OPTIMIZATION OF OPTICS WITH FOUR LONG STRAIGHT SECTIONS OF 30M FOR SP-RING-8 STORAGE RING

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Abstract

During a summer shutdown period of 2000 the SPring-8 storage ring undergoes an upgrade to the second phase lattice by locally removing and rearranging quadrupole and sextupole magnets. The upgraded ring has four long straight sections (LSS) of 27m long for installing long undulators or other advanced devices for future light sources. To realize smooth commissioning of this upgraded ring without losing high performance of the ring, we intensively studied optimization of a new optics by considering the stability of circulating electrons with large amplitudes and momentum deviations. By introducing the concept of symmetry restoration of the optics, especially of the sextupole fields, and a local correction of the chromaticity, we found good solutions having sufficiently large dynamic aperture and momentum acceptance for beam injection.

1 INTRODUCTION

Since the beam commissioning started in 1997 the SPring-8 storage ring has been operated stably and provided high quality beams of synchrotron radiation to users. From 1997 to July 1999 the ring had been dedicated to users with a hybrid optics. In this optics the horizontal betatron function takes a large value (high-beta) and a small value (low-beta) alternately in magnet-free straight sections where insertion devices are installed. The length of this section is 6.65m.

In September 1999 the optics was changed from the hybrid to the HHLV optics (optics with High Horizontal and Low Vertical betatron functions in all straight sections) to meet requirements of using undulators in the low-beta sections of the hybrid optics. In the HHLV optics, the vertical betatron function is reduced to a small value in order to avoid de-magnetization of undulators due to scattered electrons.

The brilliance of photons at the souce point can be increased further by using a unique feature of the SPring-8 storage ring that it has four missing-bend cells where quadrupole and sextupole magnets are settled in a straight line. By locally removing and rearranging these magnets, keeping other beamlines unchanged, the missing-bend cells can be converted into a magnet-free long straight section (LSS) and a very long undulator can be installed in these sections.

The rearrangement of magnets is now in progress during a summer shutdown period of 2000. The previous version of lattice (phase-1 lattice) is shown in Fig. 1 and a typical optics of an upgraded lattice with LSSs (phase-2 lattice) is shown in Fig. 2.

The phase-2 lattice, however, breaks the symmetry of optics, especially of the sextupole fields. Additional harmful resonance lines also appear near a working point. Then, a new optics must be optimized by considering the stability of circulating electrons with large amplitudes and momentum deviations. We solved this problem by introducing the concept of symmetry restoration of the optics and a local correction of the chromaticity. The resulting optics has sufficiently large dynamic aperture and momentum acceptance for beam injection. For checking the final performance, we performed simulations by taking account of systematic errors known from position measurements of magnets in addition to random errors due to unknown misalignment.

In the following, the results of these calculations are presented. The beam commissioning of the phase-2 lattice will start from the end of August, 2000.

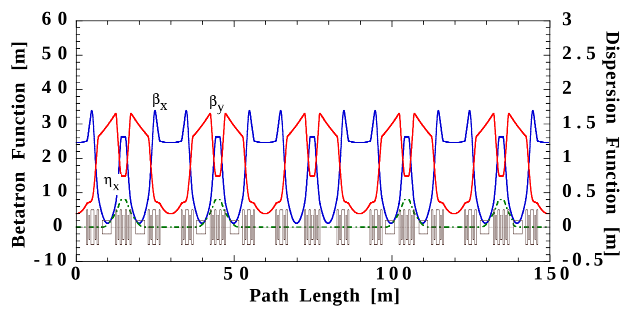

Figure 1: Phase-1 lattice

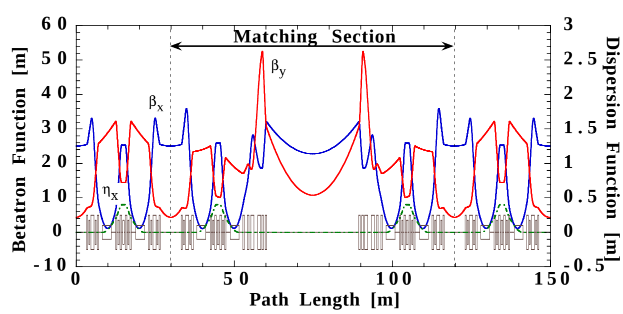

Figure 2: Phase-2 lattice

2 SYMMETRY AND STABILITY

As mentioned in the previous section, the phase-2 lattice breaks the symmetry of optics. This reduces a stable region in both transverse and longitudinal directions. To overcome this difficulty, we introduced the concept of symmetry restoration of the optics and a local correction of the chromaticity.

2.1 Restoration of Symmetry

The idea of symmetry restoration is that if the betatron phase advance in a matching section (see Fig. 2) is equal to $2\pi n$, where n is an integer, and there are no sextupole fields in this section, circulating electrons will not receive any major perturbations from this section. Since the matching section becomes "transparent" and the rest of the ring is unchanged, the symmetry of the optics is recovered for on-momentum electrons and the phase-2 lattice with four LSSs becomes effectively equivalent to the phase-1 lattice.

2.2 Local Correction of Chromaticity

The above scheme of symmetry restoration, or the phase matching, is effective for on-momentum electrons. However, this phase matching breaks for off-momentum electrons with large momentum deviations. This is because when all sextuple magnets are turned off in the matching section to restore the symmetry, the local chromaticity in this section takes a large negative value, while that in the normal cell is corrected and takes a positive value. The betatron phase of off-momentum electrons then jumps at this matching section and the phase mismatching is caused.

We then examined the correction scheme of local chromaticities in the matching section. The points are summarized as follows:

- The strengths of sextuple magnets in the matching section should be sufficiently small so that they can be treated as perturbations and the resonance structure of the ring is approximately unchanged.
- Local corrections of the chromaticity, especially in the horizontal direction, is effective for recovering the stability of off-momentum electrons.
- Introduction of weak harmonic sextupoles in the matching section is also effective for suppression of resonance excitation and recovering the stability of off-momentum electrons.

Required strengths of sextuple magnets for the local chromaticity correction are about 5-20% of normal ones. In Fig. 3 we show an example of the local chromaticity correction. The horizontal and vertical chromaticities for a matching section are plotted as a function of the strength of focusing sextupole fields. In this case, defocusing sextupoles are not used. When SF = 0, the local horizontal chromaticity is about -4.2 and the betatron phase jump for off-momentum electrons with $\Delta p/p$ = -0.03 becomes 0.13. Such a large jump of the betatron phase causes the loss of particles.

The effect of the local chromaticity correction is clearly sown in Fig. 4, where the dynamic apertures for off-momentum electrons with $\Delta p/p$ = -0.02 are drawn for different values of focusing sextupoles. We see that as the horizontal chromaticity becomes smaller, the dynamic aperture becomes larger.

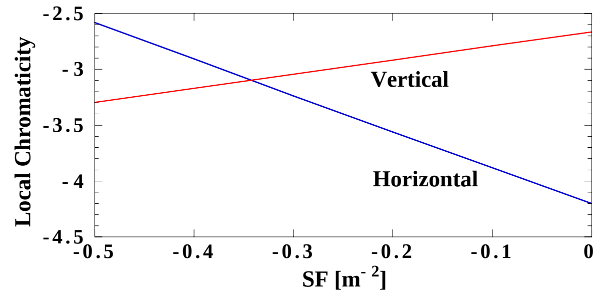

Figure 3: Local chromaticity corrections with focusing sextupole fields

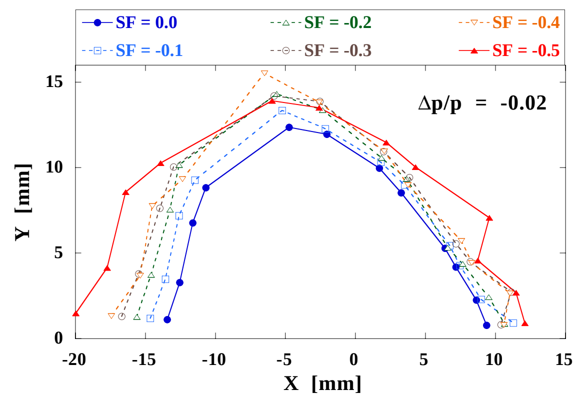

Figure 4: Recovering of dynamic apertures for off-momentum electrons (for the ideal ring without errors)

3 DESIGN OF MATCHING SECTION

The lattice structure in the matching section was determined so that all the above requirement are satisfied in addition to the requirement of tunability of the betatron function at LSSs.

Figure 5 shows the arrangement of main magnets in the matching section. The symbol SF and SD are sextupole magnets for local chromaticity corrections and SH1 and SH2 are weak harmonic sextupoles.

New power supplies to quadrupole and sextupole magnets in the matching sections are prepared to change the strength of these magnets independently of other magnets in normal cells. The stability criteria for these power supplies were determined from a viewpoint of the beam stability.

To suppress the closed orbit distortion (COD) due to random kicks generated by misalignment of quadrupole sextet (see Fig. 5), we applied the method of "two-stage alignment with common girders [1]": by using a laser-alignment system, we align these quadrupole magnets on a common girder with the accuracy of 25μm and girders with the accuracy of 200μm. These tolerances for the alignment were determined so that the amplitude of an additionally generated COD is less than 2mm.

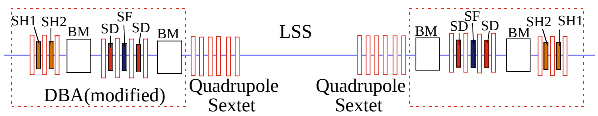

Figure 5: Schematic drawing of the matching section. The basic lattice structure is of the double-bend achromat (DBA) type.

4 STABILITY AGAINST ERRORS

For checking the final performance, we performed computer simulations for phase-1 and phase-2 lattices by taking account of alignment errors and compared the results. Since most parts of the ring are kept unchanged, the errors originated form these parts are common in phase-1 and phase-2 lattices. These common errors are obtained from position measurements of magnets and treated as systematic errors. Unknown random errors in the phase-2 lattice come in from four LSSs, where quadrupole and sextupole magnets are removed and rearranged.

The horizontal COD in the phase-2 lattice calculated by using these errors was found to be about twice larger than that in the phase-1 lattice, while the amplitude of the vertical COD was similar in phase-1 and phase-2 lattices. The large COD in the horizontal direction is due to the distortion of the horizontal betatron function and the shift of the betatron tune toward an integer. Since the calculated COD in the phase-1 lattice agrees well with measured COD, the calculated COD in the phase-2 lattice can be used in the commissioning: for example, a rough orbit corrections can be performed on the basis of these calculations before the beam injection. Furthermore, the amount of the tune shift is easily estimated when COD is large and, if necessary, we can shift an initial working point for beam commissioning. In the present case of the phase-2 lattice, when COD is large, the horizontal tune reduces and the vertical tune increases. We then set the initial tune in the horizontal direction to be slightly larger than a designed value and the vertical tune to be slightly smaller, if necessary.

In Fig. 6 and Fig. 7 we show the dynamic aperture with realistic errors for the phase-1 lattice and phase-2 lattice, respectively. In these calculations COD was corrected and reduced to less than 0.1mm in both horizontal and vertical directions. We see that the aperture in the phase-2 lattice is large enough. The momentum acceptance was also checked and we found that the acceptance is larger than $\pm$1%, being enough for beam injection.

The effect of a long undulator on the dynamic aperture was calculated and the results are shown in Fig. 7 by the dashed curve. The reduction of the aperture is seen in the vertical direction.

The distortion of betatron functions and phase caused by a long undulator can be corrected locally by using quadrupole magnets in the matching section, since they have independent power supplies. Furthermore, we added skew quadrupole magnets in both ends of LSS to cancel coupling excitation due to a long undulator.

The natural emittance of a new optics is designed to be about 6-7.5nmrad, being almost the same as that of the phase-1 case, and the natural coupling ratio in the phase-2 lattice estimated by using the above errors was found to be about 0.001. The coupling ratio in the phase-1 lattice has been deduced experimentally by analyzing measured Touschek lifetime[2] to be less than 0.001. We then expect that the coupling ratio in the phase-2 lattice is also small and the quality of the beam is maintained even after introducing four LSSs into the ring.

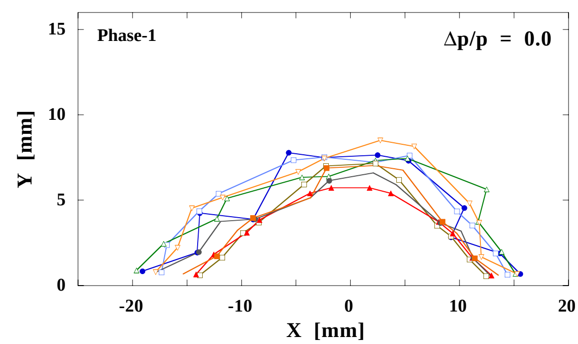

Figure 6: Dynamic apertures of the phase-1 lattice with realistic errors (typical cases). COD is corrected.

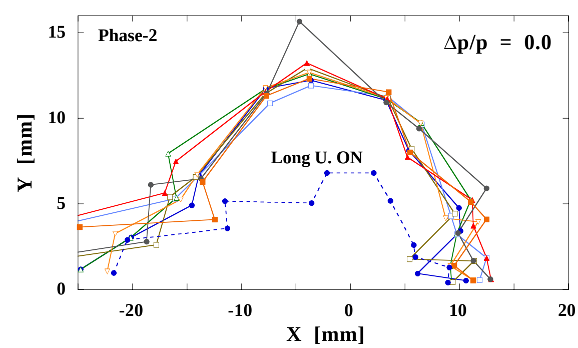

Figure 7: Dynamic apertures of the phase-2 lattice with realistic errors. COD is corrected. Also shown by the dashed curve is the aperture with a long undulator (example case).

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[2] M.Takao, *et.al.*, Proc. 1999 Particle Accelerator Conf., New York, 1999, p.2349.