Beam Dynamics

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1. Introduction

Beam commissioning of the SPring-8 storage ring was started from March 13th 1997 and electron beams of 20 mA were successfully accumulated one month later. Beam lifetime of about 100 hr had been achieved in user operation with beam current of ~ 20 mA at the end of 1997.

During this period, activities of the beam dynamics group were focused on beam commissioning of the Storage Ring. This included preparation of Graphical User Interface (GUI) for operation, GUI for optics and orbit control, correction of electron beam orbit, analysis of orbit movement, and studies to improve beam quality.

2. Preparation of GUI and other software

We prepared two kinds of GUI. One covers an operation control system of the Storage Ring [1]. This GUI implements most of the procedures for beam injection along with functions to monitor and set operation parameters and to save the used parameters on a parameter database.

A second GUI controls optics and orbit. This GUI is able to tune or correct the beam parameters including optics, chromaticities, tunes of betatron oscillations, closed orbit distortion (COD) [2].

For on- and off-line analysis on the beam trajectories and COD, we have developed software to process data in files and in both archive and on-line databases.

This GUI and software worked well in the beam commissioning period and it is also effective for the routine operation. Even so, we are continually seeking to improve the software and add new functions for easy and reliable operation.

3. Control of the electron beam orbit

It is important to correct the COD as to pass through the centers of all quadrupole and sextupole magnets to keep stability and low emittance of the stored beam. However, during the early stage of commissioning, an achievable r.m.s. COD was limited 0.25 mm above. The measured COD had lots of sharp peaks that could be hardly corrected by a small number of dipole steering magnets. These peaks seemed to be spurious and we assumed that they were the results of beam position monitors (BPM) offsets. By using a technique of low-pass filtering, it was possible to extract the tentative distribution of BPM offsets. These were almost independent of the optics and had r.m.s. values of 160 μm and 210 μm respectively in horizontal and vertical planes [3]. After subtracting the offset values, COD corrections dramatically improved the directionality of photon beams from each insertion device and this orbit is being used as a reference one for user operation. We are now analyzing the relation between the offsets and magnet misalignment data to determine a "golden orbit".

The provisional estimation of distributed offset values has already made it possible to achieve an orbit-reproducibility of about 20 μm.

4. Analysis of orbit movement

To monitor orbit stability, we prepared GUI to display amplitudes of COD tune harmonics (51th and 16th respectively for horizontal and vertical planes) and that of the 0th harmonic every 30 sec; then carried out on- and off-line analysis. The tune harmonic amplitude indicates the magnitude of orbit distortion and that of the 0th harmonic shows deviation of beam energy. From our analysis, we obtained information that is useful for orbit stabilization as follows.

(1) Orbit movement due to variation in cooling water temperature. A clear correlation was observed between changes in the amplitude of tune harmonics and cooling

water temperature variation. The period of this movement is 10 ~ 20 min.

(2) Long term increase in orbit distortion. During user operation of 1 or 2 weeks, amplitudes of the tune harmonics vary by 40 ~ 50 μm. However, the reasons for this effect are not yet clear.

(3) Orbit movement due to tidal motion. Clear correlation was observed between the amplitude change of the horizontal 0th harmonic and the change of gravity at SPring-8 site [4]. In order to investigate this effect in detail, off-line analysis is continued.

(4) Long term shift of Storage Ring circumference. Over several months, we observed a monotonous shift in the horizontal 0th harmonic. At the beginning of user operation, we compensate for this shift by adjusting the radio frequency (RF). The causes of a long term shift are now under investigation.

5. Studies on improvement of beam quality

5-1 Estimation of beam instabilities and their cure

To achieve an average current of 100 mA in multi-bunch and 5 mA in single bunch operations, we studied multi-bunch and single-bunch instabilities by using simulation codes [5-7]. We found that: (1) a current of at least 5 mA can be stored in a single bunch by adjusting chromaticities to a positive value of four; (2) an average current of at least 100 mA is achievable by chromaticity adjustment and partial filling [8].

5-2 Estimation of optics based on a model calibration method

Measurement of linear optics is an essential issue for Storage Ring parameter-tuning. Since consistent measurement of betatron functions and phases cannot be done by conventional methods, we are developing a method which estimates betatron functions and phases consistently from the distribution of focusing errors calculated with beam response matrices. To determine a calibration model and measurement condition for the response matrices, we are checking effects of monitoring errors, nonlinearity, and focusing error distribution on the estimation [9].

5-3 Analysis of nonlinear dispersion

By adjusting nonlinear dispersion, we can control the behavior of beams with large momentum deviation. This means that distribution of the nonlinear dispersion reveals where stored electrons are lost by turning off the RF power. Furthermore, there is a possibility of reducing bunch length in a small current region. Accordingly, we developed a pertubative formulation of nonlinear dispersion [10, 11]. The calculated dispersion showed good agreement with the measured variation of COD caused by changes of RF frequency.

5-4 Estimation of limit on bunch shortening

The lower limit of bunch length is determined by path length fluctuations caused by synchrotron radiation [12]. We reformulated this limit with simple equations describing dynamic equilibrium between radiation damping and excitation by path length fluctuations. Possible bunch length is estimated changing RF and optics parameters [13].

References

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