Dynamic Aperture of the MAX II Storage Ring

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Abstract

The MAX II storage ring is a new 1.5 GeV facility for synchrotron radiation. First injection will take place in the early fall of 1994.

This work presents the calculations of the dynamic aperture for the storage ring. The analysis includes sextupoles (superimposed on quadrupoles and dipoles), multipoles, misalignments of common girders for each section of the machine, misalignments of individual magnets relative girder and energy errors. It also shows the effects of insertion devices (undulators, multipole wiggler and super conducting wiggler).

The results give a picture of a machine that will operate at first time injection without taking the corrector magnets into use. To maintain the dynamic aperture while operating the insertion devices the orbit has to be corrected.

1. INTRODUCTION

At the MAX laboratory, at Lund University Sweden, a second electron storage ring is built which provide synchrotron radiation in the category of third generation light sources. The ring, MAX II [1], will be using an existing the existing system for injection. This consists of a Racetrack microtron, used as a pre accelerator, and the MAX I storage ring [2] will operate as the booster from 100 MeV to injection energy (500 MeV). MAX II will then operate at 1.5 GeV. First injection is planned for early fall of 1994, and routine operation for the summer of 1995.

A technique using long girders holding one cell each of the magnet structure is used for MAX II. The aim is to move the tolerances in a favourable direction. The tolerances for individual magnets within a cell are still severe while the overall girder alignment is more relaxed. The chromaticity correction by sextupoles is included into the quadrupole magnets by the pole faces shape and adjusted through backleg windings on the magnets. Thus cost and space used is minimised and unfortunately also slightly the flexibility. A tuning range of +/- 20% of the natural chromaticity is still excepted though.

2. BEAM PARAMETERS

The machine consists of a ten period Double Bend Achromat Lattice with slight changes (table 1). The sextupoles which are included into the quadrupoles, reduce the number of magnets around the ring, and thus the peak strength of the sextupole components as they are present over fairly large areas. The sextupoles are also positioned where the beta functions are large, which further help to reduce the strengths. The dipole magnets will contribute with an additional sextupole component.

The chromaticity is corrected to +2, in absolute values, both in horizontal and vertical direction.

Table 1. Beam parameters

Energy	1.5 GeV
Current	200 mA
Momentum compaction	$4.05*10^{-3}$
Damping time horizontal	6.6 ms
Damping time vertical	6.7 ms
Damping time longitudinal	3.4 ms
Energy spread	$7.05*10^{-4}$
Emittance, horizontal	8.6 nm Rad
Natural chromaticity, horizontal	-27.40
Natural chromaticity, vertical	-10.55
Tune, horizontal	9.22
Tune, vertical	3.18
Dispersion in straight, horizontal	0.13 m
Circumference	89.969 m
Periodicity	10

3. THE DYNAMIC APERTURE

3.2 Simulations

To calculate the dynamic aperture programs modelling the storage ring are used. These follow particles with given initial conditions around a large number of turns (hundreds). These simulations were performed over 400 turns. This is only 2% of the damping time, but increasing this value to 10 % of the damping time did not give any substantial change in the trackings. In the analysis one looks for which initial conditions that give particles remaining in the machine, which in turn gives the dynamic aperture.

The middle point of one straight section was chosen as the starting point for all calculations. Here several points were taken in x-y space. These simulations have been performed with the program RACETRACK [3] and the beam parameters cross checked by the code DIMAX [4].

3.3 Chromaticity

The chromaticity correction is +29 and +12 in the horizontal and vertical plane respectively. The resulting chromaticity is +2 / +2. This correction produces a sharp drop in dynamic aperture, and is put as the maximum aperture in the following calculations (fig 1).

3.4 Misalignments

The tolerances for MAX II are given in two steps, which also gives the "opportunity" for two kinds of misalignments: girder misalignments and individual magnets relative girder misalignments (table 2). The girder misalignments move all magnets on that girder to the same error and the individual magnets will be aligned relative the girder, giving an additional individual error.

Table 2.
Alignment tolerances for magnetic elements

	σ_{hor}(mm)	σ_{ver}(mm)
Girders	0.3	0.1
Quadrupoles	0.03	0.03
Dipoles	1.0	0.15

The misalignments were first treated separately. The individual misalignments were checked, leaving the girders at perfect positions. Several random generations of the magnet positions were made which all had only a small effect on the dynamic aperture.

Following this the girder errors was checked, leaving the individual magnets at perfect positions. It was assumed that the errors were present at two points, one at each end of the girder. This also generated a rotation of the girder. The errors were assumed to be non correlated, which resulted in certain cases with fairly large angular errors. Several different sets of random misalignments were generated out of which at least one had misalignments close to 1 mm, which is not a realistic case as almost any alignment procedure would be able to produce a better situation. A decrease in the dynamic aperture by a couple of mm was seen as a cause of girder errors.

3.5 Multipoles

Measurements of the multipoles present in the magnets gave the possibility to use actual values for the simulations (table 3). The influence of the multipole components is of the same magnitude as the girder misalignments.

3.6 Total case

A total case is here defined as the machine including sextupoles, multipoles, girder misalignments and individual magnet misalignments, i.e. all errors mentioned above. The result of such a situation for the dynamic aperture is shown in fig 5. Three sets of random generated girder misalignments from above were combined with the sextupoles, misalignments of individual magnets and multipoles. By neglecting the worst case for reasons mentioned above, the dynamic aperture is found to be 22 mm horizontally and 10 mm vertically.

Table 3.
Multipole content of magnets (at radius 21.8 mm) according to measurements made by Scanditronix before delivery. The signs of the multipoles are unknown.

Order	Defocusing quadrupole	Focusing quadrupoles
1	0.08	0.04
2	89.67	94.26
3	9.20	4.85
4	0.11	0.07
5	0.02	0.02
6	0.25	0.22
7	0.05	0.09
8	0.17	0.08
9	0.01	0.12
10	0.14	0.05

3.7 Energy deviations

The energy acceptance of the machine is of importance, especially at injection. The "total case machine" above was used, together with energy errors for the electrons. As expected the aperture decreases, but the machine accepts errors up to +/- 3%. The limiting factor is in fact not a collapse of the dynamic aperture, but finding a stable orbit around the machine.

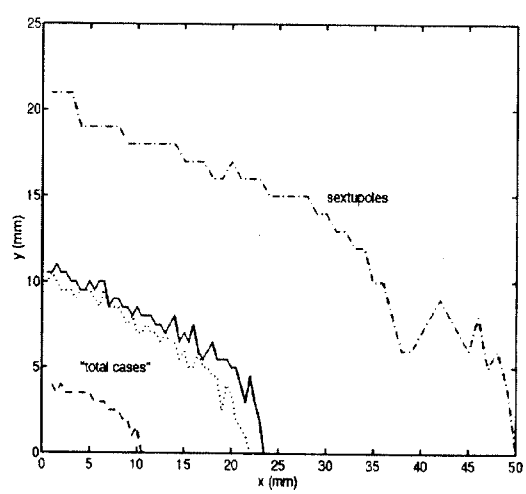

Figure 1. Dynamic aperture.

4. THE CLOSED ORBIT

The closed orbit was calculated, and the 2nd best "total case machine" shows a deviation of +/- 3.5 mm horizontally and +/- 1.5 mm vertically (fig 2). The typical beat of the horizontal closed orbit tells that the main contribution comes from a small number (may be one) of dominating errors.

This is turns implies that a rough correction of the vertical closed orbit should be fairly simple.

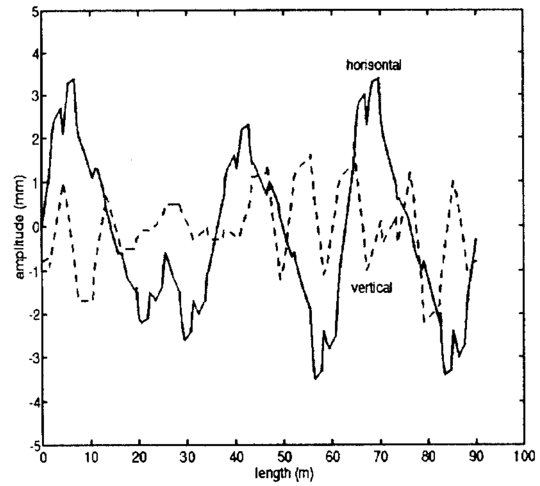

Figure 2. Closed orbit deviation.

5. INSERTION DEVICES

MAX-II is built to house a large number of insertion devices, out of which at least one will be a super conducting wiggler (SCW) with a very large magnetic field (7.5 T) (table 4).

Table 4. Insertion devices for MAX II

	Period (mm)	No. poles	Mag gap (mm)	B(T)	K
SCW	244	½+1+½	36	7.6	173
MPW	174	27	22	1.8	29.3
U (typical)	66	77	22 - 300	0.74	4.5

Out of these the SCW and one MPW is under construction, two undulators are ordered and a second MPW is planned. The trackings include all these 5 insertions devices.

The vertical tune-shift is severe and has to be corrected for. The emittance growth due to the SCW though is not very large, which was feared due to the non zero dispersion in the straight sections, and the MPWs help reducing the emittance again.

The resulting dynamic aperture shows a further reduction, but the machine is still operable.

The sensitivity for errors in the machine is proportional to the beta function amplitude, and this is changed due to the insertion devices. The SCW introduces a beat in the vertical beta function, and the MPWs can enhance or reduce this beat. Due to the relative position of the SCW to the main errors of the machine and the positions of the MPWs relative the SCW the sensitivity for errors can be reduced, giving a larger dynamic aperture. As the position of the errors is not known this is purely academical and can only be seen in these kinds of simulations.

6. LIFETIME

The specified design value for the vertical acceptance is 22.5 mm mRad [5]. This is due to a vertical acceptance in the dipoles of +/- 15 mm. Transforming this value into the straight sections give a design acceptance of +/- 7.0 mm. This is well within limits for the uncorrected machine without insertion devices (fig 1). With insertion devices the aperture for the uncorrected machine becomes slightly smaller than the design value.

An allowable lower limit for the straight sections is reached by matching the Elastic gas scattering to the Touchek lifetime [5]. This gives a lower aperture of +/- 4.5 mm in the straight sections, well below the dynamic aperture including insertion devices.

7. SUMMARY

The situation for the MAX II storage ring seems to fulfil the demands that are put on the ring. It will be possible to start up the machine without taking use of the corrector magnets. The closed orbit will be displaced by several millimetres, but stable. The chromaticity is corrected to slightly positive values and the necessary sextupoles act hard on the dynamic aperture, but the situation is well acceptable.

The main source of aperture reduction, apart from the sextupoles, are the girder alignment errors and multipoles. The tolerances for the machine could have been changed to stronger tolerances on the girders (s_x = 0.1 mm, which is technically feasible), and more relaxed on the individual magnets.

The design criteria of a vertical acceptance of 22.5 mm mRad is fulfilled for an uncorrected machine without insertion devices, and a corrected machine including insertion devices.

A dynamic tune control is necessary as the ID's move the tunes over large areas.

References

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