DAΦNE MAIN RING OPTICS

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Abstract

DAΦNE [1] is the e⁺ e⁻ Φ-Factory presently under commissioning at INFN Frascati. The two beams have been successfully injected and stored and the optics has been tuned to operate in collision mode. The optics solutions adopted to solve the problems set by the requirements of a high intensity, high luminosity Φ-Factory are described. Preliminary measurements of the optical parameters are presented and compared with a machine model.

1 INTRODUCTION

In order to reach the high design luminosity at the low c.m. energy of the Φ (1.02 GeV) the scheme of a double ring collider with a maximum number of 120 bunches per ring has been chosen. The beams collide in two 10 m long Interaction Regions (IRs) at a crossing angle in the horizontal plane.

Particular care has been taken in the design to make the damping times as short as possible in order to counteract any harmful instability in such low energy range. Low bending radius in the dipoles and 4 high field wigglers in each ring produce large energy loss (9 KeV per turn).

A peculiar feature of the lattice is the Interaction Region (IR) where the two beams travel together in a common vacuum chamber. Due to the crossing angle in the horizontal plane, the beams pass through the low-β quadrupoles off axis. A correction scheme with the splitter magnets [1] and corrector dipoles allows to change the crossing angle so that the effect of parasitic crossings can be finely tuned.

Two large detectors, each one equipped with a longitudinal field solenoid, will be installed at the Interaction Points (IPs). Due to the large free solid angle required by the experiments, the low-β triplets are realized with permanent magnet quadrupoles. At this stage of DAΦNE commissioning the two low-β interaction regions are operated without solenoidal fields and with conventional electromagnetic quadrupoles.

2 MAIN RINGS LATTICE

2.1 General layout

The Main Rings layout is shown in Fig. 1. Each ring is divided in two sectors, an outer one, called Long, and an inner one (Short) each one symmetric with respect to its own center.

The lattice consists of 4 achromats (called arcs in the following), each housing: three quadrupoles, a 2 m, 1.8 T

normal conducting wiggler and 2 chromaticity correcting sextupoles between two bending magnets. The quasi-achromatic structure of the cell allows for vanishing dispersion at the Interaction Points (IPs) and in the R.F. cavity. One of the dipoles has parallel end caps providing vertical focusing in order to obtain well separated optical functions at the sextupoles. The wigglers run always at top field to obtain strong damping. Moreover, by changing the dispersion inside the wigglers, it is possible to tune the emittance to large values (an order of magnitude larger than the contribution from the dipoles). This kind of cell has been tested successfully for the first time in a storage ring and we call it BWB.
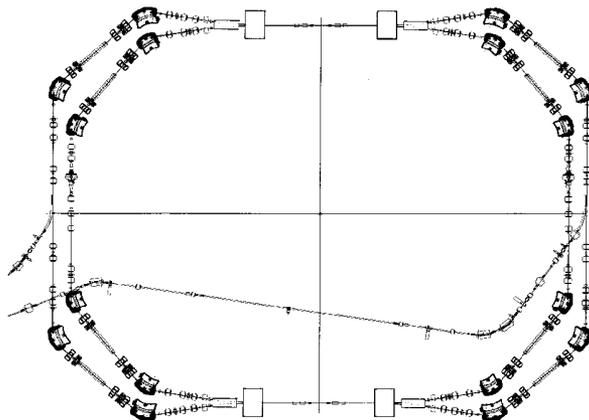

Figure 1: Layout of DAΦNE Main Rings.

Injection kickers, RF cavity and longitudinal feedback are housed in the straight sections orthogonal to the IRs. Outside the arcs 8 sextupoles are used to correct the tune shifts with amplitude and momentum. Eight skew quadrupoles are installed in each ring to control coupling.

The optical functions of the Long and Short sectors have been designed as much as possible similar, even if there is no symmetry with respect to the IPs. Non vanishing dispersion in the injection region is used to obtain large momentum compaction, improving the threshold for microwave instability. Due to the low energy spread of the beams coming from the Accumulator [2] injection efficiency is not affected by this dispersion.

The betatron tune working point has been chosen on the basis of beam beam simulations [3]. In order to have the maximum flexibility each quadrupole is individually powered. Anyway the tunes can be varied on a large range by changing the quadrupole settings only in the Short straight section, leaving the optical functions in the rest of the ring unchanged.

The single ring parameters are summarised in Table 1.

C (m)	97.7	β_x^* (m)	4.5
F_{rf} (MHz)	368.26	β_y^* (m)	.045
h	120	κ	.01
ε (m*rad)	10^{-6}	σ_x^* (m)	$2.1 \ 10^{-3}$
θ (mrad)	20÷30	σ_y^* (m)	$2.1 \ 10^{-5}$
α_c	.02	σ_E^{nat}	$4. \ 10^{-4}$
U_o (keV/turn)	9.3	τ_x (ms)	36.

2.2 Interaction Regions

The IRs are a large fraction of the ring circumference (≈20%). The optical functions are symmetric with respect to the IP. The beams travel off axis in the IRs, being separated at the IR ends by about 12 cm. To increase the separation and to lower the chromaticity, mainly due to the low-β insertions, a focusing sequence FDF has been chosen. The IR modelling [4] takes into account the linear effects of the fringing quadrupole fields on the off axis trajectories.

Four different IR lattices have been designed: three for the experiments and one for commissioning. The total IR first order transport matrix is nearly the same for all configurations, thus allowing to interchange the four IRs with small adjustments of the optical functions in the arc.

The large detector solenoids are a strong perturbation to the machine optics (BL = 2.4 Tm) and give the major contribution to the coupling. A sophisticated compensation scheme has been designed [5].

For machine commissioning the DAY-ONE IR houses seven electromagnetic quadrupoles, to allow tuning of the optical functions, with a quadrupole placed at IPs. These scheme reduces the chromaticity. A Beam Position Monitor (BPM) at the IPs allows to align the two beams for the colliding configuration.

3 OPTICS MEASUREMENTS

Commissioning started with the nominal β^*.

The first working point was far from the integer ($\nu_x = 5.14$, $\nu_y = 5.21$) to reduce closed orbits and make first injection and storage easier. In order to optimize the luminosity, the working point has been then moved closer to the integer ($\nu_x = 5.11$, $\nu_y = 5.07$). Injection has been optimized and measurements to characterize the ring lattice have been performed on this working point as well.

3.1 Lattice Modelling

Due to the high beam emittance the machine aperture is large; for this reason and because of the short lengths of the magnetic elements the effect of the fringing fields is not negligible and a correction to the rectangular model has been applied for most of them. The edge effect of the dipole is represented by a thin lens on each side with a focusing strength computed from magnetic measurements. This effect accounts for a change of almost 0.5 in the vertical tune. The wiggler magnets are modelled by a sequence of parallel face dipoles, taking into account also the focusing effect of the sextupole field component on the oscillating trajectory whose amplitude is ≈3 cm.

The measured tunes on the first stored beam where in agreement with those calculated with this preliminary model within 0.05.

The horizontal and vertical β functions along the rings have been measured by recording the change in tunes given by a variation of the current in each quadrupole. As an example, Fig. 2 shows the comparison between measured and computed β functions for the e⁻ ring. The model fits quite well the measurements for different tunes. The computed emittance agrees with the design value within 10%.

3.2 Closed orbit

The closed orbit measurement, available under the DAΦNE Control System [6], provides the beam position in real time. Four methods to correct the closed orbit have been implemented:

- best corrector
- harmonic correction [7]
- eigenvalues of measured response matrix
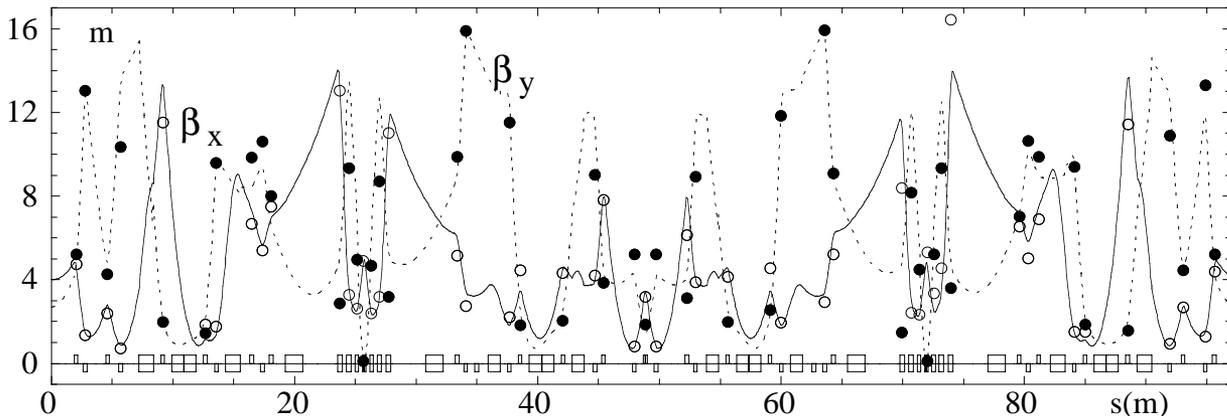- bumps in the IRs.

Figure 2: Horizontal and vertical β functions in one ring. White and black dots are measured β_x and β_y respectively.
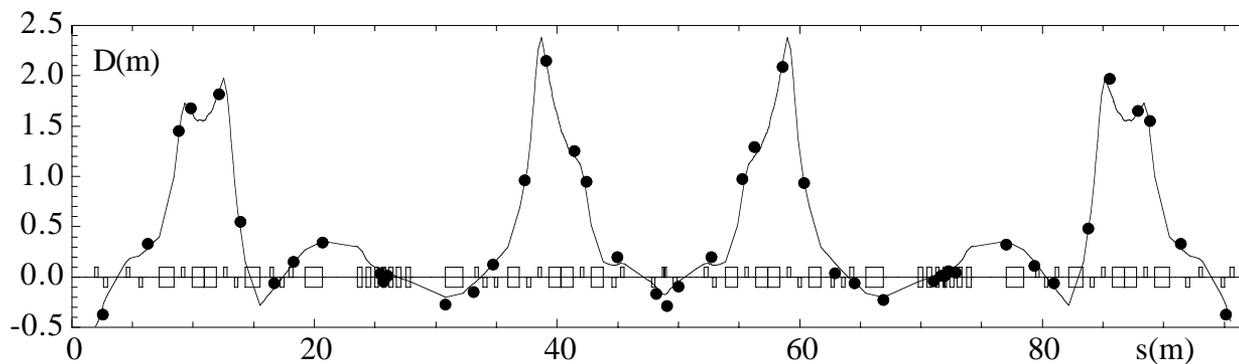
Figure 3: Horizontal dispersion function in one ring. Dots are measured values

Orbit bumps in the IRs, with four correctors, have been used to precisely adjust angle and displacement in the horizontal and vertical plane at the IP. The orbit measurement in the IRs is performed separately for each beam in the same monitors and therefore the superposition of the two beams is not affected by monitor offsets. Bumps are also used to vertically separate the beams in one IR when colliding in one IP only.

The Response Matrix of the ring, giving the beam position in all BPMs versus the perturbations in corrector magnets, has been measured. It has been used to check the machine model as well as for calibration of the corrector strengths.

Since the two rings are very close to each other , there is magnetic cross-talk between the two rings. Fringing fields from high field elements produce orbit changes on the nearby ring. These effects have been corrected. The horizontal closed orbit is determined not only by magnetic misalignments, but also by the compensation of the trajectory in the wigglers and by the splitter setting as a function of the crossing angle at the IP. The closed orbit without correctors is within the aperture in both rings.

The dispersion function, shown in Fig. 3, has been measured from closed orbits at different RF frequencies. Coupling has been estimated from the beam image given by the Synchrotron Light Monitor [8] for both beams. Closed orbit correction has led to κ values around 0.03. Skew quadrupoles have been adjusted reaching the coupling design value of 0.01.
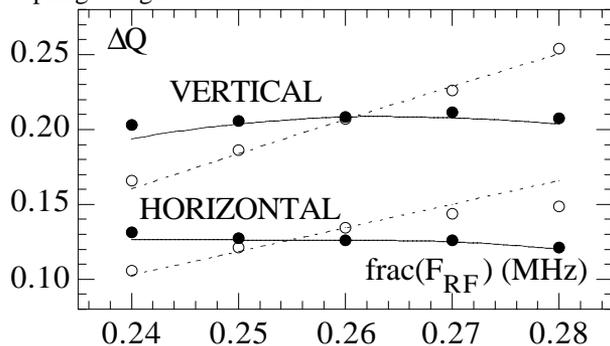

Figure 4: Measured (dots) and computed (lines) chromaticity with (black) and without (white) sextupoles

3.3 Chromaticity

Fig. 4 shows the comparison between theoretical (lines) obtained from a tracking code and measured (dots) horizontal and vertical chromaticities for the e⁻ ring, with and without sextupoles, performed on the working point (5.14, 5.21). The agreement is pretty good up to energy deviations of the order of ±0.5%. The difference in horizontal tune with and without sextupoles at the central RF frequency is due to closed orbit in the sextupoles.

4 CONCLUSIONS

The optics measurements described here have been useful to establish a machine model to adjust the operating point and to tune the lattice for the two beams operation. The closed orbit in the rings is small enough to obtain design coupling with sextupoles on. More accurate modelling for two beams operation is proceeding in parallel with the commissioning.

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