LOCAL MODIFICATION OF LATTICE OF A LONG STRAIGHT SECTION FOR INSTALLING SMALL GAP IN-VACUUM UNDULATORS AT SPring-8

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Abstract

In the SPring-8 storage ring there are four magnet-free long straight sections (LSS's) of about 30m. Recently we locally modified one of these sections by installing two sets of the quadrupole-triplet and divided it into three sub-sections. The vertical betatron function at the middle of each sub-section was lowered to 2.5m so that small gap in-vacuum undulators with a short period can be installed. By this lattice modification the symmetry of the ring was lowered but we could keep sufficient dynamic aperture and momentum acceptance by taking optics matching into account and rearranging sextupole magnets. The beam commissioning of the new lattice has successfully been finished and from September 2011 it is used in user operation. We review our method of realizing a storage ring lattice having a very low symmetry and report the beam performance of the modified lattice.

LATTICE DESIGN OF LONG STRAIGHT SECTION

The SPring-8 storage ring is a third generation synchrotron radiation light source operated at the electron energy of 8GeV. The basic cell structure is of the double-bend type and the ring was originally constructed from 48 unit cells including four missing-bend cells, where bending magnets were removed but quadrupole and sextupole magnets were settled as in the normal cell.

In 2000, three years after the beam commissioning, we modified the missing-bend cells to realize a ring having four magnet-free long straight sections (LSS's) [1]. At that time we took care of the lattice symmetry to ensure a large dynamic aperture for on- and off-momentum electrons. In designing the LSS optics (see Fig. 1) we developed a method of "quasi-transparent matching of sextupole fields" by combining two key concepts of "betatron phase matching" and "local chromaticity correction" [2]. The condition of "betatron phase matching" imposes a constraint on the betatron phase advance in the matching section including the LSS: 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. 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 it affects the momentum acceptance. We then excited a sextupole magnet in the arc of the matching section with a weak strength.

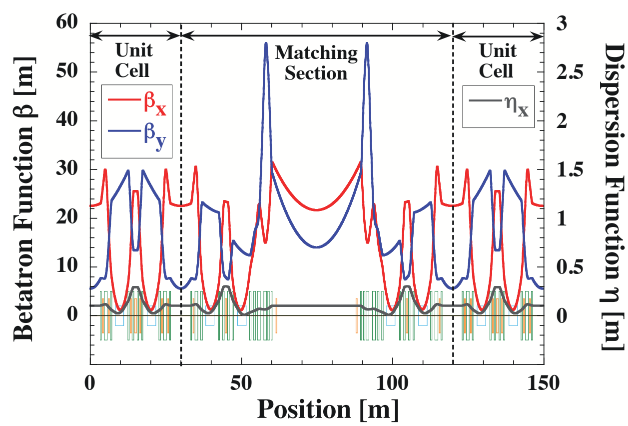

Figure 1: Original lattice functions of the matching section including the LSS. Also shown is the magnet arrangement (blue: bending, green: quadrupole, orange: sextupole).

In 2007, to enlarge the dynamic aperture further, we introduced "counter-sextupole" magnets in the matching section [3]: a dominant effect of the nonlinear kick due to sextupole magnets for the local chromaticity correction is cancelled by newly added "counter-sextupole" magnets in a similar manner to the non-interleaved sextuple scheme [4, 5, 6]. By the introduction of the "counter-sextupole" magnets, the injection efficiency was increased by about 5% and the Touschek beam lifetime became longer by about 10%. We note that the introduction of "counter-sextupole" magnets also enables us to make independent tuning of the lattice functions of each LSS, since the matching section is now quasi-transparent for on- and off-momentum electrons. This is important for the efficient use of LSS's because each insertion device will require different optimum values of the betatron and/or dispersion functions.

In 2009 it was approved to construct a new beamline BL43LXU in one of four LSS's. In this beamline small gap in-vacuum undulators with a short period are installed for generating an intense X-ray beam with very high flux and brilliance between 14.4 keV and 26 keV [7]. To realize a small gap of less than 6 mm it is needed to lower the vertical betatron function at the center of each undulator, and for this purpose we installed two sets of the quadrupole-triplet in one LSS.

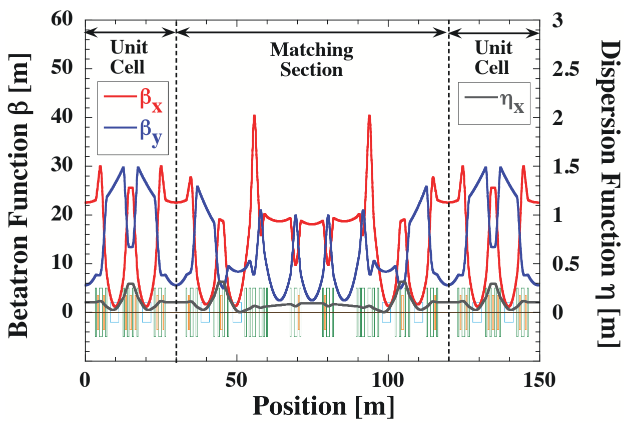

Figure 2: Lattice functions and magnet arrangement modified for the new beamline BL43LXU.

This LSS was then divided into three sub-sections as shown in Fig. 2 and at the center of each sub-section the vertical betatron function takes the minimum value of 2.5 m. The betatron phase advance in the matching section was set to be 4π in both horizontal and vertical directions. The position of the "counter-sextupole" magnets was changed by considering the betatron phase advance. From computer simulations we found that though the new lattice has a very low symmetry, the dynamic aperture and the momentum acceptance are large enough. Figure 3 shows the dynamic apertures for on-momentum electrons. The dashed line (blue) is for the ring before modification (shown in Fig. 1) and the solid line (red) is for the modified lattice (shown in Fig. 2). Though we see some reduction by the lattice modification, the dynamic aperture is still large enough. In Fig. 4 we compare the dynamic apertures for off-momentum electrons having the momentum deviation of $\Delta p/p = \pm 1\%$. We see that off-momentum dynamic apertures are sufficiently large even after modifying the lattice. Further details on the design of the modified lattice are given in Ref. [8].

BEAM COMMISSIONING

After installing the quadrupole-triplets in March 2011 we started beam commissioning of the new lattice and checked its performance. Machine parameters, such as dispersion and betatron functions, beam size, coupling ratio, injection efficiency and beam lifetime, were measured and compared to the design value or to that for the original lattice before modification. We then carried out fine tuning of the machine and concluded that the beam performance of the ring is not deteriorated by the local modification of the

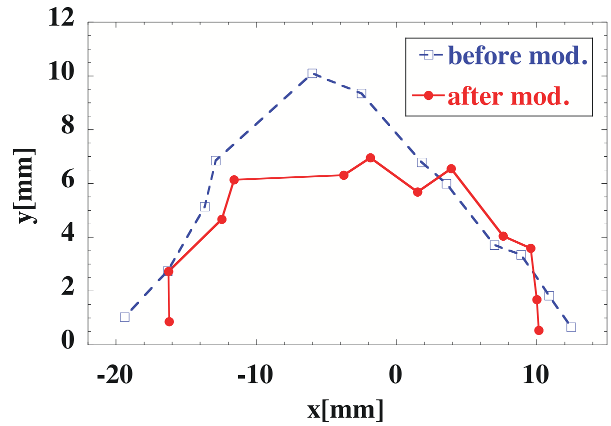

Figure 3: Comparison of dynamic apertures for on-momentum electrons calculated at the beam injection point.

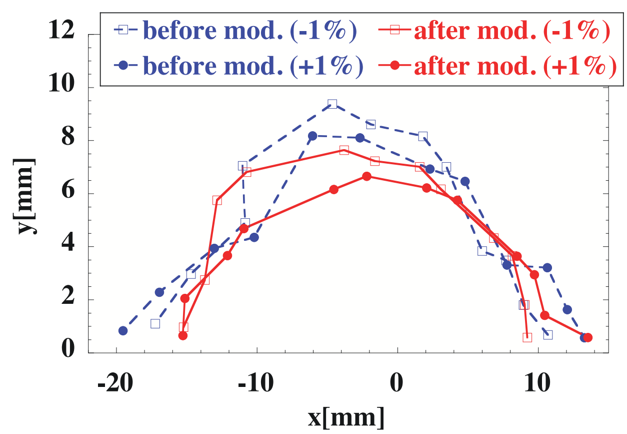

Figure 4: Comparison of dynamic apertures for off-momentum electrons with $\Delta p/p = \pm 1\%$.

LSS and the new lattice can be applied to user operation.

As an example of measured machine parameters, we show the horizontal and vertical betatron functions in Fig. 5. These were obtained from the response matrix analysis, and we see a good agreement between measured and design values. In this measurement the overall distortion of the betatron function along the ring is 2.3 % in the horizontal direction and 2.4 % in the vertical direction. The distortion has been corrected with 49 auxiliary power supplies to quadrupole magnets. Further corrections are planned to suppress the distortion to less than 2 %.

The horizontal dynamic aperture at the injection point was measured by using pulsed bump magnets as shown in Fig. 6. We stored a beam in a single-bunch mode, shifted its orbit instantaneously by using a pair of pulsed bump magnets located upstream or downstream from the injection point and measured a survival rate of stored electrons after giving the orbit shift. The dynamic (or physical) aperture corresponds to the point where all electrons are lost. From Fig. 6 we can confirm that the horizontal dynamic aperture after the lattice modification is as large as the orig-

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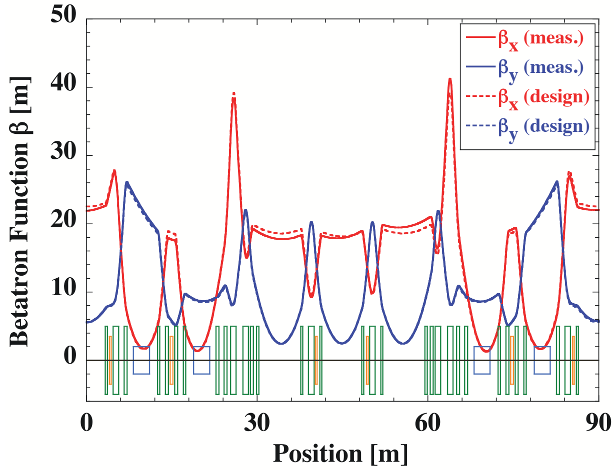

Figure 5: The betatron function of the modified section. The solid lines are the measured values obtained from the response matrix analysis, and the dashed lines are the design values.

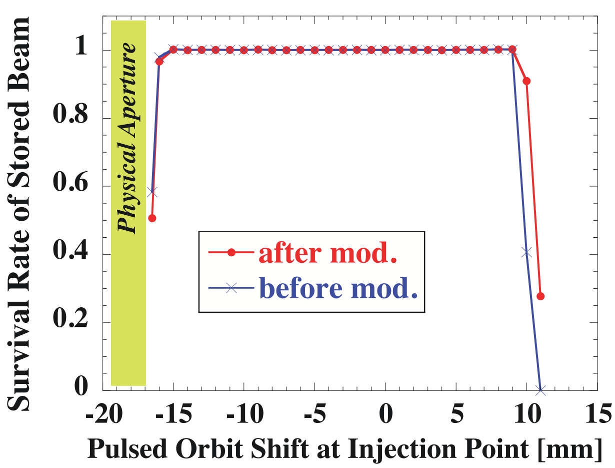

Figure 6: The horizontal dynamic aperture measured at the injection point. The position of the injection septum wall is indicated as "Physical Aperture".

inal aperture before modification.

The momentum acceptance was also checked by measuring the Touschek beam lifetime. The results are shown in Fig. 7. To eliminate the bunch-length dependence of the Touschek beam lifetime τ, we plotted τf_s as a function of the RF accelerating voltage, where f_s is the synchrotron frequency. The resulting value of the momentum acceptance was 3.3 % for the ring before modification and 3.2 % after modification. The momentum acceptance is slightly reduced by the lattice modification, though the value of 3.2 % is enough for stable user operation. This reduction was expected from Fig. 4, since the off-momentum dynamic apertures for the modified lattice are slightly smaller than the original lattice. This will be due to the fact that the cancellation of the non-linear kick due to sextupole magnets in the matching section is not perfect. The suppression of this

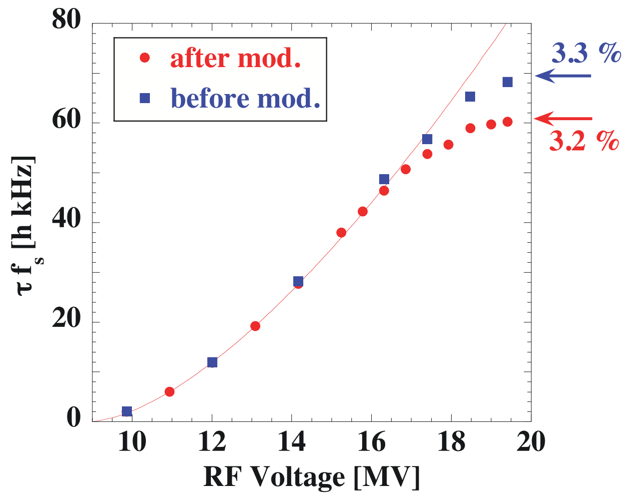

Figure 7: The momentum acceptance deduced from measured Touschek beam lifetime.

residual effect is our next target for improving dynamical stability of the beam.

SUMMARY

In one of four long straight sections of the SPring-8 storage ring, the lattice was modified locally to install small gap in-vacuum undulators with a short period (see Fig. 2). Though the symmetry of the ring was lowered by this modification, the dynamic aperture and the momentum acceptance could be kept large. This is owing to our scheme of lattice design of the LSS: we imposed the betatron phase condition to this section to make it transparent for on-momentum electrons, made a local chromaticity correction with weakly excited sextupole magnets to enlarge the off-momentum dynamic aperture, and introduced "counter-sextupole" magnets to cancel a dominant effect of the non-linear kick due to sextupole magnets. The beam commissioning of the new lattice has successfully been finished and, after checking the beam performance, it is now used in user operation. One undulator has been installed in the middle sub-section and at present the minimum gap of 5.8 mm is allowed. The other two undulators are going to be installed for achieving the design goal of the beamline.

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