SLS LATTICE FINALIZATION AND MAGNET GIRDER DESIGN

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Abstract

We describe the studies on dynamic aperture for the Swiss Light Source (SLS) 2.4 GeV storage ring including mini gap insertion devices, magnet misalignments and magnet multipole errors. We present a novel method for calculating the Touschek relevant effective lattice momentum acceptance and lifetime. Finally we describe the design of girders optimized for static and dynamic fatigue with high precision mounting of magnets on girders and a system of girder movers to be used for alignment of the girders around the ring.

1 DYNAMIC APERTURE

The 2.4 GeV storage ring of the Swiss Light Source SLS assembles 12 TBA cells and 6×4 m, 3×7 m and 3×11 m straights on a circumference of 288 m [1]. The »D0 mode« of the lattice with zero dispersion in the straights provides an emittance of 4.8 nm, and the »D1 mode« with 4, 5 and 8 cm dispersion in the straights provides an effective emittance of 4.1 nm.

Dynamic aperture, in particular horizontal aperture over a wide range of momentum deviation, was one of the most important design issues in order to provide sufficient Touschek lifetime.

1.1 Dynamic Aperture Optimisation

We use 120 sextupoles in 9 families for chromaticity correction while maintaining large dynamic apertures, with the 3 families inside the TBA cells mainly acting on the chromatic terms and the 6 families in the straights mainly acting on the geometric terms [2,3,4]. Numerical minimization of the sextupole Hamiltonian in first and second order of sextupole strength, including second order chromaticity obtained from numeric differentiation was applied successfully to obtain horizontal, vertical and momentum acceptances exceeding the physical acceptances as given by the beam pipe (full width 65 mm, full height 32 mm). This provides a safety margin for inevitable deterioration after introducing alignment and multipole errors and insertion devices.

1.2 Magnet misalignments

A group of elements comprising 3–4 quadrupoles, 2–3 sextupoles and 1–2 BPMs will be precisely mounted onto a girder (see figure 3). A total of 48 girders will be virtually connected around the ring in a so-called »train link« scheme. Thus we have to distinguish between three types of alignment errors: misalignment of magnets relative to the girder, violation of the train link, i.e. play of the virtual joints between adjacent girders, and misalignments of the girders relative to their ideal positions.

Fig. 1 displays the results for momentum dependant dynamic acceptances (i.e. phase space area enclosed by the particle at dynamic aperture) after closed orbit correction for an error setting of 30 μm for magnets relative to girders, 10 μm joint play and 200 μm girder misalignment (rms values, cut at 2σ).

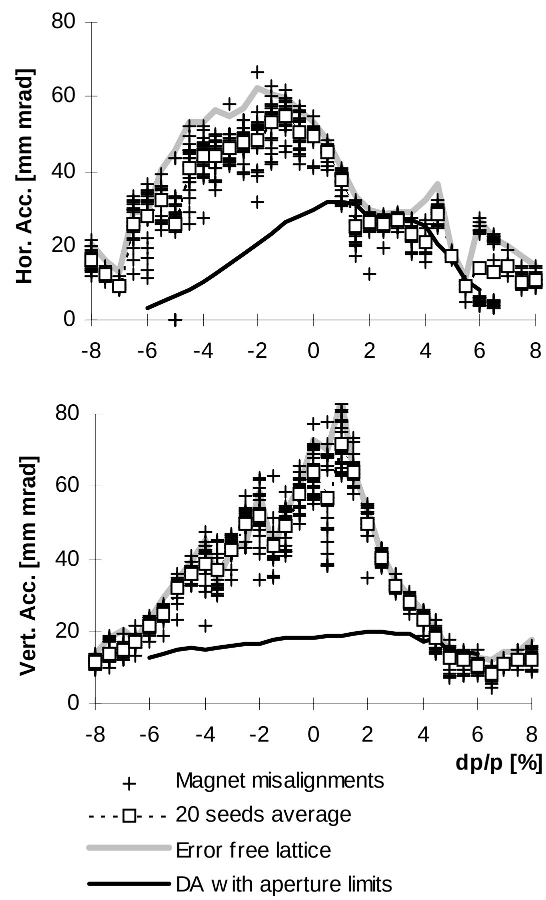

Figure 1: Dynamic acceptances for »D0 mode«

1.3 Magnet multipole errors

Multipole components in quadrupoles and bending magnets as predicted by an engineering study [5] were tested in respect to how they affect dynamic aperture [6]. We found that the multipoles in quadrupoles reduce the dynamic aperture down to the physical aperture limit but not further. This reduction is simply due to the fact that

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multipole expansion is defined only within the pole inscribed radius.

1.4 Insertion devices

The SLS protein crystallography beamline requires the undulator U19 with 102 periods of 19 mm and a peak field of 1.2 T, and the materials science beamline requires the superconducting wiggler W40 with 50 periods of 40 mm and a peak field of 2.1 T. Both devices would be in-vacuo with a full gap height of only 4 mm.

For investigation of the impact on dynamic aperture, the insertion devices were treated as purely linear element, as nonlinear element with infinite pole widths ($k_x = 0$) and eventually with finite pole widths [7]. We found that the insertion devices do not seriously affect the dynamic aperture.

1.5 Emittance coupling

For our layout with 72 correctors and 72 BPMs the SVD and sliding bump orbit correction schemes converge to the same residual orbit. Rms values of about 200 µm are observed in both planes (200 seeds average, misalignments for girders, joints and elements were 300, 100 and 50 µm).The maximum corrector kicks needed are well below (50%) the design maximum of 1 mrad.

The beam ellipse twist which is obtained from the computation of generalized sigma matrices [8] is calculated to be around 40 mrad in the straight sections. The corresponding value for the emittance coupling in »D1 mode« is 0.2% and 1% in »D0 mode«. This relatively large coupling factor for the latter mode can be explained by the fact that the vertical working point had been chosen very close to the integer ($\nu_y = 7.08$) in order to optimize the dynamic aperture. This leads on the other hand to a significant increase of the spurious vertical dispersion. A change of the vertical tune to $\nu_y = 8.28$ reduces the emittance coupling to 0.25%.

The remaining vertical dispersion of 0.3 cm is mainly induced by sextupoles. The contribution from quadrupoles is nicely compensated by the dispersion generated by the adjacent orbit correctors. The contribution from the feeddown of horizontal dispersion via sextupoles remains. It turns out that this dispersion and the remaining beam ellipse twist can be partially corrected utilizing asymmetric orbit bumps in the arcs resulting in a residual emittance coupling of < 0.1% and a beam ellipse twist of < 10 mrad in the straight sections [9].

2 MOMENTUM ACCEPTANCE AND TOUSCHEK LIFETIME

2.1 Nonlinear Calculation of Touschek Lifetime

Both RF and lattice momentum acceptance (MA) contribute to the Touschek lifetime, with the RF MA constant along the lattice, but the lattice MA depending on the optical functions at the location of the Touschek scattering event. Light source lattices like SLS show significant nonlinear effects

- nonlinear variation of Twiss parameters α, β with relative momentum deviation $\delta = \Delta p/p$,
- higher order dispersion, i.e. nonlinear variation of the closed orbit with δ,
- nonlinear betatron motion.

Momentum dependant nonlinearities already had been included in previous methods [10]. We now also include the nonlinear betatron motion implicitly by determination of MA from tracking for every lattice location [11]. Since Touschek scattering occurs in the beam core and leads to a sudden change of momentum we define the local lattice MA by testing whether a pair of particles with initial conditions $x = x' = y = y' = 0$ and $\delta = \pm\delta$ survives a given number of turns or not. Binary search for δ determines the local MA. In case of SLS the novel nonlinear calculation gives approx. 5–10% lower lifetime results compared to common linear calculations.

2.2 Definiton of Lattice Momentum Acceptance

In order to characterize lattice MA by a single number from a Touschek scattering point of view we define the TRELMA (Touschek Relevant Effective Lattice MA) as the value of MA (derived from the RF voltage) where the calculation with only the RF MA (assuming infinite lattice MA) and a calculation with only the lattice MA (assuming infinite RF MA) give the same result for the Touschek lifetime (normalised to bunch length). I.e. if the RF voltage is set to give an RF MA equal to TRELMA both RF and lattice contribute same Touschek losses. Fig. 2 shows the linear and nonlinear TRELMA as a function of beam pipe width for the »D0 mode«: We find a TRELMA of 5.4 % including the ±32.5 mm wide beam pipe and a purely dynamic value of 7.6 % without.

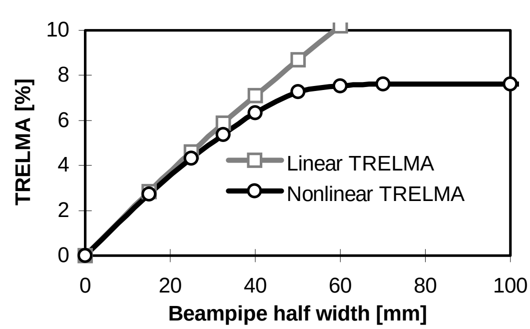

Figure 2: Touschek relevant effective lattice momentum acceptance as a function of beam pipe width

2.3 Lifetime results for SLS

The design standard operation [1] of SLS is at 2.4 GeV, 1 nCb/bunch (400 bunches), 2.6 MV RF (giving 4% RF MA), 4.8 nm emittance (»D0 mode«) and <1% emittance coupling (however a halo coupling of 100%

was assumed for the scattered particles). With these parameters we expect a Touschek lifetime of 23 hrs (bunchlengthening neglected, IDs not installed). For comparison the gas scattering lifetime (1 nT CO) is 56 hrs, i.e. beam lifetime in SLS will be dominated by the Touschek effect.

3 MAGNET GIRDER DESIGN

The girder design is guided by requirements for static and dynamic fatigue and by real ambient boundary conditions at the SLS site. The magnets are mounted on girders, fixed by a precisely machined groove without further adjustment (see fig. 3). The resulting sum tolerances should not be larger than for separate adjustment mechanisms at every magnet. The most important criteria to meet these requirements are

- lifetime: t_{OH} $> 10^5$ h
- max. stress (SF = 2.5): σ_{max} $< 0.4 \cdot \sigma_B$
- max. vertical deflection: $\Delta u_{vertical} < 50$ µm
- eigenfrequencies (EF): 1. EF > 40 Hz
- max. sum tolerance of girder ±15 µm without magnets and ±25 µm including magnets.

The girder design proceeded by defining design criteria for fatigue and function, analysis of basic designs derived from existing machines and sensitivity studies. The optimization process lead to our final new design and to magnet mover specifications.

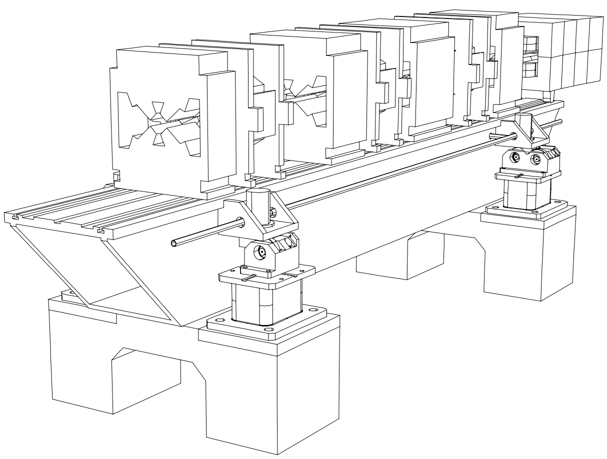

Figure 3: Magnet girder

Detailed Finite Element Method (FEM) analysis of »conventional« designs with 3 point bearings at ground gave results that could not fullfill the design criteria. The axial distance between the bearings points and their vertical position relative to the center of mass of the whole structure (girder and magnets) turned out to be the critical geometric parameters, determining possible torques and resulting eigenfrequencies. In particular a design with two bearings at the ends and one bearing in the middle of the girder leads to a torsional eigenmode with very low EF value. Optimization of both parameters lead to a 4 point bearing with significantly better stress distribution, higher eigenfrequencies and lower amplification factors for vibrational excitations.

The final SLS magnet girder design is characterized by the following properties:

- Uniform girder design including reference surface for direct postitioning of magnets at sum tolerances of ±25 µm including magnets.
- Optimized geometry (bearing distance and position, wall thickness, internal stiffness) for all components of girder assembly. Maximum stress $\sigma_{max,v.Mises} \approx 95$ MPa.
- 4 point bearing system to eliminate torsional eigenmodes. This bearing system will be realized by 5 or 6 magnet movers. First EF is at 44 Hz, no EF coincides with 50 Hz.
- Mover systems are based on excentrical cam shaft drives and allow full motion of girder in all degrees of freedom. The working window is ±3.5 mm vertically and horizontally.
- The position measurement system includes a hydrostatic levelling system (10 µm resolution) for the vertical and a wire frame positioning system (10 µm resolution) for the horizontal.
- A »train links« of all 48 girders around the ring is realized by establishing virtual joints between adjacent girders by means of the position measurement systems and the magnet mover system.

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* For more technical information on SLS please visit http://www1.psi.ch/~betalib/slsnotes.html