additional studies within a reasonable time period consistent with the desired schedule.

We recommend that before issuing the RFQ, tracking studies be carried out including the effects of synchrotron radiation and the nonlinearities of the existing insertion devices. Our other recommendations - if possible - should be addressed before the final order is placed for the in-vacuum undulator. These additional recommendations are presented in the body of this report, which addresses issues related to the lattice optics, dynamic aperture, lifetime, insertion device field specifications and current limitations.

We really appreciated the friendly and open atmosphere of the review and were impressed by the quality of the work presented. The project appears to be well on track to meet the desired schedule. The design has been advanced effectively and continuation of the work in progress will address the recommendations we have made in the body of this report, and will provide a proper foundation for the implementation of the lattice upgrade.

LINEAR OPTICS

It is proposed to modify one of the two long straight sections of the SPEAR3 storage ring. Presently, the SPEAR3 lattice includes two 7.6m long straight sections, of which one is used for the rf-system. It is proposed to convert the other straight section into a chicane such that two insertions devices and photon beam lines could be installed. Two chicane versions were studied, a symmetric and an asymmetric one. The proposal is to use the asymmetric one, which allows a more convenient extraction of both photon beams through existing storage ring vacuum chambers. The chicane lattice is designed to provide two low beta insertions for in-vacuum undulators with a minimum gap aperture of between 5.5 and 7mm.

A solution was presented that meets these requirements very well while minimizing the impact on the rest of the storage ring lattice. The vertical betatron function or source size could be reduced even further were it not for a limitation of one of the matching quadrupoles. The chicane optics introduces a vertical betatron phase shift of about 180 degrees. To avoid the proximity of a sum resonance it was decided to move the vertical tune further for a total of one unit. This was accomplished by a modification of the rf-long straight section such that it now has about the same betatron phase shift as the chicane section. Thus, from a phase point of view, the two-fold symmetry of the SPEAR3 lattice for all sextupoles outside the matching sections has been preserved. Although the optics of the long straight sections have been altered significantly, it was possible to keep the maximum values of the betatron functions within the level elsewhere in the ring. In the chicane section there is a small, localized dispersion function, which seems to be of no apparent consequence. The impact on the natural emittance is at +1.7% negligible.

The tune shift from nu_x/nu_y=14.19/5.23 to nu_x/nu_y=14.13/6.22 seems to move the lattice closer to structural coupling resonances because of SPEAR’s near two-fold symmetry. The consequence of this move, however, must be evaluated through nonlinear dynamics and the determination of the dynamic aperture.

The committee briefly discussed if this chicane implementation would preclude any future development one might want to implement into the SPEAR3 lattice. No obvious such impact could be identified. In particular, it seems still possible in terms of the linear lattice to implement finite dispersion into all insertion straight sections to further reduce the beam emittance in the future. However, no studies of the nonlinear dynamics for such a lattice have been performed so far. Overall, the committee agrees with the proposal for an asymmetric chicane section as presented.

However, if additional nonlinear studies should show that one wants to improve the dynamic (momentum) aperture, an alternative approach could be tried, similar to the one chosen at the SLS, to implement a low beta insert using an additional quadrupole triplet for their fs-slicing project. By locally changing the phase advance in the vertical plane by 180 degrees, it effectively maintains the lattice symmetry. A similar design was proposed at the ALS as well. The triplet has been installed at the SLS and successfully commissioned.

DYNAMIC APERTURE

The dynamic aperture and dynamic momentum aperture in SPEAR3 as in most third generation light sources are critical both for injection efficiency and beam lifetime (Touschek as well as gas lifetime). Extensive simulation and experimental studies were presented using state-of-the-art simulation and measurement techniques. The overall impression is that the studies do not show any fundamental show stoppers. However several measurements and simulation results indicate that the available dynamic aperture even before the upgrade might only be adequate but not generous. Since all simulation results indicate that the upgrade will reduce the dynamic aperture, this is a potential concern. It is likely that there will be some impact on injection efficiency and beam lifetime and we feel that it needs to be quantified better.

Frequency map analysis seems to be a very adequate tool to study the effects. The presented simulations are very good and should be continued with more complete error sets (especially including insertion devices). The frequency maps indicate a few mm reduction in dynamic aperture with the double waist lattice, which is a concern for injection, and even more so for the Touschek lifetime.

One of the two **action items to be completed before the RFQ** is to conduct tracking studies where synchrotron radiation is included. This simulates the injection process much better and can give quantitative information about injection efficiencies to be expected. It can clarify the effect of vertical physical apertures on the horizontal dynamic aperture and provide additional guidance on how to interpret the frequency map results. To quantify the impact on the lifetime, similar tracking studies including synchrotron radiation should be conducted tracking off-energy particles, simulating Touschek scattering events and the dynamic momentum aperture. For both studies radiation damping definitely needs to be included. To include quantum excitation would be nice, however it is not expected to be essential. Very good initial studies were presented at the review but they need to be significantly extended.

The second **action item to be completed before the RFQ** consists of tracking studies including the nonlinearities of the existing insertion devices. In the studies so far, they were neglected. However, the measurements presented at the review showed that they currently contribute significantly to the SPEAR3 dynamic aperture. For the simulations it would be best to use symplectic integrators for the wiggler fields or Runge-Kutta generated Taylor maps (compare methods used for ALS, NLC damping rings, Duke FEL, CESR, …). The impact on the double waist lattice likely will not be much worse than for the current lattice, but since the safety margin is expected to be smaller, the impact needs to be evaluated.

In order to optimize the nonlinear transverse dynamics over the baseline design, it could be beneficial to analyze the tune shift with amplitude and look into approaches to reduce it (e.g. by increasing the number of sextupole families).

Many experimental studies have already been completed with many good but some inconsistent or inconclusive results. The most important improvement will be to make use of a scraper for which a plan was presented to install it as soon as possible. We strongly support an installation at the earliest possible time. Studies with the scrapers will be critical to clarify the effect of the reduced vertical aperture on dynamic aperture and lifetime, complementing the additional simulation studies mentioned above. This is an area of studies, which definitely needs to be completed before issuing the final IVID contract at the beginning of next year.

In general there is the need for additional machine studies as well as more direct comparisons to clarify the relation between model and observation. Finally we would like to see more experimental studies conducted with insertion devices closed, to clarify their effect on the dynamics, since most dynamics studies in principle can be carried out with ID gaps open and closed.

In case the decision is taken to realize the double waist lattice in the presented form, we would like to recommend an early installation of at least the new quadrupole triplet, in order to ease the final commissioning and allow time to solve potential problems in a timely fashion. Similar approaches to install additional quadrupoles significantly before implementation of the full upgrade have been chosen at the ALS (Superbends) and SLS (low beta double waist insertion for fs-slicing) with very good results.

LIFETIME

Since the lifetime in third generation light sources usually is closely related to the dynamic (momentum) aperture, many issues have already been discussed in the previous section. Especially the recommendations concerning the tracking with synchrotron radiation, insertion device errors and scraper studies are directly related to quantifying the potential lifetime impact of the upgrade. Many good studies have already been conducted, however we feet that the impact of the double waist lattice (at least without further optimization which could potentially improve the situation significantly) on the lifetime may possibly be underestimated. Again, we do not foresee any show stoppers. However, we feel that it will be necessary to quantify the potential impact on the lifetime better, so that an informed decision about the project can be taken and no unpleasant surprises arrive during the commissioning phase.

Experimentally, it will be possible to understand the different effects of the Coulomb and Touschek lifetimes much better once the scraper is installed. The effect of coupling and especially of small vertical physical apertures on the energy aperture and therefore the Touschek lifetime should be studied further. This can be done both in additional simulations (with and without synchrotron radiation) and in experiments. The experience at other labs suggests that the effect of the vertical aperture as well as the effect of coupling on the dynamic (momentum) aperture might be bigger than indicated by the calculations done thus far.

Finally we want to warn that small vertical apertures can be the prime location of beam loss in the machine. Therefore Bremsstrahlung into the B12 beamline may be an issue and should be studied in the beamline design. Other accelerators (APS, ESRF) have also experienced radiation damage to small gap undulators (mostly out of vacuum) due to bad injection efficiency and injection ‘accidents’. Collimation elsewhere in the ring may be helpful to minimize both problems. To optimize a collimator system, tracking studies and detailed collimator design (impedances) are necessary and should be done early enough in the project.

INSERTION DEVICE FIELD SPECIFICATIONS

The chosen approach to come up with field specifications is reasonable and consistent with approaches used at other places. The project team has extensive knowledge in this area and people worldwide are using their expertise. An improvement to evaluate the impact of the ID fields on the dynamics may be to use a symplectic integrator for real or calculated magnetic field data or a taylor map based on a runge-kutta integrator. However, since the ID is a weak field, short period device, no significant problems are expected.

The material choice for the ID of NdFeB vs SmCo deserves further consideration based on recent experimental results on radiation hardness showing equal or better radiation hardness of heat treated NdFeB materials compared to SmCo with significantly higher remanent magnetic fields for NdFeB.

CURRENT LIMITATIONS

A comprehensive analysis was presented of the potential current limitations due to the impedance of the small-gap undulators. The effect of the resistive wall impedance was well characterized. A preliminary study of the geometric impedance of the undulator chamber was also reported. This work should be extended to take into account an elliptical (or rectangular) geometry. The limitation of bunch current is being studied both theoretically and experimentally at several synchrotron radiation facilities, including ALS, APS, ESRF and NSLS. It would be worthwhile to collect the results of these investigations and compare their conclusions with your own. The work carried out thus far suggests that as long as care is taken in the design of the movable tapers, the impedance should not produce an unacceptable reduction in stored current.