# Lattice Design of SPring-8 Storage Ring with Four Magnet-free Long Straight Sections

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## 1. Introduction

It is scheduled that four magnet-free long straight sections (LSSs), which are about twenty seven meter long, are going to be realized in the storage ring of SPring-8 in summer 2000 by re-arranging quadrupole and sextupole magnets in the straight cells with bending magnets removed. As a result of many years long effort, we have already found a good scheme to realize four LSSs in the ring [1].

In autumn 1998, design of matching sections at both ends of each LSS was fixed. Then, design on machine components has been started and being continued. We are also checking detailed performance of the ring in consideration of the final specification. Among the design works related to the LSSs, we briefly show here the lattice design and some parameters of the ring with four LSSs.

## 2. Scheme to Realize Four LSSs [1]

In the SPring-8 storage ring, four missing bending magnet cells have already been installed. This allows us to construct four LSSs keeping all existing beam lines unchanged. In addition, by using optical and phase matching between the lattice without the LSSs (Phase I) and that with the LSSs (Phase II), we can separate new error sources caused by the re-arrangement from the existing sources. We can thus keep sufficient dynamic stability for machine tuning under large closed orbit distortion (COD).

At first, we planned to realize four LSSs in the ring by three stages via transient state, where we can simulate tuning of the Phase II lattice with the real SPring-8 storage ring. Due to the reasons why the construction schedule is tight and the transient state is not essential, it was skipped.

## 3. Design of LSSs

*3.1 Structure of LSSs*

Structure of each LSS is shown in Fig. 1. A drift space of about 27 m is available for the installation of an insertion device (ID). A matching section at each end of the LSS is about 10 m. Four LSSs are installed at #6, #18, #30 and #42 cells keeping four fold symmetry.

Each matching section is composed of a quadrupole sextet and the quadrupole magnets are arranged in mirror symmetry with respect to a middle point of the LSS as shown in Fig 1. This configuration was adopted in consideration of the following five points:

(a) Possibility of lowering natural emittance down to 5 nmrad
(b) Optics flexibility at both LSS and normal ID sections
(c) Reuse of existing quadrupoles to be removed
(d) Minimum modification of the ring
(e) Maximum length of magnet-free straight section

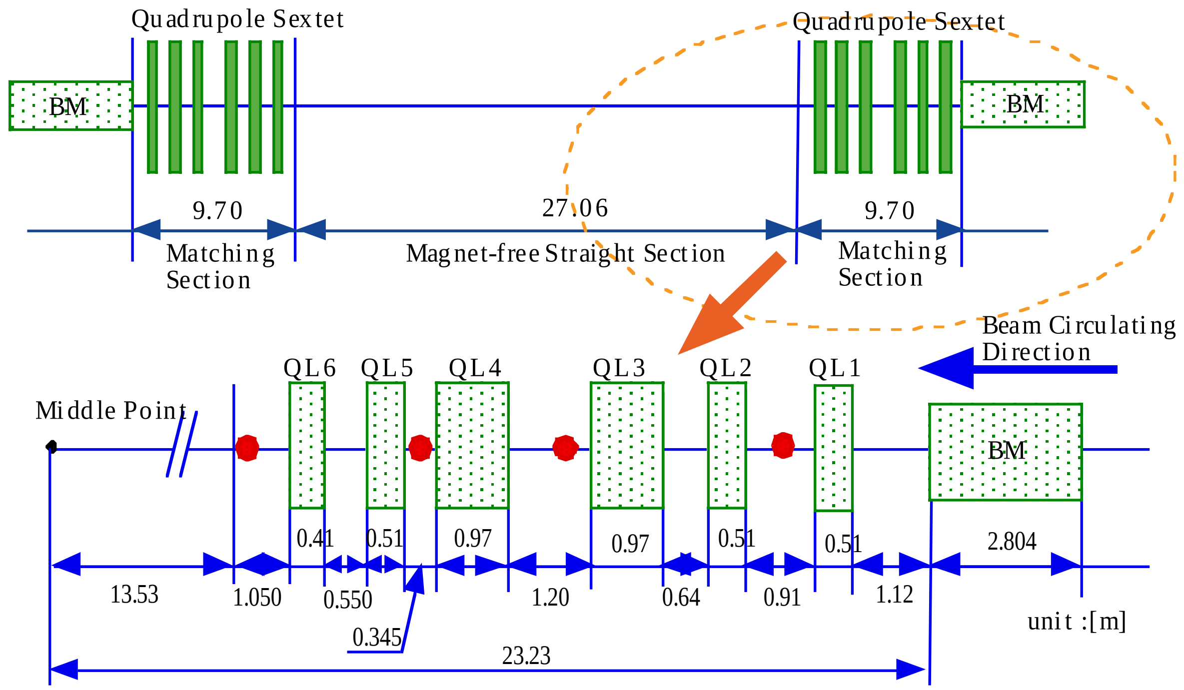


Fig. 1. Structure of long straight section (LSS). The symbols BM and QL represent respectively bending and quadrupole magnets. The circles show beam position monitors.

*3.2 Optics*

To perform mapping of possible optics, we developed a program to automatically find all solutions under a given boundary condition. By using this program, we found as the best combination of quadrupole polarities, FDFDDF which implies that focusing and defocusing magnets are respectively (QL1, QL3, QL6) and (QL2, QL4, QL5). In Fig. 2, the obtained solution map is shown for the FDFDDF combination. As seen in the figure, both horizontal and vertical betatron functions are adjustable from 3 to 50 m at a middle point of the LSS.

Among the solutions, one candidate satisfying optics and phase matching in Section 2 is shown in Fig. 3. The emittance of this optics is 6.6 nmrad. Horizontal and vertical betatron tunes are respectively 47.16 and 15.31.

*3.3 Correction of Distortion caused by long ID*

To control the distortion caused by long IDs, we prepare two kinds of corrections linking to a change of the ID gap.

One is the correction of a quadrupole field, which distorts betatron functions. By a simple model calculation, serious distortion of about 20 % is estimated in a vertical plane. To cancel out this distortion, the strength of six quadrupole families should be adjusted in accordance with the ID gap change.

The other is the correction of a skew quadrupole field, which mainly increases vertical emittance. The strength of an induced skew field is estimated to be about 250 (G/cm)•cm [2]. A simple estimation shows that this strength increases a HV coupling ratio up to 0.8 %. To control the coupling ratio, a skew quadrupole magnet is installed at each side of the long ID. The strength of skew quadrupole magnets should be also adjusted in accordance with the ID gap change.

*3.4 Error Tolerances*

Target precision of the magnet alignment is almost the same as that for the Phase I lattice. The tolerances of magnet and girder misalignment are respectively 25 and 200 μm. By these misalignment tolerances, an expectation value of horizontal and vertical closed orbit distortion (COD) is suppressed to be less than 2 mm. This value is sufficiently small compared with a minimum vertical half aperture of 7.5 mm.

We have investigated effects of a current ripple of a quadrupole magnet on the betatron tune shift and COD. We assumed: (a) The ripple induces only dipole and quadrupole field components and measured values [3] can be used as the strength of each field component. (b) The strength of the induced field has the frequency dependence of $1/\sqrt{f}$ in the region where $f$ is larger than 30 Hz. Here, $f$ represents a frequency of the induced field. From the obtained calculation results, we have set the tolerance of a current ripple as

$$\frac{\Delta I}{I} = 1.8\times10^{-5}\times\sqrt{\frac{f}{60}},\ f > 30\ \text{Hz}, \qquad \frac{\Delta I}{I} = 1.8\times10^{-5},\ 0 \le f \le 30\ \text{Hz}, \qquad (1)$$

where the $I$ and $\Delta I$ represent respectively the magnet current and the ripple current with the frequency $f$.

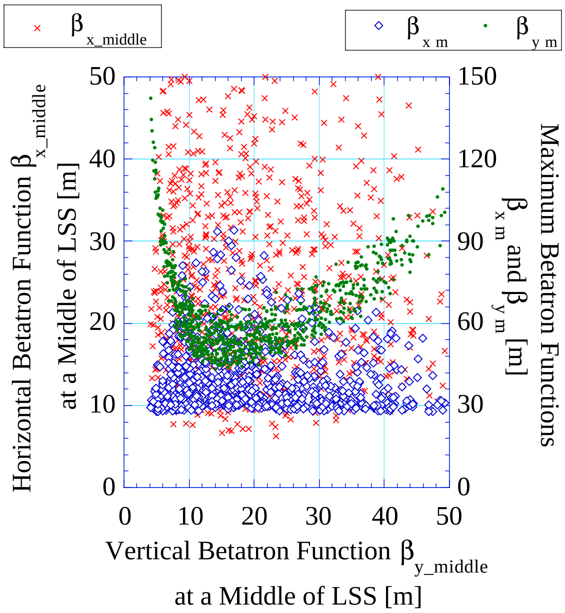


Fig. 2. Solution map for the FDFDDF combination. Natural emittance is 7 nmrad and the total step number for the search is $20^6$.

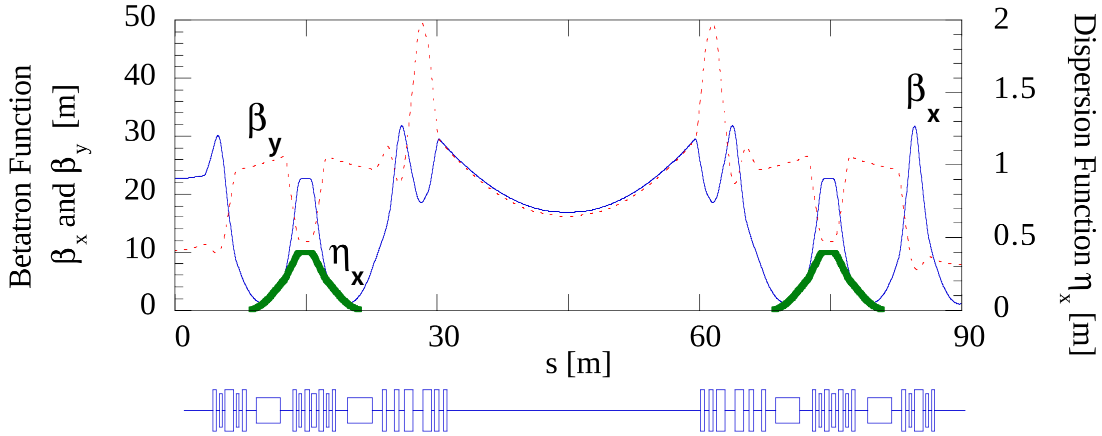


Fig. 3. One optics candidate to be used at beam operation.

## 4. Toward Commissioning of LSSs

Following items should be carried out before summer 2000, *i.e.*, before the installation of four LSSs from the view point of lattice design.

(a) Estimation of nonlinear effects of long IDs on beam dynamics and cure of the effects if necessary
(b) Optimization of COD and coupling correction system

Preparation of a commissioning scenario is also important for smooth commissioning of the Phase II lattice.

## References

[1] H. Tanaka *et al.*, J. Synchrotron Rad. **4** (1997) 47.
[2] T. Tanaka, private communication.
[3] H. Takebe, private communication.