PAUL SCHERRER INSTITUT	Project **SLS 2.0**
Title **Investigation of installing an insertion device with solenoid field into SLS2 lattice**	Document identification **SLS2-AM81-002-1**
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1 Introduction

It was requested by the insertion device group to investigate if an insertion device with rather strong solenoid field can be installed into SLS2. The impact of solenoid to the storage ring performance is briefly studied.

2 Impact of solenoid field to the lattce

Solenoid field "rotates" horizontal axes, x and y. The rotation angle is defined as

$$\phi = -\frac{1}{2}\int_0^s S\left(s'\right) ds' \tag{1}$$

(Equation from Wiedemann's text book but it should be without '-' sign?), where S is the normalized solenoid strength, and s is the path length along the solenoid. Solenoid introduces a linear coupling, depending on the rotation angle. Only when the angle is a multiple of π, the lattice remains uncoupled. This condition can be easily achieved by splitting the solenoid into pieces and alternating the field such that the integrated field is zero, i.e. $\phi = 0$. In this study, we consider a set of three solenoid magnets, of which length are 0.5 m, 1 m and 0.5 m. The field is negative in the first and the last ones and positive in the middle one. They are installed into a straight section symmetrically (the middle of 1-m long magnet is at the centre of straight section). As discussed, we can avoid introducing a coupling with this configuration. The lattice functions are, however, disturbed due to the focusing by the solenoid. Figure 1 shows the beta function with and without the set of solenoids.

In Fig.1, horizontal and vertical beta functions are shown. They are actually Beta11 and Beta22 in Ripken's (or MADX-PTC) notation and do not exactly reflect the beam sizes within the solenoid because Beta12 and Beta21 are not zero there. However, they are negligibly small (<10 cm), and the beam sizes are therefore dominated by Beta11 and Beta22. The beta beat arising from the solenoid focusing can be corrected to some extent by additional quadrupoles located in the straight section, where the solenoids are installed. A sketch of magnet arrangement is shown in Fig. 2. A correction with four additional quadrupoles is examined, and the result is shown in Fig. 3.

Two quadrupoles each are put upstream and downstream of the solenoid, and also four lattice quadrupoles of the solenoid straight section are also used for the correction. The matching condition is zero alpha function in both planes at the middle of straight section and keeping the tunes in both planes, in total four conditions. The eight quadrupoles used in the matching are paired symmetrically. Hence, the number of knobs equals to the number of conditions. The beta beat is almost corrected except for the location of the solenoids while the tunes are shifted (or uncorrected) by -0.05 and +0.072 in the horizontal and vertical plane, respectively. Strengths of additional quadrupoles are weak, resulting in only a slight change in the chromaticity. At lower solenoid

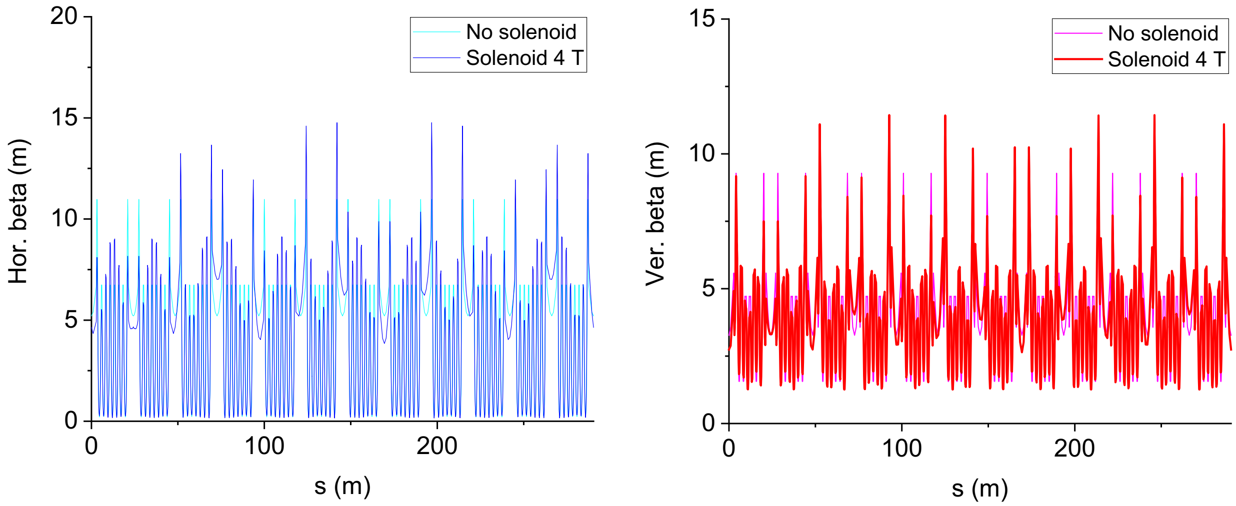

Figure 1: Beta functions with and without solenoid. The solenoid field is set to (-4T, 4T, -4T).

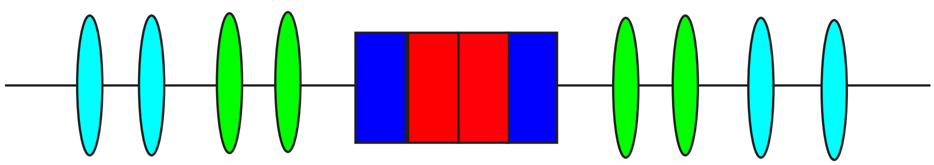

Figure 2: A schematic view of magnet arrangement. Solenoid magnets are represented in red (positive field) and blue (negative field). Additional quarupoles are in light green while the lattice quadrupoles (QM3 and QM4) are in cyan.

fields, the beta beat can be almost fully corrected, and the tune shifts are smaller. As indicated in Fig. 3, the beta function within the solenoid becomes larger in the horizontal plane and smaller in the vertical plane. The dynamic apertures are also computed for various solenoid fields, and with and without optics correction. The results are shown in Fig. 4.

The dynamic aperture is not recovered by the optics correction, or even deteriorated especially in the horizontal plane. However, the phase space trajectories (Fig. 5) show the effect of periodicity restoration. When the solenoid is excited to 2 T, resonance islands of 6Qx=229(?) appear at around the amplitude corresponding to x= 3 mm. These are eliminated by the optics correction. Instead, resonance islands of 9Qx=343(?) appear at around the amplitude corresponding to x=4 mm. The injection beam particles may be trapped by these islands, and therefore an on-axis injection or a quasi on-axis injection might be necessary if not better optics correction scheme is found and applied. The effect of optics correction is much more visible when the solenoid is excited to 4 T (Fig. 6).

3 Conclusion

The following conclusions are drawn from this first (and quck) investigation:

- It seems possible to install an insertion device with solenoid field up to a few T.
- The insertion device should be divided into two or three pieces to avoid linear coupling by alternating the field.
- The optics is disturbed by the focusing of solenoid while the coupling is fully canceled.

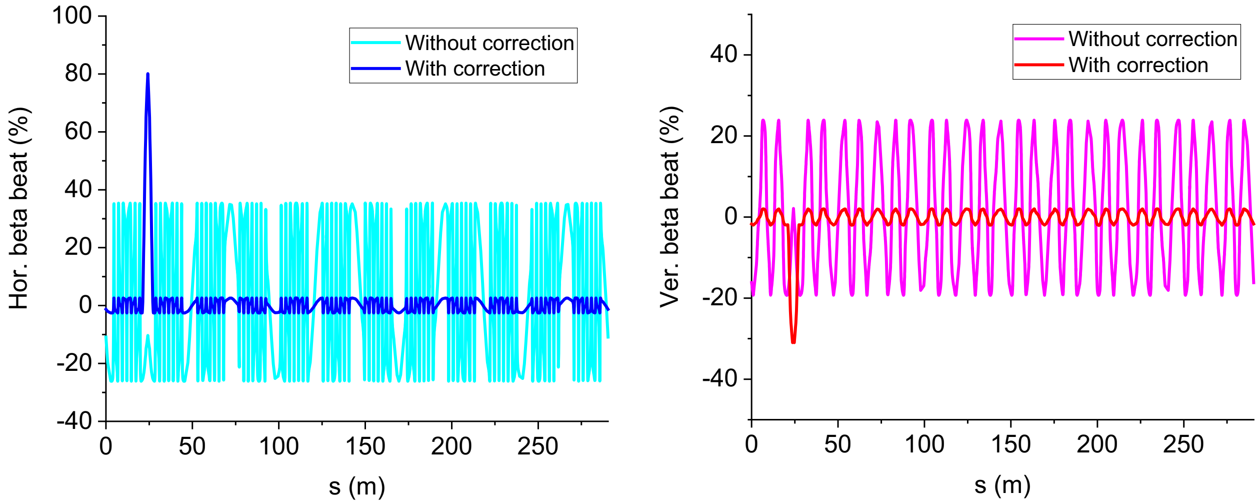

Figure 3: Beta beat with and without correction. The solenoid field is set to (-4T, 4T, -4T). The solenoids are installed at around s=25 m.

- An optics correction applied here slightly deteriorates dynamic aperture but the effect of correction is visible in the phase space trajectory, i.e. the resonance islands are eliminated.
- As seen in 2 T case, the resonance islands can be still visibly large in the phase space after the optics correction. In cases, where injection beam particles can be trapped, an on-axis or a quasi on-axis injection may be necessary if not a better correction scheme is found and applied.

Further studies, such as misalignments of the solenoid and other components, tracking with undulator field overlapping with the solenoid field, the effect of solenoid fringe field etc., need to be performed.

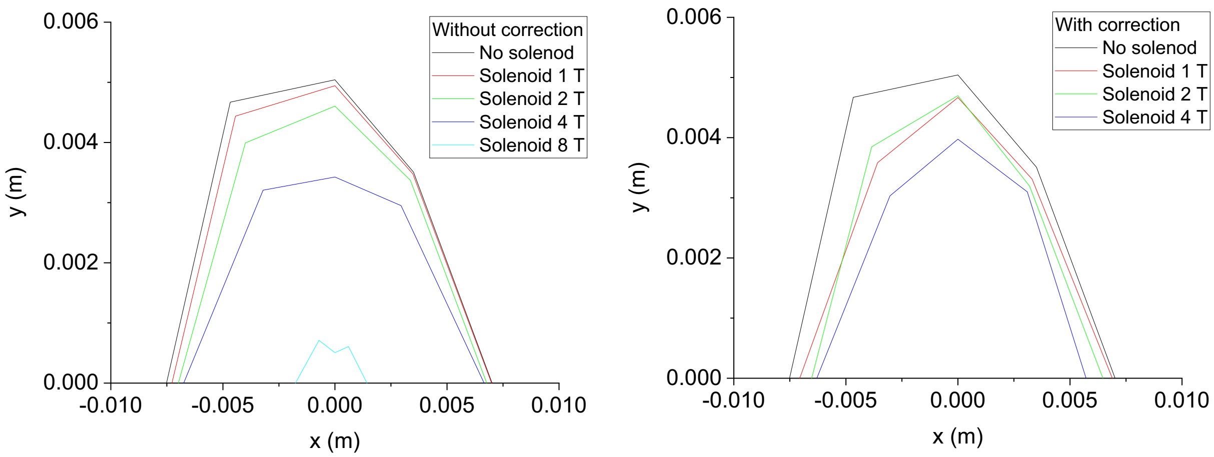

Figure 4: Dynamic aperture with and without optics correction. The dynamic aperture is significantly spoiled with 8 T solenoid, and the correction was not possible.

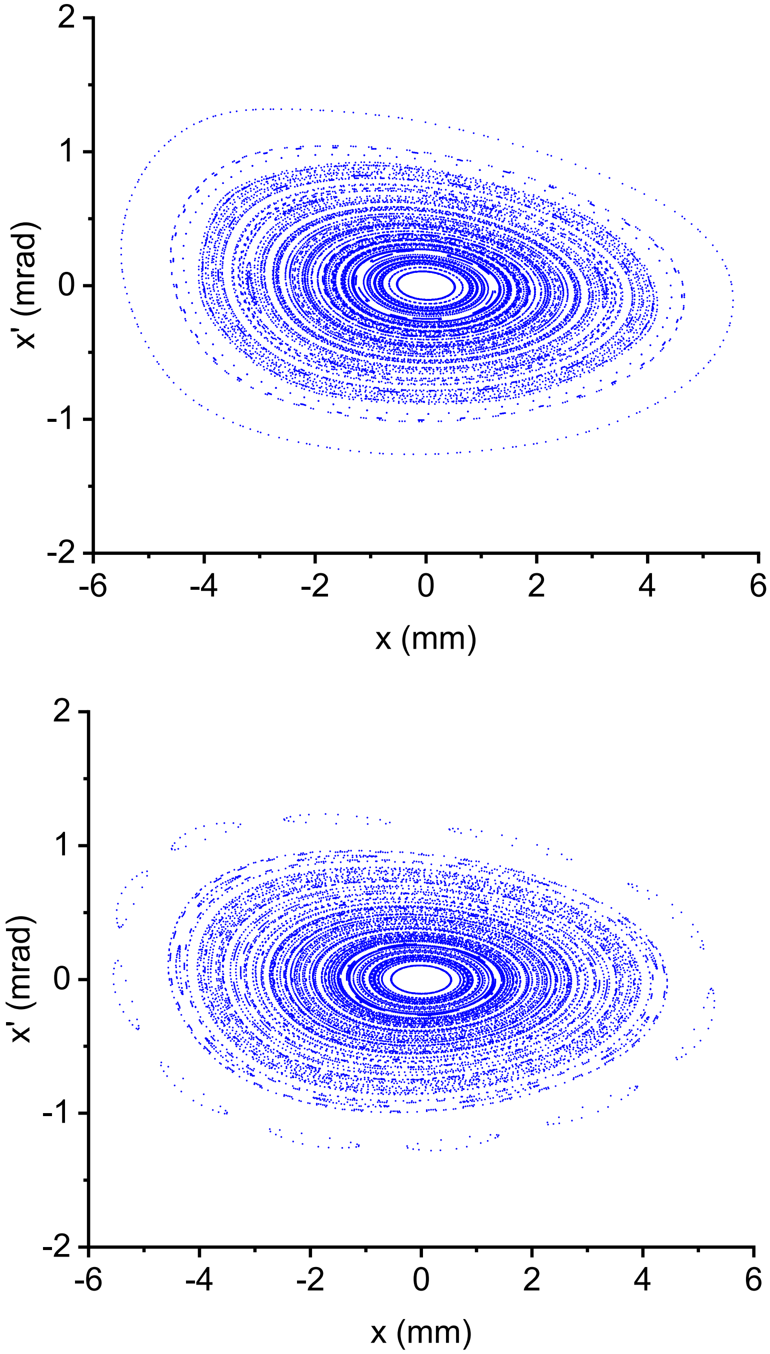

Figure 5: Horizontal phase space trajectory without (top) and with (bottom) optics correction. 100 particles with Gaussian distribution are tracked over 200 turns to visualize the trajectories. Solenoid is set to 2 T.

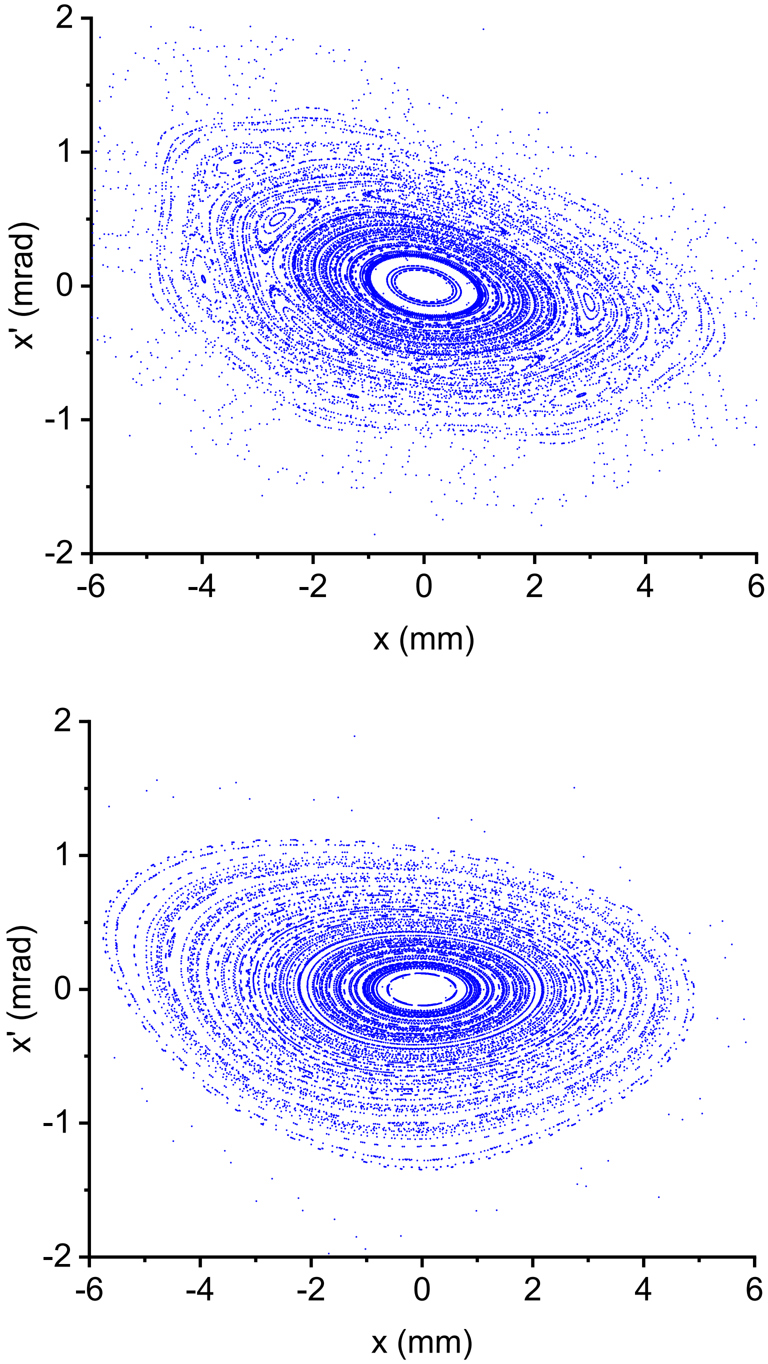

Figure 6: Same plots to Fig. 4 but with 4 T solenoid.