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Introduction

The strategy of SLS2 lattice correction is to realize the accelerator performance, namely long-enough beam lifetime and high injection efficiency, after orbit and linear optics corrections. Nonlinear optics correction is therefore not essential but helpful to maximize the performance. This study is to reveal nonlinear optics correction capability of the machine and to decide how we power sextupole families.

Third order resonances

Around the working point $[39.35, 15.25]$, we have third order resonances of $3Q_x=118$, $Q_x+2Q_y=70$ and $Q_x-2Q_y=9$. These are all non-systematic resonances, and thus they are excited by machine imperfections (for on-momentum beam). The first two resonances are overlapping with the tune foot print (Figure 1).

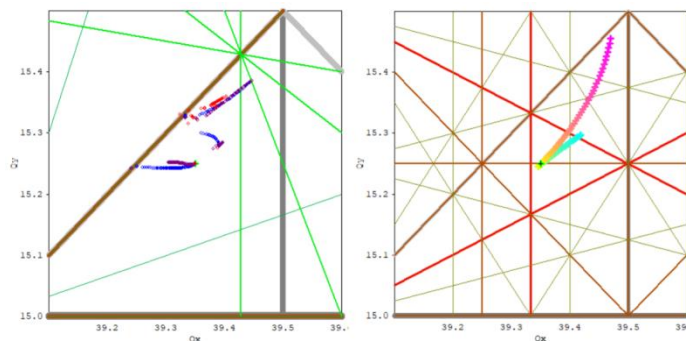


Figure 1: Tune footprint. Tune with amplitude for $dp/p = \{0, -4\%, +4\%\}$ (left). Tune for $\pm 5\%$ energy variation and chromaticities of $+1$ (right). Figure from SLS2-SA81-004.

$3Q_x=118$ creates resonance islands in the horizontal phase space. Even with small perturbation to the lattice, the resonance islands can be large enough to trap the injection beam particles. It is thus important to correct this resonance. At the same time, a slight shift of the working point brings the islands to the larger amplitude beyond the physical aperture determined the injection septum. Therefore a new working point [39.36, 15.25] is suggested.

$Q_x+2Q_y=70$ can deteriorate the performance since the coupled particle motion can be unstable when such a sum resonance is excited. It is therefore also important to correct this resonance.

$Q_x-2Q_y=9$ resonance is not as important as $Q_x+2Q_y=70$. Although it couples the horizontal and vertical planes, the particle motion is stable (or bounded). Moreover, it is not overlapping with the tune foot print. It may not be essential to correct this difference resonance.

The knobs to correct third order resonances are sextupoles. So far, two powering schemes are suggested, (A) 72 power supplies with 4 magnets each: 4 successive sectors are grouped (3 groups), and first sextupoles of each sector are powered with one power supply. The same for the rest of sextupoles (A. Streun), (B) 48 power supplies with 6 magnets each. A smaller number of power supplies is preferable for Power supply group (B. Ronner). They are referred to as Scheme A and Scheme B in the following.

The correction knobs are set up based on a single resonance theory with Hamiltonian formalism. The 118th harmonic content of sextupole distribution multiplied by $\beta x^{3/2}$ as a function of the normalized horizontal phase advance, which ranges from 0 to 2π along the ring, is controlled for $3Q_x=118$, for example. The theory indicates that not only third order resonances but also integer resonances are excited by sextupoles. However, integer resonances are ignored here since they may be very strong already with dipole errors, and moreover the working point is not close to the integer resonance ($Q_x=39$). The higher order effects are also ignored but the fourth order resonances are covered by octupoles as discussed later.

Scheme A is examined first. The ideal lattice without superconducting bending magnets (B062) is used to compute response matrix (RM), i.e., 3 harmonic contents are computed by changing the current of 72 power supplies one by one. Each harmonic content has sine and cosine terms (or amplitude and phase). Therefore, we have 72 knobs to correct 6 targets. At this moment, chromaticity is not considered for simplicity but it will be included later.

After computing RM, the ideal lattice but with superconducting magnets is used for testing third order resonance correction. The lattice symmetry is broken due to the slight change of linear optics arising from superconducting bending magnets although it is corrected by quadrupole correctors. The asymmetry is not so strong but the goal here is to see whether given knobs are enough orthogonal to control harmonic contents. The result is shown in Table 1.

Table 1: Harmonic contents with and without correction (Scheme A).

Second row with 72 knobs, the chromaticity is not kept constant. Third row with 18 knobs, only harmonic sextupoles are used.

	3Qx=118		Qx+2Qy=70		Qx-2Qy=9	
	Cosine	Sine	Cosine	Sine	Cosine	Sine
W/o correction	0.33	0.34	-0.051	-0.19	0.074	-0.0065
W/ correction, 72 knobs	0.00012	-0.00094	-0.0058	0.021	0.074	-0.0064
W/ correction, 18 knobs	0.00011	-0.00008	0.00007	-0.00036	0.074	-0.0064

The correction is computed using SVD. Two small eigenvalues, which corresponds to the sine and cosine terms of $Qx-2Qy=9$, have to be discarded otherwise the correction is too strong. Therefore, as seen in Table 1, $Qx-2Qy=9$ is not corrected even with a full set of 72 knobs. Moreover, it turned out that 18 knobs, only harmonic sextupoles, are enough or even better to correct other two resonances.

As discussed above, it is not essential to correct $Qx-2Qy=9$ since it is not harmful for the design working point. Therefore, Scheme A with 72 power supplies essentially fulfills beam dynamics requirements.

The same exercise is performed for Scheme B with 48 power supplies. Sextupoles are connected to the power supply similarly to Scheme A but 6 magnets each. Various set of knobs are examined as in Table 2.

Table 2: Harmonic contents with and without correction (Scheme A).

Second row with all 48 knobs, the chromaticity is not kept constant. Third row with 12 knobs, only harmonic sextupoles are used. Fourth row with 36 knobs, only chromatic sextupoles are used, and the chromaticity is kept constant in this case.

	3Qx=118		Qx+2Qy=70		Qx-2Qy=9	
	Cosine	Sine	Cosine	Sine	Cosine	Sine
W/o correction	0.33	0.34	-0.051	-0.19	0.074	-0.0065
W/ correction, 48 knobs	0.33	0.34	-0.051	-0.19	0.00035	-0.00056
W/ correction, 12 knobs	0.33	0.34	-0.051	-0.19	0.00018	-0.00023
W/ correction, 36 knobs	0.33	0.34	-0.051	-0.19	0.0062	-0.0006

Only two eigenvalues, which corresponds to the sine and cosine terms of $Qx-2Qy=9$, are included otherwise the correction is too strong. As seen in Table 2, $Qx-2Qy=9$ is approximately under control with Scheme B.

Different powering scheme may be considered, for example, 96 power supplies with 3 magnets each in order to control all the three resonances. However, a larger number of power supplies is not preferable. A few more different schemes with reasonable number of power supplies were examined but no better solution was found. It is, therefore, proposed to mix Scheme A and B: Scheme A for harmonic sextupoles and Scheme B for chromatic sextupoles if the power supply works for different number of magnets (Figure 2). If not, we will take Scheme A (no mixture). Clearly, Scheme B (no mixture) is discarded; the important resonances, $3Q_x=118$ and $Q_x+2Q_y=70$, cannot be corrected.

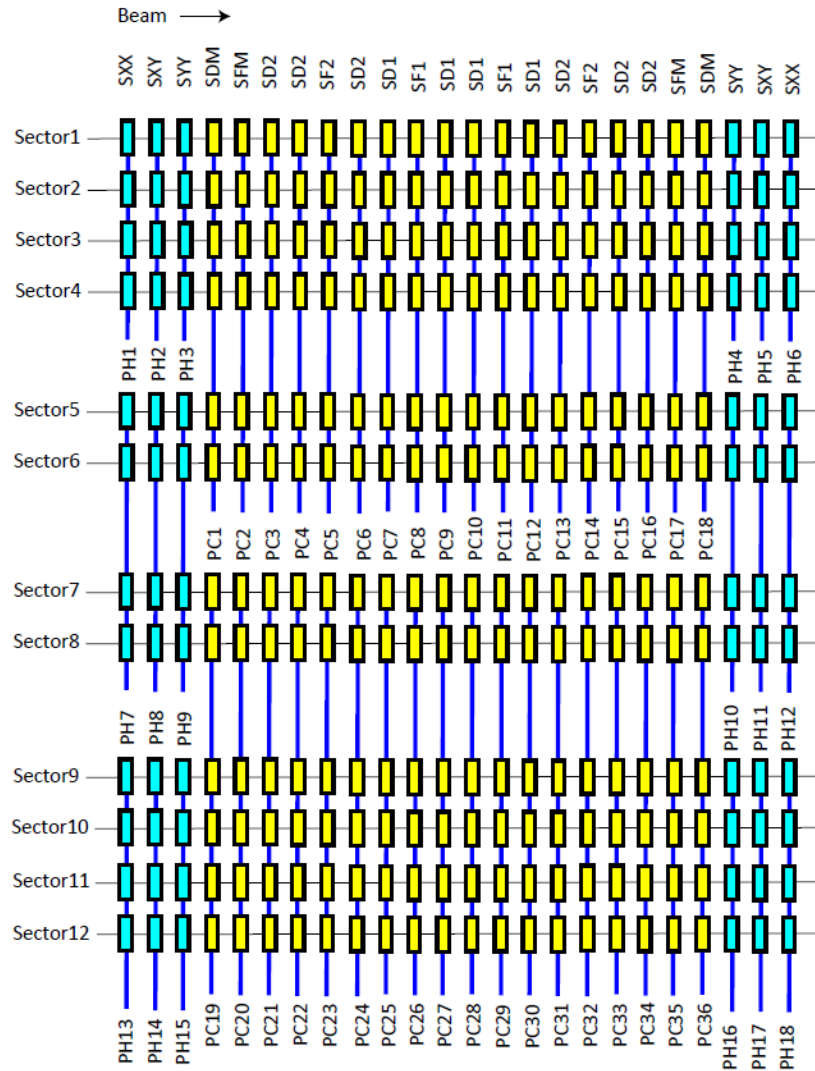


Figure 2: Proposed sextupole powering scheme – a mixture of Schemes A and B. Cyan boxes indicate harmonic sextupoles, which are connected to power supplies PHnn. Yellow boxes are chromatic sextupole, which are connected to power supplies PCnn. 54 power supplies in total.

Fourth order resonances

Around the working point [39.35,15.25], we have fourth order resonances of $4Q_x=157$, $2Q_x-2Q_y=48$ and $4Q_y=61$. These are all non-systematic resonances, and thus they are excited by machine imperfections. The first two resonances are overlapping with the tune foot print. In addition, octupoles excite half integer resonances and causes amplitude dependent tune shifts.

$4Q_x=157$ creates resonance islands in the horizontal phase space. Since the working point is not very close to this resonance, the islands are located at large amplitude, which is beyond the physical aperture imposed by the injection septum or collimators. Hence it is not very important to correct this resonance.

$2Q_x+2Q_y=109$ can be harmful as $Q_x+2Q_y=70$. It would be important to correct this resonance.

$2Q_x-2Q_y=48$ is a structural resonance (4×12), and thus it would be impossible to suppress this resonance. Tune foot print is slightly touching the resonance line at positive momentum deviation and/or large betatron amplitude. The correction will be computed not to change the 48th harmonic content.

$4Q_y=61$ creates resonance islands in the vertical phase space. The working point is actually exactly on resonance. Therefore a new working point [39.36, 15.22] or [39.36, 15.27] is suggested, including the change in horizontal tune due to $3Q_x=118$.

$2Q_x=79$ is a half integer resonance which can be excited by not only quads but also octupoles. There is a qualitative difference depending on how it is excited: the stopband will be amplitude dependent when excited by octupoles. Since only a part of tune foot print (where the momentum deviation is positive and large) is close to this resonance, it may not be very harmful to the performance.

$2Q_y=31$. The above description applies to this resonance as well.

Amplitude dependent tune shifts (ADTSs) are also considered although the correction may not change ADTS significantly.

Each octupole has its own power supply, and the correction capability is maximized. All correction targets are fully under control.

Tuning in the real machine

Unfortunately, it is not enough to control the harmonic contents of fourth order resonances by octupoles because the second order effect of sextupoles also excites them. However, in the real machine, we can find “best possible compensation” by a heuristic approach to maximize the performance by tuning both sextupole and octupole families iteratively. Therefore, what is needed is to set up orthogonal knobs as it is done here as much as possible with a reasonable number of power supplies.

Summary

Concerning the sextupole cabling, a mixture of Schemes A and B is proposed, which requires 54 power supplies. In case, where the number of magnets per power supply should be fixed, Scheme A is recommended.

It is planned to power all octupoles individually. Therefore, we have enough flexibility to control fourth order resonances.