DAΦNE Lattice Update

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Abstract

The final version of the lattice for the DAΦNE main rings is presented. This solution satisfies all the design requirements and has a larger dynamic aperture respect to the previous one. A systematic analysis of the effect of magnetic errors on the dynamic aperture has been performed on it. The criteria for the choice of the vacuum pipe aperture are discussed and the beam lifetime is calculated.

1. INTRODUCTION

An improved version of the DAΦNE high emittance lattice[1] is presented. The basic criteria of the design are the same as in [2], but the structure of the arcs has been slightly modified in order to achieve a better β separation at the location of the chromaticity correcting sextupoles, and a higher momentum compaction. Moreover, a new working point has been chosen in order to improve the dynamic aperture and a more realistic model for the wiggler magnet has been adopted. Let us remind that each ring is divided in a long and a short part, for simplicity called hereafter *Long* and *Short*, each simmetrically reflected.

2. BEAM OPTICS

The optical functions of half of the ring (*Short* and *Long*) are shown in Fig 1. In Table I the single ring lattice parameters are shown.

The working point is below the integer in both planes: this results in a larger dynamic aperture.

The **low-β insertion** is essentially the same as in the previous design (quadrupole lengths and strengths have been slightly modified).

Table I
Single ring lattice parameters

Circumference (m)	97.69
Horizontal betatron tune Q_x	4.87
Vertical betatron tune Q_y	4.85
Horizontal natural chromaticity Q'_x	- 6.9
Vertical natural chromaticity Q'_y	- 16.9
Emittance ε (m-rad)	1.0×10^{-6}
Energy loss/turn with wigglers (keV)	9.3
Momentum compaction α_c	0.017
Betatron damping time τ_x (msec)	36.02
Relative energy spread (rms)	3.97×10^{-4}

In the **achromat**, the D quadrupole near to the second bending magnet has been eliminated and the vertical focusing is provided by the parallel faces of the dipole. This gives a very good separation of the β-functions at the sextupole locations. Moreover the lattice has been modified in order to have a similar structure between *Short* and *Long* and to place the F and D sextupoles in the same locations.

The main modification for the ***Long* straight section** is the decision to allow a non-vanishing negative dispersion in the injection region, in order to obtain a higher value of the momentum compaction. In fact the value of the momentum compaction has an influence on the instability thresholds and on the RF parameters.

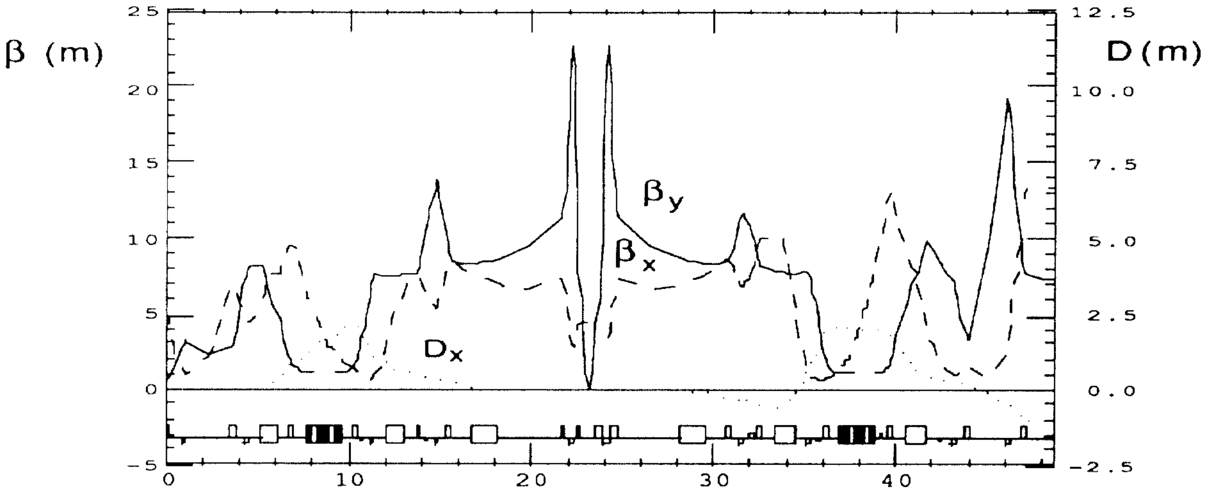

Fig. 1 - Optical functions for half ring

Due to the low value of the energy spread of the beam coming from the accumulator (~10^{-3}) the injection efficiency should not be affected by a dispersion of about one meter at the injection point.

The horizontal betatron phase in the *Long* is related to the value of the dispersion in the injection section, therefore, to easily tune the betatron wavenumber of the ring in both planes, a quadrupole has been added in the *Short* (which still has zero dispersion in the RF straight section).

3. THE DYNAMIC APERTURE

The good separation of the optical functions in the arcs allows a more efficient chromaticity correction, with lower sextupole strengths and therefore less sensitivity to the resonances and a larger dynamic aperture.

The total tunes, 4.87 for the horizontal and 4.85 for the vertical one, are quite far from the integer. The resulting tune and beta functions dependence from the energy is very good.

The dynamic aperture is quite good: as large as the vacuum chamber in the horizontal plane and much larger in the vertical one (± 14 σ_x out coupling in the horizontal plane and ±26 σ_y full coupling in the vertical).

Fig. 2 shows the the on-energy dynamic aperture at the IP, compared to the off-energy ones. There is a small reduction for positive energy deviations and an increase for the negative ones. For comparison the physical aperture is shown on the same scale.

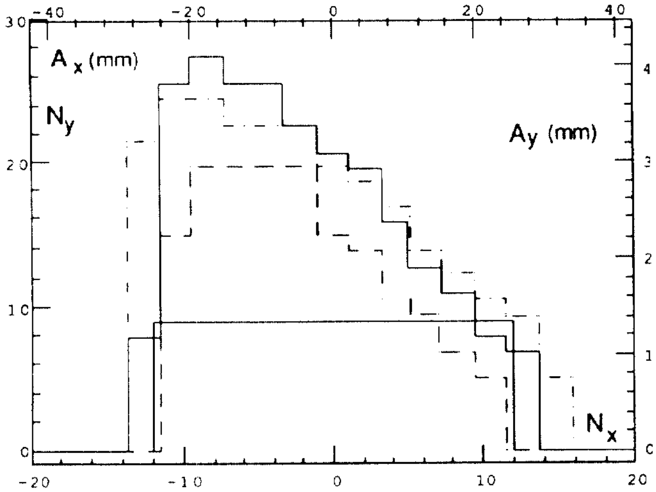

Fig. 2 - Dynamic aperture for Δp/p=0 (solid line), .5% (dashed), -.5% (dot-dashed) compared with the vacuum chamber aperture (solid)

3.1 *Multipole errors sensitivity*

The effect of sistematic multipole errors in the magnetic elements on the dynamic aperture has been simulated with the code Patricia. We have considered separately the effect of each type of multipole term. The strength for the multipolar coefficients has been calculated assuming for each one a value of $\Delta B/B = 5\ 10^{-4}$ at 3 cm from the center. We have considered: dodecapoles in the quadrupoles, sextupoles and decapoles in the dipoles and sextupoles in the wigglers.

The results of these simulations have been used to give upper limits for the design of the magnetic components.

Finally we have made a simulation inserting all together the multipolar terms calculated from the magnet design[4] for both bendings and quadrupoles. The resulting dynamic aperture for three different values of the relative energy deviation (Δp/p = +.5%,0 and -.5%) is shown in Fig. 3.

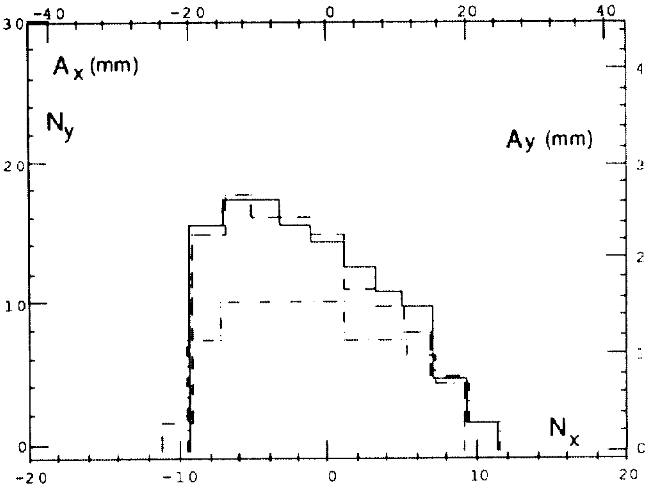

Fig. 3 - Dynamic aperture with multipole errors Δp/p=0, .5%, -.5%

4. ALIGNMENT TOLERANCES AND ORBIT CORRECTION

At the start-up, our idea [5] is to run the machine without sextupoles, operating at low current. At this stage the possibility of a quadrupole mechanical displacement, to correct the orbit distortion, is foreseen to perform a first alignment correction. Later on all the sextupoles are switched on and an appropriate corrector scheme can be used to minimize the residual closed orbit distortion.

The computer code MAD[6] has been used to study the machine sensitivity to errors and to look for an optimal corrector configuration in three different cases: without and with sextupoles and finally adding monitor errors.

The study on the lattice sensitivity, assuming error values from experience in operating machines, has shown that the particle orbit remains inside the physical aperture of the machine, ± 4 cm in horizontal and ± 3 cm in vertical.

No errors have been included in the wigglers and in the low-β quads, that are to be treated as a separate problem. In particular due to the lack of space for correctors and monitors in the low-β, the possibility of correcting the orbit by just moving the magnetic elements has been considered .

The following errors have been assumed in all bends and quads:

$$\Delta x = \Delta y = 0.2 \text{ mm};$$

$$\Delta\theta = \Delta\Phi = 0.25 \text{ mrad}; \quad \Delta B/B = 5 \times 10^{-4}$$

The proposed layout includes 30 beam position monitors and 18 correctors. In Table II the averaged data before and after correction are reported, compared with the ideal ones, for the case with sextupoles on and monitor misalignment errors $\Delta x = \Delta y = 0.2$ mm.

Table II

Closed orbit parameters before and after correction

	no errors	before corr.	after corr.
X_{rms} (mm)	0	7.7±5.7	0.44±0.16
X_{max} (mm)	0	16.8±10.9	1.35±0.48
Y_{rms} (mm)	0	3.2±1.3	0.36±0.09
Y_{max} (mm)	0	8.48±3.38	1.01±0.25
α_{Xrms} (mrad)	0		0.46±0.09
α_{Xmax} (mrad)	0		0.96±0.23
α_{Yrms} (mrad)	0		0.31±0.09
α_{Ymax} (mrad)	0		0.72±0.29
β_x (m) @ IP	4.5	4.49±0.58	4.52.±.006
β_y (m) @ IP	0.045	0.0456±0.012	0.0451±.0008
η_x (m) @ IP	0	-.18±0.30	-.014±0.046
η_y (m) @ IP	0	-0.009±0.038	-.0006±0.003

The results are satisfactory showing a maximum residual orbit less than 1.5 mm in the horizontal plane and around 1 mm in the vertical one with a corrector strength always lower than 1 mrad.

5. BEAM LIFETIME AND VACUUM CHAMBER APERTURE

Due to the low energy of the machine, the main effect limiting the beam lifetime is the single Touschek scattering, which gives a lifetime proportional to the third power of the energy. The Touschek lifetime has been calculated using the formulae given by H. Bruck[7], assuming that the machine acceptance is limited by the RF bucket height and by the transverse aperture (physical or dynamic aperture).

The parameters used for beam lifetimes calculations, listed in Table III, correspond to the design values for the maximum luminosity. The bunch length has been calculated in the anomalous lengthening regime, assuming a vacuum chamber broad band impedance of 2 Ω.

The Touschek lifetime is very sensitive to the horizontal aperture R_x (increases nearly linearly with the aperture up to 10 cm). The choice of the aperture is crucial for this machine because we want a high emittance (for high peak luminosity) and a good beam lifetime (for high average luminosity). Therefore we want the largest vacuum chamber aperture compatible with the technical constraints; moreover also the dynamic aperture has to be as large as the physical aperture. We have chosen a value of $R_x = 4$ cm, which gives a Touschek beam lifetime of nearly three hours.

The vertical vacuum chamber aperture has been chosen in order to get a good value of the gas scattering beam lifetime. With a value of 3 cm the scattering lifetime, calculated assuming a gas pressure of 1nTorr with a nitrogen equivalent gas composition ($Z = 8$), is ~17 hours, much larger than the Touschek lifetime, and therefore has a small influence on the total lifetime.

In Table III the contributions of the various phenomena to the beam lifetime for the single beam mode are listed, together with the beam-beam bremsstrahlung lifetime.

We want to point out that, due to the choice of many bunches and high crossing frequency, the beam-beam bremsstrahlung gives a negligible contribution to the beam lifetime also at the maximum luminosity.

Table III

Beam lifetime

N particles/bunch	$8.9\ 10^{10}$
RF energy acceptance	1.23%
Bunch length (cm)	3
Relative energy spread	$1.46\ 10^{-3}$
Coupling factor	.01
Single beam lifetime (min):	
Quantum lifetime	$8.18\ 10^{9}$
Gas bremsstrahlung	1832
Gas scattering	967
Touschek	207
Total	156
Two beams lifetime @ L=6.0 10^{32} cm^{-2} s^{-1}:	
Beam-beam bremsstrahlung	1426
Total	141

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