LATTICE STUDIES FOR THE TRIESTE SYNCHROTRON RADIATION MACHINE

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Abstract

A study on a low emittance lattice for a synchrotron radiation storage ring in the energy range 1.5 to 2.0 GeV has been carried out in Frascati. The emittance is 4.5×10^{-9} m.rad at 1.5 GeV. The lattice has 16 dispersion free straight sections for insertion devices. Two different structures are presented. Both lattices are based on the "Chasman-Green" achromat, the former with no focusing in the bending magnets and 5 quadrupoles in the achromat, the latter with vertical focusing in the magnets and a single quadrupole in the dispersion section.

Introduction

A lattice study for a 1.5÷2.0 GeV synchrotron radiation source to be built in Trieste is presented. To satisfy the requirements of many, independently tunable, high brilliance sources, a low emittance machine with long dispersion free straight sections for insertion devices (undulators and wigglers) has been designed.

The typical lattice used to satisfy this condition is a periodic structure of cells, each consisting of an achromat and an insertion straight. Different types of achromat have been studied, in particular the FODO, the Chasman-Green (CG) and the Expanded Chasman--Green (ECG).

The FODO has been abandoned because it exhibits a high density of magnetic elements leading to layout and engeneering problems.

The CG and ECG have been studied with two different periodicities (12 and 16) and the same emittance. The examples with 16 periods, which are presented in the following, have smoother optical functions and smaller chromaticities, leading to a more flexible and reliable machine.

The ECG has been studied in more detail and used for the design study.

Linear optics

The main specifications for the magnetic structure of the ring are the following:

- Nominal energy — 1.5 Gev
- Maximum energy — 2.0 GeV
- Number of straight sections for insertion devices — 14
- Free straight section length — 6 m
- Natural emittance at max. energy — $<10^{-8}$ m.rad
- Vanishing dispersion in the insertion straights
- Tunability of the β functions in the insertion straights.

Both lattices are based on the Chasman-Green type achromat, which consists of only one focusing quadrupole between the two bending magnets.

For the first lattice the achromat consists of 5 quadrupoles, arranged in a FODO-like sequence, in between the two bending magnets. It is therefore called "Expanded Chasman-Green".

Two triplets are used in each insertion to tune the betatron functions over a wide range of values in the 6 meter long dispersion free section. The bending magnets have no gradient.

An emittance about three times the theoretical minimum[1] has been chosen to obtain a smooth behaviour of the betatron functions.

The lattice parameters are given in Table 1 and the optical functions in Fig. 1.

The second lattice is a Chasman-Green. In this case the central quadrupole is splitted in two halves to accomodate the horizontal chromaticity correcting sextupole in a maximum β_x point.

The focusing quadrupole strength is fixed by the condition of obtaining zero dispersion at the ends of the bending magnets. A quadrupole doublet in the insertion is used to tune the Q values. A third quadrupole may be added in the insertion to obtain the required tunability of the β functions.

Table 1 - Parameters of the linear lattices

	ECG	CG
- Energy (GeV)	2.0	2.0
- No. of periods	16	16
- Circumference (m)	300.	233.
- Emittance (m.rad)	8.4×10^{-9}	8.0×10^{-9}
- Relative energy spread	7.6×10^{-4}	7.5×10^{-4}
- Momentum compaction	6.8×10^{-4}	1.1×10^{-3}
- Horizontal betatron tune	19.84	13.80
- Vertical betatron tune	11.63	11.80
- Horizontal chromaticity	-32.4	-26.1
- Vertical chromaticity	-22.9	-36.2
- Horiz. damping time (ms)	14.2	10.5
- Vertical " " "	14.1	13.2
- Synchrotron damping time (ms)	7.0	7.6
- No. of bending magnets	32	32
- Bending radius (m)	5.0	6.0
- Field index	0	20
- Bending field (T)	1.333	1.111
- No. of quadrupoles	176	96
- No. of quadrupole families	6	3
- Maximum gradient (T/m)	17.0	16.0

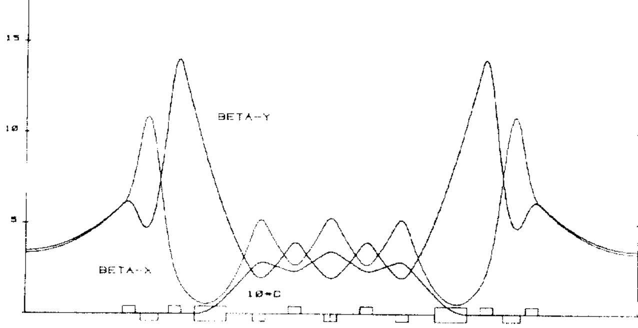

Fig. 1 - β functions and dispersion in one period of the ECG structure.

To get a smoother behaviour of the optical functions and to decrease the horizontal emittance, vertical focusing in the bending magnets has been added. With a field index n=20 we obtain a betatron damping partition number J_x=1.27 and an emittance ε =8.0 10^{-9} m.rad.

A list of parameters of the lattice is given in Table 1. Fig. 2 shows the behaviour of the optical functions in one period.

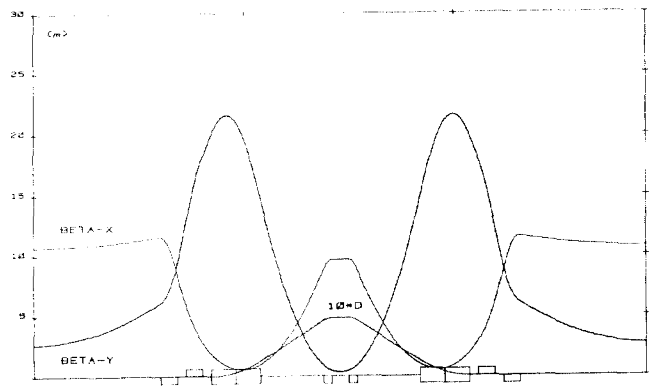

Fig. 2 - β functions and dispersion in one period of the CG structure.

Chromaticity correction and aperture

The chromaticities of low emittance lattices for synchrotron light sources are normally rather large and need strong sextupoles to be corrected. The optimization of the sextupole intensity and distribution and the study of the nonlinear properties of the lattices has been carried out with the tracking programs PATRICIA and DIMAD[2,3].

The ECG lattice requires only two independent sextupole families to correct chromaticity, but with a high number of sextupoles (192) and high strength, because the β functions at the sextupole locations are not very well separated. The maximum sextupole gradient needed for zero chromaticity at 2 GeV, with 0.2 m long sextupoles is 615 T/m^2.

The CG lattice requires two sextupole families in the achromat to correct chromaticities and two more families in the insertion straight to correct the dependence of tune on betatron oscillation amplitude. As the β functions at the sextupoles are well separated the sextupole strengths are smaller than in the ECG case: the maximum gradient is 245 T/m^2 at 2 GeV for 0.2 m long sextupoles and the number of sextupoles is 112.

After correction both lattices exhibit weak dependence of tunes, dispersion and β functions on momentum; moreover the tune shift on amplitude is quite small for beam sizes up to 100 σ_x and energies in the range -3%< Δp/p<+3%.

The aperture has been computed at three different fixed energies: 0, +3%, -3% tracking particles for 400 turns. The results are presented in Figs. 3 and 4 respectively for the two lattices.

The ECG lattice presents a much larger stable area for on-energy particles. For $\pm$3% momentum deviation both the lattices show a reduced aperture, but still sufficient to achieve the required Touschek lifetime, as computed by the computer program ZAP[4]. A direct comparison of the dynamic apertures is difficult, because the β values at the undulator insertion, where the dynamic aperture is calculated, are different for the two lattices.

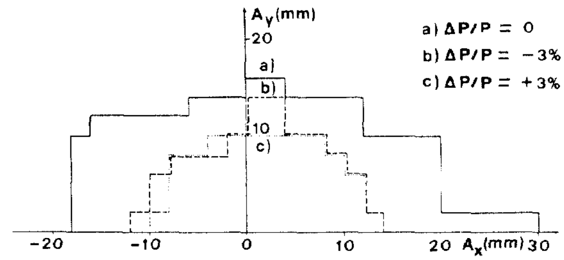

Fig. 3 - ECG Dynamic aperture.

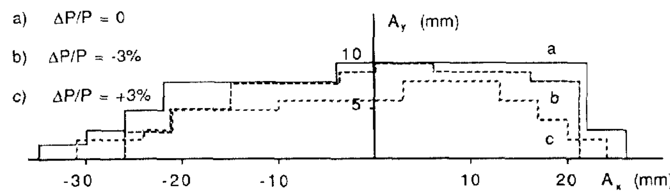

Fig. 4 - CG Dynamic aperture.

For the ECG lattice also the effects of field errors, both systematic and random, on the aperture have been computed. The error magnetic field is expanded in terms of multipole components as:

$$B(x) = \Sigma_n K_n (x^n/n!) \cdot B_o \rho$$

where n = 0 corresponds to the dipole term, n = 1 to the quadrupole term, and so on. Table 2 lists the multipole values used in the simulation (the "0." means the component is not dangerous, and has therefore been neglected) and Fig. 5 shows the reduction of the dynamic aperture, which is well tolerable.

Table 2 - Systematic and random field errors

		Dipoles		Quadrupoles	
	n	B_n/B_o	$K_nL(m^{-n})$	G_n/G_1	$K_nL(m^{-n})$
system	1	6.4×10^{-6}	1.3×10^{-4}	0.	0.
	2	1.7×10^{-5}	6.8×10^{-2}	0.	0.
	5	0.	0.	1.3×10^{-4}	6×10^{5}
random	1	10^{-5}	2.0×10^{-4}	10^{-5}	4.0×10^{-6}
	2	10-4	4.0x10-1	10-5	8.0x10-4
	3	10^{-5}	12.0	10^{-5}	0.24
	4	10-5	4.8×10^{3}	10-5	96.0
	5	0.	0.	10^{-5}	4.8×10^{4}
	9	0.	0.	10^{-7}	1.5×10^{14}

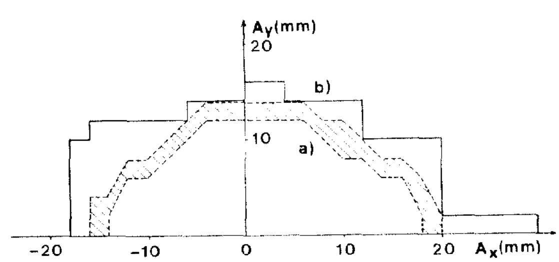

Fig. 5 - ECG Dynamic aperture with (a) and without (b) field errors.

Table 3 - Parameters of the ring before and after orbit correction

	ECG			CG		
	Unperturbed Machine	Perturbed Machine	Corrected Machine	Unperturbed Machine	Perturbed Machine	Corrected Machine
Q_x	19.828	19.783±0.033	19.827±0.007	13.820	13.817±0.025	13.819±0.002
Q_y	11.673	11.624±0.024	11.674±0.005	11.720	11.738±0.039	11.722±0.006
$<x^2>^{\frac{1}{2}}$ (mm)	0.0	4.0±1.7	0.04±0.03	0.0	3.1±1.3	0.03±0.005
x_M (mm)	0.0	8.4±3.2	0.12±0.03	0.0	6.9±2.2	0.13±0.02
$<y^2>^{\frac{1}{2}}$ (mm)	0.0	2.0±0.5	0.08±0.05	0.0	3.3±0.9	0.03±0.003
y_M (mm)	0.0	6.3±1.4	0.31±0.04	0.0	10.7±2.9	0.10±0.03
$<D_x{}^2>^{\frac{1}{2}}$ (mm)	149	152±2	150±1	180	180±3	180±0.2
D_{xM} (mm)	342	384±15	364±6	480	508±15	490±4
$<D_y{}^2>^{\frac{1}{2}}$ (mm)	0.0	15±4	9±4	0.0	37±23	3±1
D_{yM} (mm)	0.0	58±12	30±10	0.0	96±56	19±3
ε_x 10^9 m.rad	4.41	4.25±0.22	4.49±0.16		4.28±0.37	4.67±0.05
ε_y 10^9 m.rad	0.0	0.21±0.02	0.04±0.03	0.0	0.83±0.98	0.005±0.005
$(\varepsilon_y / \varepsilon_x)$ 10^2	0.0	5.1±3.5	0.8±0.5	0.0	22±30	0.1±0.1
ϑ_{xM} (mrad)			0.22±0.05			0.19±0.04
ϑ_{yM} (mrad)			0.22±0.03			0.16±0.04

As it is very time consuming, this calculation has not been carried out for the CG lattice, which has lower gradients, but field index in the bending magnets.

Sensitivity to alignment and field errors

Orbit correction

A PETROS simulation of ten machines has been carried out under the assumption of Gaussian distribution of errors with the following rms values:

- displacement 0.1 mm
- tilt 0.01°
- relative field error 5×10^{-4}.

All machines were stable for the ECG lattice, while 8 over 10 were stable before correction for the CG lattice.

Some characteristic parameters averaged over the stable machines before and after correction are listed in Table 3 for the two lattices.

The computed amplitude of the average closed orbit is in good agreement with that estimated using the standard formula for random distribution of quadrupole displacements:

ECG	$<x_{co}>/\Delta x = 41$	$<y_{co}>/\Delta y = 28$
CG	$<x_{co}>/\Delta x = 28$	$<y_{co}>/\Delta y = 32$

A total of 80 horizontal correctors, 48 vertical correctors and 128 monitors is foreseen for orbit correction for the ECG lattice. For the CG lattice 64 monitors and correctors for each plane were considered. The best corrector method has been used. Monitor displacement errors of the order of quadrupole displacements increase the required corrector strengths by ~ 10%.

The overall correction method gives good results for both lattices, reducing the rms closed orbit to less than .1 mm in both planes with reasonable corrector strengths.

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