Beam Dynamics

1. Introduction

In September 1999 optics of the storage ring was drastically changed from hybrid to HHLV optics (optics with High Horizontal and Low Vertical betatron functions in all straight sections). To achieve both the smooth optics change and good performance in the new optics, we conducted extensive preparatory studies and participated in ring tuning from the viewpoint of beam dynamics. At the same time, we have been investigating the storage ring upgrade in preparation for the installation of four straight sections of about thirty meters long, which is scheduled for the summer of 2000. As a basic activity, we have also been making efforts to establish an accurate accelerator model which will describe all measured data and to improve the machine performance. In this context, we have carried out both experimental and theoretical studies.

2. Optics Change

The storage ring optics was changed from hybrid to HHLV optics shown in Fig. 1 in order to make efficient use of undulators in the low-beta sections of the hybrid optics [1]. In HHLV optics the horizontal betatron function is 25 m in all straight sections, while the vertical is reduced to a small value of 3.9 m in order to avoid de-magnetization of the undulators due to scattered electrons and reduce the vertical beam size at the source point.

One of the main difficulties in the change was the distortion of horizontal dispersion even after correcting closed orbit distortion (COD). Finally, we suppressed this distortion by slightly modulating the orbit with two hundred horizontal steering magnets. The orbit modulation is about twenty microns and is acceptable for the users. Another difficulty is high sensitivity in the Radio Frequency (RF) cavity Higher Order Modes (HOMs) due to a large horizontal betatron function in the RF cavities. We thus tuned the cavities carefully so that the beam doesn't hit the HOMs. To stabilize the beam in any filling mode, the horizontal and vertical chromaticities have been set to +7 and +4, respectively.

The emittance was estimated by measuring the horizontal beam size and found to be about 6 nmrad, which is the exact value in the design. The vertical dispersion was corrected with twenty four skew quadrupole magnets to a level of 1.1 mm in an rms. value. This is the first trial to control vertical dispersion here. By this correction, the vertical emittance was reduced to several pmrad. The momentum acceptance was found to be about 3.2 % with an RF voltage of 16 MV, larger than that of the hybrid optics (about 1.4%).

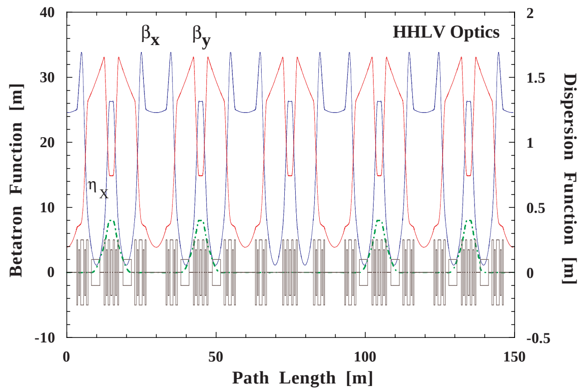

Fig. 1. HHLV Optics.

3. Design Study on Ring Upgrade

In the summer shutdown period of 2000, we plan to upgrade the storage ring to the second phase lattice by locally removing and rearranging the quadrupole and sextupole magnets. The upgraded ring has four long straight sections each 27 m long to install long undulators or other advanced devices for future light sources. The new lattice, however, breaks the symmetry of the optics, especially of the sextupole field potentials and this symmetry break excites additional harmful resonance lines near a working point. For this reason, the new optics must be optimized taking into account the stability of the circulating beams with large amplitudes and momentum deviations. We solved this problem by introducing the concept of symmetry restoration of the optics (betatron phase matching) and local correction of the chromaticity [2]. The resulting optics has a sufficiently large dynamic aperture and momentum acceptance for beam injection. In order to verify the final performance, we performed particle tracking taking into account systematic errors known from position measurements of magnets in addition to random errors due to unknown misalignment. So far, the results on the stability of the new optics have been promising.

4. Performance Analysis and Improvement

4.1 Mechanism of Beam Lifetime

The optics change gave rise to a longer beam lifetime even in multi-bunch operation. For the purpose of resolving the mechanism of prolonging the lifetime, we first studied the momentum acceptance of the storage ring, particularly from the viewpoint of the dependence on the operation point. The study showed that acceptance of the HHLV optic reduces as the fraction of the horizontal tune increases, while one of the hybrid optics becomes larger. From these results, we concluded that momentum acceptance is determined by the dynamic aperture. Taking the nonlinear chromaticity of the betatron tune and the amplitude dependent tune shift into account, we found that the resonance determining the dynamic aperture is the horizontal integer in the hybrid case and the linear sum in the HHLV.

The distance from the determinative resonance in the HHLV optics is much longer than that in the hybrid optics, so that the momentum acceptance of the former optics is much larger than that of the latter. The calculated Touschek lifetime based on the simple model of this stability limitation agrees fairly well with the measurement [3].

4.2 Orbit Stabilization

As increasing the number of installed Insertion Devices (IDs), the variation pattern of the COD becomes more intricate. Due to this change, we increased the number of correction harmonics of the COD from three to five in the periodic COD correction system [4]. And also, at the time of routine beam injection, the residual orbit distortion with higher harmonics is corrected as necessary.

In the operation of the new HHLV optics, we frequently observed an orbit jump which has not seen in the hybrid optics. This jump coincides with a period of the periodic COD correction and its magnitude is some several microns at about twenty meters downstream from the source point. We are now investigating the cause from the viewpoints of both possibilities, the noise from the orbit measurement and any setting error of the steering magnet strength. At the same time, we are continuing with our investigation of the source for AC components of the orbit movement.

4.3 Vertical Emittance Reduction and Its Estimation

The storage ring still has a large vertical dispersion, especially in the operation of HHLV optics, and even after setting up the reference orbit. Correction of the vertical dispersion is thus essential for generating highly brilliant X-rays. We suppose that the main sources for the vertical dispersion are skew quadrupole error fields in the dispersive arcs. Our idea for the correction is that such vertical dispersion can be compensated by superimposing single kick-like dispersions generated in the proper arcs. The simulation results showed that the rms. dispersion of 1 mm is achievable by 24 skew quadrupoles installed in the dispersive arcs of the even cells. In actual beam tuning, this correction scheme successfully reduced the vertical dispersion down to a level of ~ 1 mm in an rms. value [5]. Since autumn 1999, the vertical dispersion correction has been used in user operation to maintain the small vertical emittance.

To accurately estimate small vertical emittance of the order of a few pmrad in an electron storage ring, we developed a new method [6], which uses vertical dispersion to systematically change a vertical beam size along the ring. Vertical dispersion of 1 mm, which can be adequately controlled by skew quadrupoles, corresponds to a vertical beam size of 1 micron. This means that the vertical dispersion can be a good probe to measure a vertical beam size of the order of 1 micron. The response of physical observable which depends on the emittance clearly reflects the magnitude of vertical emittance in changing the dispersion. We can thus estimate vertical emittance by analyzing the dependence of a Touschek lifetime on the change of vertical dispersion with 4 by 4 ring model describing the measured dispersion. By using this method, we were able to estimate that the vertical emittance of the HHLV optics is ~5.5 pmrad under nominal operation condition [6].

4.4 Feasibility Study on Top-up Operation

Top-up operation is one of the most promising schemes to increase time-averaged brilliance under the high peak current. We started work on a study which involves the development of a monitoring system for turn by turn injected beam loss toward achieving top-up operation in the storage ring.

We investigated the possibility that a Single Pass Beam Position Monitor (SPBPM) might work as a precise current monitor, i.e., a beam loss monitor. By using the SPBPM we investigated the turn by turn injected beam loss in the ring with all ID gaps opened. We obtained clear current decay signals and found that the injected beam loss mainly occurs around the injection point at specified turns.

We also developed radiation monitor composed of shield covers, a plastic scintillator cubic and photo multiplier tube, which directly detects high energy γ-rays generated by the beam loss. We also obtain clear turn by turn signals using this monitor.

By using two kinds of complementary monitors, we started to investigate mechanism of the injected beam loss in detail.

4.5 Measurement of Tune Variation

Oscillation amplitude of the beam in the storage ring was observed using stripline electrodes. To enhance the beam oscillation signal, the signals from two electrodes facing each other were subtracted. The betatron tunes were measured during user operation and we found that the tunes fluctuate about ±0.003. The frequency of the main AC component is about 1 Hz. Before and after the routine beam injection, the gap of each ID is moved and the tunes were found to vary according to the gap change. This tune variation was measured to be less than 0.004 [7].

5. Development of Simulation Code

5.1 Development of Particle Tracking and Beam Dynamics Analysis Code

We have been developing some codes for particle tracking and beam dynamics analysis for a long time. We unified these codes, including a newly developed parameter fitting code, into code RACE99_DA to design and analyze the second phase lattice of the storage ring. The RACE99_DA consists of four sub-codes, DYNAM for particle tracking, PARAM for parameter fitting, STAT for optics calculation and TRAJ for trajectory trace with radiation. Though we have not examined TRAJ in detail, however, the other three sub-codes have been confirmed to work well.

The RACE99_DA uses differential algebra for map extraction, linear optical parameter and the calculation of nonlinear properties. The differential algebra gives a 6 by 6 expression for a one turn transfer matrix. We simplified this into a 4 by 4 matrix and use it to calculate optical parameters, because most of the treatment in the code remains in a 4 by 4 basis in the present stage. Now, we are preparing to change the code from a 4 by 4 to 6 by 6 basis.

We installed an ID model into the RACE99_DA to simulate a long ID planned to be installed into the long straight section. This model employs a first order symplectic integrator to integrate the equation of motion through the ID. Validity of the model is confirmed by comparing the computation results with a series of rectangular bending magnets.

5.2 Development of Simulation Code for Slow Positron Production

We developed a Monte Carlo simulation code for processes from energetic positron production to reemission, named PCM (Positron Creation and Moderation) [8], based on EGS4 and LEPRE which simulates positron behavior in a moderator system [9].

Some preliminary simulations have been examined. In this simulation, reasonable reemission rates were obtained, though code verification with experimental data should be completed.

References

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