DESIGN OF MODIFIED LATTICE OF LONG STRAIGHT SECTION IN THE SPring-8 STORAGE RING

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Abstract

A set of three in-vacuum undulators is going to be installed in one of four long straight sections of the SPring-8 storage ring. In order to make the undulator gap as narrow as possible, we plan to divide this long straight section into three sub-sections and install quadrupole magnets between these sub-sections to lower the vertical betatron function. With such a local modification of lattice, however, the symmetry of the ring is lowered and it becomes difficult to keep a sufficient dynamic aperture for on- and off-momentum electrons. In this paper we describe how we avoid this difficulty by introducing "counter-sextupole magnets" that cancel a dominant effect of nonlinear kicks by other sextupole magnets.

INTRODUCTION

The SPring-8 storage ring is a third generation synchrotron radiation light source and has four magnet-free long straight sections (LSS's) of about 30m. In designing the storage ring lattice with four LSS's, we took care of lattice symmetry to ensure a large dynamic aperture for on- and off-momentum electrons. To this end, we developed a method of "quasi-transparent matching of sextupole fields" by combining two key concepts of "betatron phase matching" and "local chromaticity correction" [1] .

The condition of "betatron phase matching" imposes a constraint on the betatron phase advance in the matching section. Figure 1 shows the lattice functions for the matching section inserted between two normal cells. The betatron phase advance in the matching section is chosen to be $2\pi n$, where $n = 2$ for the horizontal direction and $n = 1$ for the vertical direction. By this betatron phase matching, the matching section becomes transparent for on-momentum electrons and the dynamic aperture can be kept large.

To enlarge the dynamic aperture for off-momentum electrons, we need to make a "local chromaticity correction" to a certain extent, since chromatic aberration in the matching section cannot be neglected and affects the momentum acceptance. We then need to excite a sextupole magnet at the dispersive section with a weak strength. The SF shown in Fig. 2 is used for this purpose.

The SCT in Fig. 2 indicates a "counter-sextupole magnet" that cancels a dominant effect of the nonlinear kick by SF in the horizontal direction [2]. The S1 is used as an auxiliary sextupole to enlarge the dynamic aperture in the vertical direction. The point of our scheme is the betatron phase advance between sextupoles. As seen from Fig. 2, the three sextupole magnets are separated by about π in horizontal betatron phase and this ensures a higher degree of transparency of the matching section and enlarges the dynamic aperture and momentum acceptance. Similar considerations (interleaved / non-interleaved schemes) for chromaticity correction are found in [5, 6, 7]. After installing the counter-sextupole magnets in all of the match-

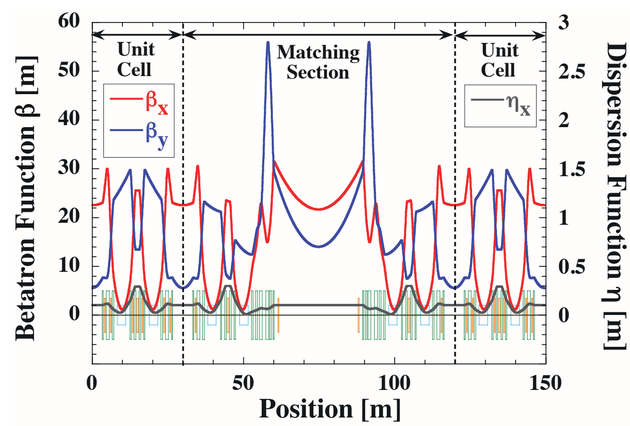

Figure 1: Lattice functions and magnet arrangement (blue: bending, green: quadrupole, orange: sextupole) before lattice modification. The unit cell and the matching section are shown.

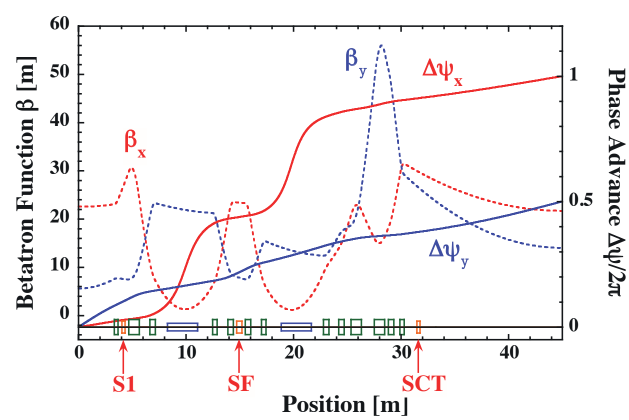

Figure 2: The position of sextupole magnets and the betatron phase advance for a half of the matching section. The SF is a sextupole magnet used for local chromaticity correction and SCT is a counter-sextupole magnet to cancel the nonlinear kick by SF.

ing section in 2007, the effectiveness of the above scheme was checked experimentally [8].

Figure 3 shows the horizontal and vertical betatron functions along the ring. It should be noted that though the linear optics has an apparent four-fold symmetry due to four LSS's, the ring has an approximate 18-fold symmetry from the viewpoint of the nonlinear sextupole field. (See Ref. [2] for details.)

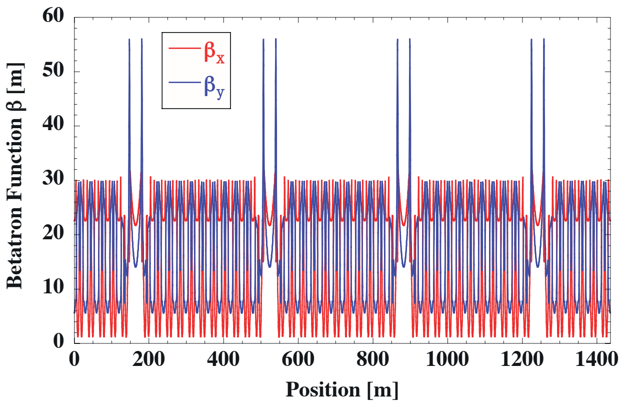

Figure 3: Betatron functions of the ring before lattice modification (present lattice).

MODIFIED LATTICE

At present, in two of LSS's a 25-m long undulator and a series of figure-8 undulators have already been installed and dedicated to user experiments. In addition to these undulators, a set of short-period undulators with a narrow gap is planned to be installed in one of remaining LSS's to build a high performance beamline for inelastic X-ray scattering [3]. To obtain sufficient photon flux and brilliance over a desired energy range, it is required to make the minimum undulator gap as small as possible.

To this end, we designed a new lattice in which one of LSS's is divided into three sub-sections for installing three 5-m long undulators and the rest of the ring is kept unchanged. Additional quadrupole magnets are installed between the sub-sections to lower the vertical betatron function and this allows us to use smaller-gap undulators [4].

Figure 4 shows the new lattice functions for the locally modified LSS. The vertical betatron function takes the minimum value of 2.5 m at the middle of each sub-section and the allowable minimum gap of undulators is 5.2 mm. (This value of the minimum gap was obtained so that it is effectively equal to the currently allowed values for existing in-vacuum undulators at other straight sections when scaled with the vertical betatron function at the edge.) By this local modification of lattice, the betatron tunes of the ring change from $(\nu_x, \nu_y) = (40.15, 18.35)$ to $(40.15, 19.35)$.

As shown in Fig. 5 we have kept the condition of "betatron phase matching" in modifying the lattice and the betatron phase advance of the matching section is chosen to be 4π in both horizontal and vertical directions. The position

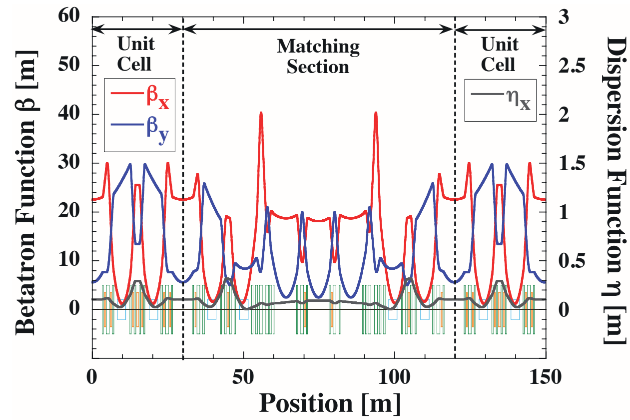

Figure 4: New design of the matching section for the modified lattice.

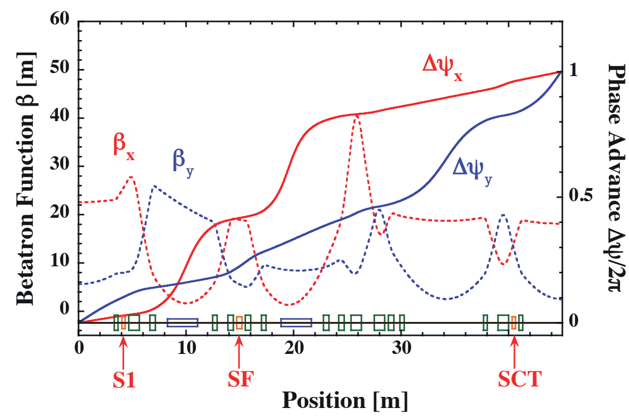

Figure 5: The betatron phase advance for a half of the matching section of the modified lattice.

of the counter-sextupole magnet SCT is shifted to make our scheme of sextupole optimization effective. Though the betatron functions of the ring are no longer symmetric as shown in Fig. 6, the 18-fold symmetry of the sextupole field is kept due to the "quasi-transparent matching" and the dynamic apertures for on- and off-momentum electrons can also be kept large after optimizing the sextupole strengths.

BEAM PERFORMANCE

Figure 7 shows the dynamic apertures for on-momentum electrons. The dashed line (blue) shows the one for the ring without counter-sextupole magnets. The ring had been operated without counter-sextupole magnets until September, 2007. The dot-dashed line (green) shows the dynamic aperture for the ring with counter-sextupole magnets, and we see that a stable area has become remarkably larger when compare to the dashed line. The dynamic aperture for the modified lattice is shown by the solid line (red). Though we see some reduction when compared to the dot-dashed line, the dynamic aperture is still larger than the dashed line. We also checked the injection efficiency of the modified lattice

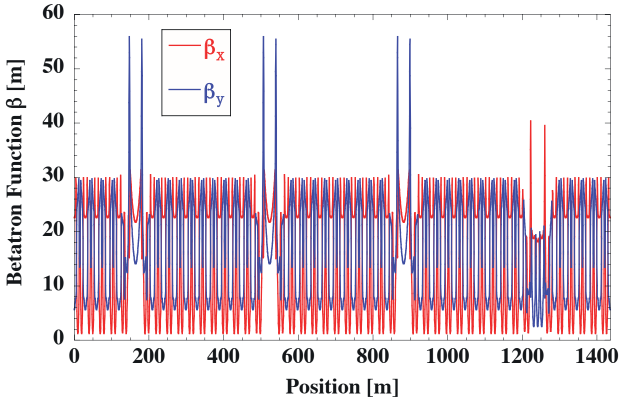

Figure 6: Betatron functions of the ring after lattice modification.

by computer simulations, and the results show that we can obtain a high injection efficiency even after the local modification.

As explained before, we have made a local chromaticity correction in addition to the betatron phase matching. This enlarges the dynamic apertures for off-momentum electrons. A large off-momentum dynamic aperture is needed for a large momentum acceptance and hence for a long beam lifetime. In figure 8 we compare the dynamic apertures for off-momentum electrons with $\Delta p/p = \pm 0.01$. We see that off-momentum dynamic apertures are sufficiently large even after modifying the lattice.

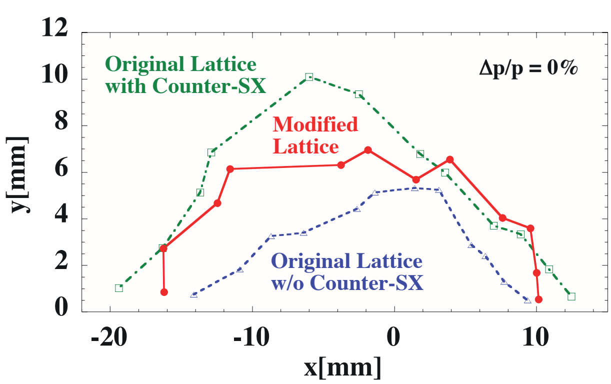

Figure 7: Comparison of dynamic apertures for on-momentum electrons calculated at the beam injection point.

SUMMARY

We have shown the method of optimizing sextupole fields for the ring with a locally modified lattice. Our scheme is summarized as follows: (i) impose the betatron phase condition to the locally modified section to make it transparent for on-momentum electrons, (ii) make a local chromaticity correction to this section with weakly excited sextupoles to enlarge the off-momentum dynamic aperture, and (iii) introduce counter-sextupoles to cancel a dominant effect of nonlinear kicks by the chromaticity correcting sextupoles. With this technique of sextupole optimization, we could keep sufficiently large dynamic apertures for on- and off-momentum electrons and realized independent tuning of LSS optics of the SPring-8 stirage ring. Commissioning of the new beamline is planned in the second half of 2011 and accelerator components (magnets, vacuum chambers, girders, new power supplies, etc.) will be rearranged and settled in accordance with the schedule.

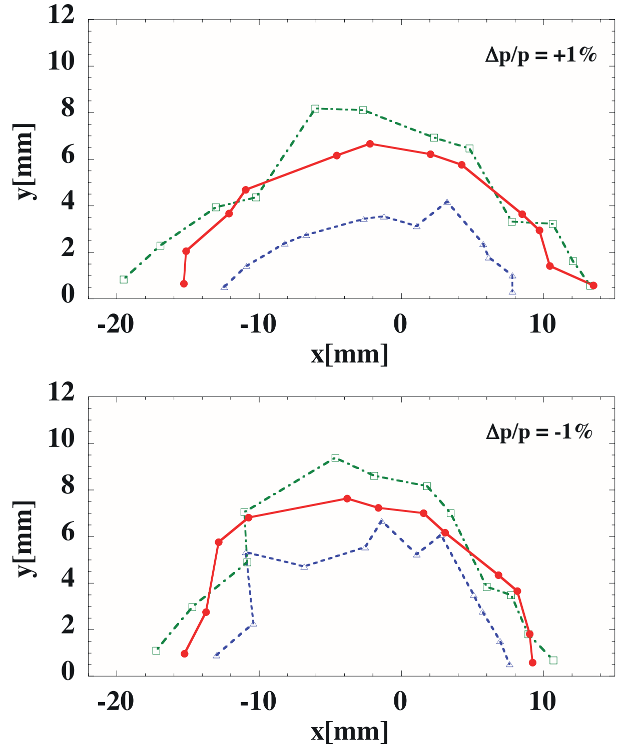

Figure 8: Dynamic apertures for off-momentum electrons with $\Delta p/p = \pm 0.01$.

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