Dynamic Properties of the ROSY Optics

D.Einfeld, H.Büttig, W.Gläser, Th.Goetz*), H.Guratzsch, D.Janssen, W.Matz, J.B.Murphy+),W.Neumann, M.Picard*), M.Plesko~), D.Pröhl, R.Rossmanith#), R.Schlenk, D.Tomassini~),H.Tyrroff
Research Center Rossendorf
P.O.Box 51 01 19
D - 01314 Dresden

Abstract

ROSY is a proposed third generation synchrotron radiation light source. The electron storage ring has been designed to operate from the injection energy of 800 MeV up to the nominal energy of 3 GeV. The lattice is of the modified multiple bend achromat (MBA) type with spaces for up to 8 insertion devices. Different sextupole arrangements are investigated to find the largest dynamic aperture. The effects of multipole and positioning errors of the magnets are shown. The variation of the optics during the ramping, the beam lifetime and the emittance change due to IDs are estimated. It is shown that overall the dynamic properties of the modified MBA lattice are very good in the whole energy range, making it an excellent candidate for a low-cost third generation light source.

1. INTRODUCTION

The light source ROSY has been proposed as a dedicated sinchrotron radiation source for material science [1]. It consists of a microtron preinjector, a booster synchrotron [2] and a storage ring. The electron energy of the storage ring will be 3 GeV and the emitted synchrotron radiation is in the hard X-ray region with a critical energy of 8.4 keV, corresponding 0.14 nm. The natural emittance is below 30 nm.rad. For the insertion devices 8 places are foreseen four of which are located in dispersive regions. The storage ring is of fourfold symmetry and has a circumference of 148 m.

The optics of the storage ring is based on a modified multiple bend achromat (MBA) [3]. The main feature of the modified MBA lattice is the use of horizontally defocussing bending magnets with different bending angles to keep the radiation integrals low. A storage ring with such a lattice can have a low emittance at a relatively compact size [4]. The lattice of the modified MBA structure consists of several unit cells accompanied on each side by a matching section followed by a straight section (figure 1 shows one achromat).

Each unit cell consists of one bending magnet and two quadrupoles, one on each side of the bend. The matching section contains additional quadrupoles on the side of the straight section (two in the case of ROSY) to assure that the dispersion is zero in the straight sections and that the beta-functions can be set to the requirements of either undulators (high beta) or wigglers (low beta). The bending magnets within the unit cells have a deflection angle of φ, whereas the ones in the matching section deflect by $\varphi/2$.

The linear optics of ROSY has been described in a previous article which found that the modified MBA lattice of ROSY has very good dynamic properties [3]. Here, further studies of the dynamic properties of the ROSY optics are presented which prove that the lattice is excellent also under realistic conditions like the presence of multipole and positioning errors and that a storage ring based on the modified MBA lattice is feasible.

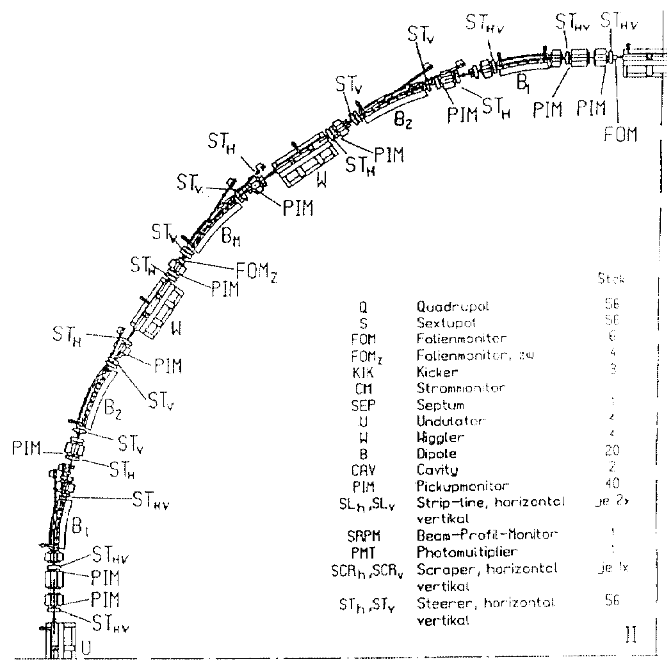

Figure 1. One achromat of ROSY whit all magnets and instrumentation shown.

2. DYNAMIC APERTURE AND ORBIT DISTORTIONS

A. The Arrangement of Chromatic Sextupoles

Chromaticity correcting sextupoles introduce nonlinear terms on the beam and thus limit the dynamic aperture. The rule of thumb here is to position the sextupoles in places where the horizontal and vertical beta functions are decoupled so that the sextupole strengths necessary for the compensation of the chromaticity are kept at a minimum. But the distortion of the dynamic aperture does not depend

*): University of Bonn, Germany.
+): NSLS Brookhaven, Upton NY, USA.
~): Sincrotrone Trieste, Italy.
#): CEBAF, Newport News, VA, USA.

on the strengths only - the values of the beta functions at the positions of the sextupoles and the phase advances between them are important, too. Therefore a total of nine different sextupole arrangements were investigated and the resulting dynamic aperture for particles of the nominal energy and energy deviations of +/- 2% were determined by tracking. Both computer codes used, RACETRACK [5] and BETA [6], gave consistent results.

The sextupole arrangement giving the largest dynamic aperture (+/- 70 mm horizontally and +/- 25 mm vertically within +/- 2% of $\Delta E/E$) is shown in figure 2. This configuration was then used in further tracking studies with different types of insertion devices placed at all eight ID sections. The dynamic aperture was only slightly reduced. In addition, the energy and amplitude dependencies of the tune became even slightly better.

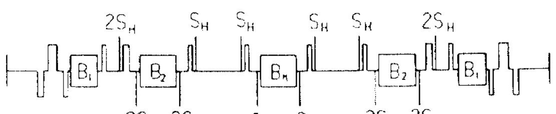

Figure 2. The optimal sextupole arrangement for one achromat of ROSY. SH and SV stand for horizontal and vertical sextupoles, respectively. The symbols 2*SH and 2*SV denote that these sextople has twice the strength.

B. Multipole Errors

The bending magnet of ROSY [7] is similar to the one of ELETTRA [8], therefore the integrated multipole errors which were measured there [9] were scaled to the field and bending angle of ROSY magnets. For the quadrupoles, available measurements from all third generation light sources were used [10-12]. All higher multipoles up to the 20-pole (N=10) were included in the calculations. The resulting dynamic aperture, including sextupoles and IDs is shown in figure 3. It is interesting to note that the multipole errors of the bend reduce the dynamic aperture in the vertical plane, while horizontally it is limited by the multipole errors of the quadrupoles. The multipole errors approximately halve the dynamic aperture in both planes. Still the physical aperture limitation is smaller. In terms of beam sizes, the dynamic aperture is about +/- 65 sigma_x and +/- 160 sigma_y.

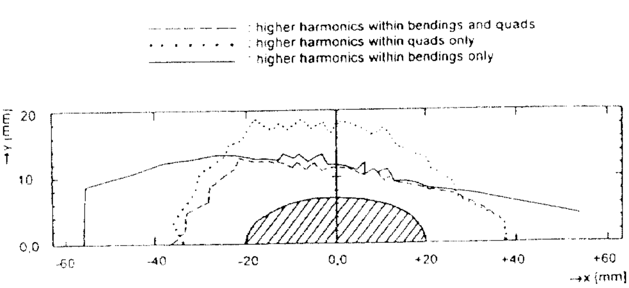

Figure 3. The dynamic aperture of ROSY in the presence of sextupoles, IDs and multipole errors.

C. Positioning Errors

The worst case amplification factor (maximal orbit deviation over magnet displacement) was estimated by displacing each single element by 0.5 mm and tracking the closed orbit. The amplification factor turned out to be 80 in both planes, both for quadrupoles or bending magnets. By placing the matching and unit cells on girders and displacing the whole girder by 0.5 mm, but not the magnets relatively to each other, the worst case amplification factor dropped to 20 (horizontal plane) and 40 (vertical plane), respectively. In these calculations, only the code BETA was used as it provides superior input capabilities over RACETRACK. The best alignment precision currently achieved in third generation storage rings is between 0.1 mm and 0.2 mm. In this paper, r.m.s. alignment errors of 0.2 mm are taken in order to obtain a conservative estimate. Several random configurations of misaligned magnets were generated. The worst reduction in the dynamic aperture was by 30 to 40% in the vertical plane and only by 10% in the horizontal plane. Therefore the first turn and subsequent accumulation during commissioning should not be problematic. For the closed orbit correction, different steerer configurations were investigated. Other third generation storage rings have at least 4 steerers for each full betatron wave. For ROSY this would correspond to 36 horizontal and 20 vertical steerers, respectively. A configuration with 40 horizontal and 32 vertical steerer reduced the maximal closed orbit distortion to 0.3 mm in both planes with maximal steerer strengths of 1 mrad. By placing 48 horizontal and vertical steerers (shown in figure 1), the maximum can be reduced below 0.1 mm with strengths below 0.6 mrad. Such a closed orbit distortion is smaller than the natural beam width.

3. MISCELLANEOUS DYNAMIC PROPERTIES

A. Tolerances during ramping

For reasons of cost, the booster synchrotron does not provide the final energy. Therefore a relatively slow ramping procedure is foreseen. Due to saturation effects in the bending magnet, the superimposed gradient field changes differently than the dipole field which results in an energy dependence of the relative index n [see 7]. Going from 2.6 GeV to 3 GeV, the quadrupole strength is reduced by up to 3% resulting in a significant vertical tune shift. In order to keep the tune constant during ramping, the quadrupole triplets in the straight sections will be used. The new optics due to the new index and quadrupole strengths was checked for 2.8 and 3.0 GeV. The dynamic apertures were slightly reduced, but were still larger than the physical aperture.

B. Beam Lifetime

Most of the processes which reduce the beam lifetime are stronger at lower electron energies. Therefore in the lifetime calculations a conservative lowest injection energy of 750 MeV was assumed. The lifetime limiting processes that were considered are elastic (el) and inelastic (inel) scattering of electron off the atoms, elastic scattering off the nuclei (scat), bremsstrahlung (brem) off the nuclei and Tuschek electron-electron scattering (Tous). The quantum lifetime and the physical aperture lifetime limitations can be neglected for the given paramters of ROSY.The results of the calculations are summarized in table 1. For the calculations, an average pressure of 3.10^{-9} mbar, two-atom molecules with Z=7, and 1% coupling were assumed. The RF acceptance is 1.93%.

Table 1:
The different contributions to the ROSY lifetime for the lower limit injection energy (750 MeV) and the nominal energy (3 GeV).

E [GeV]	τ_{scat}	τ_{brem}	τ_{ese}	τ_{ise}	τ_{Tou}	τ_{tot}
0.75	11	31	570	91	4.5	2.8
3.0	175	31	2280	81	209	18

C. Emittance Change

Due to inserion devices four insertion devices are placed in dispersive regions. Therefore their effect on the emittance was carefully studied. The optimal configuration is when the strongest wigglers are placed in dispersion-free sections, where they slightly reduce the emittance. The undulators and wigglers in the dispersive regions change the H-functions and the damping partition number and increase the emittance. However, both processes almost compensate such that for the ROSY setup with all eight insertion devices, the emittance is practically the same as without IDs.

4. CONCLUSIONS

Both the linear and nonlinear dynamic properties of ROSY were shown to be excellent. The injection, accumulation, ramping and subsequent storage of the electron beam should have no difficulties. The IDs and multipoles do not reduce the dynamic aperture below the physical one. The orbit correction scheme can reduce the maximal closed orbit deviation below the electron beam size.The modified multiple bend achromat (MBA) lattice which was applied for ROSY thus proves to give a lower emittance at a smaller circumference than comparable DBA and TBA lattices without any drawback on the electron dynamics. Given its advantages it appears to be the lattice of choice for low budget third generation light sources.

5. REFERENCES

[1] D.Einfeld and W.Matz, ROSY- Rossendorfer Synchrotronstrahlungsquelle, project proposal, 2-nd edition, FZR 93 - 27, Rossendorf / Dresden, 1993.

[2] D.Einfeld, H.Guratzsch and G.Müller; Design of the 800 MeV Booster Synchrotron for the Light Source ROSY, these proceedings.

[3] D.Einfeld et al., "The Synchrotron Light Source ROSY", Particle Accelerator Conference 93, Washington 1993, pp. 1477-1479.

[4] D.Einfeld, M.Plesko, A Modified QBA Optics for Low Emittance Storage Rings, Nucl. Instr. Meth., A335 (1993) 402-416.

[5] F.Iazzourene, C.J.Bocchetta, R.Nagaoka, L.Tosi, A.Wrulich, "RACETRACK User's Guide", Sincrotrone Trieste, ST/M-91/11, July 1991.

[6] L.Farvacque, A.Ropert, "BETA User's Guide", ESRF-SR/LAT 88-08, 1988.

[7] D.Einfeld, A.Krüssel, H.Tyrroff, Design of the Magnets for the Synchrotron Light Source ROSY, these proceedings.

[8] ELETTRA Conceptual Design Report, Sincrotrone Trieste, April 1989.

[9] D. Tommassini, private communications.

[10] J.Tanabe, private communication.

[11] A.Ropert, Results of Magnetic Measurements of Storage Ring Quadrupole Prototypes, ESRF-SR / LAT -90-25.

[12] D.Zangrode, R.Walker, Magnetic Measurements and Alignment of the ELETTRA - Storage - Ring Quadrupole, Sextupole and Steerer, Proc. PAC - 93, Wash.,D.C.,1993.