MAIN FEATURES OF DAΦNE OPTICS

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Abstract

The main features of DAΦNE's lattice are described in the following. Some characteristics are common to other factories, and others, peculiar of DAΦNE, are mainly related to the low energy of the Φ resonance and to the design of the two interaction regions. Optics measurements performed after the KLOE detector installation are also described.

1 INTRODUCTION

High current, multibunch, flat beam approach has been adopted for DAΦNE, similar to other factories. Electron and positron beams, stored in two separate rings, travel in the same vacuum chamber in the Interaction Regions (IR) and collide in two Interaction Points (IP) with an horizontal angle of 25 mrad.

The status of the machine after the KLOE detector installation has been presented in this workshop [1].

The main features of the lattice, related to the low energy of the Φ-factory (E=510MeV/beam), are the small circumference, the high emittance and the wigglers integrated in the lattice [2]. The presence of two IRs and the horizontal separation of the two rings reduce to one the periodicity of the rings. The KLOE detector, installed in interaction region IR1, has a solenoid with 2.4 Tm integrated field, which is a strong perturbation for the 510 MeV beams and the main source of coupling. A brief description is presented together with the commissioning results.

2 MAIN RING OPTICS

The circumference of each ring is very short, nearly 100 m, in order to increase the single bunch luminosity and reduce the damping time. This makes the lattice extremely compact and has allowed the installation of the machine in the building of the ADONE accelerator, shut down in 1993.

The single ring parameters are shown in Table I and the layout of the two rings is shown in Fig. 1.

The two 10m long IRs are limited by the splitter magnets used to separate the beams. In each ring two sections connect the IRs: an outer one, called *Long*, and an inner one, *Short*. Each section (*Short* and *Long*) is made of two arc cells with an utility straight section in between.

Table 1: DAΦNE Single Ring Parameters

E (MeV)	510		
C (m)	97.7	F_{rf} (MHz)	368.26
Q_x	5.15	β_x^* (m)	4.5
Q_y	5.21	β_y^* (m)	.045
h	120	κ	.01
ε (m*rad)	1÷.5 10^{-6}	θ (mrad)	20÷30
α_c	.015	σ_E^{nat}	4. 10^{-4}
U_o (keV)	9.3	τ_x (ms)	36.

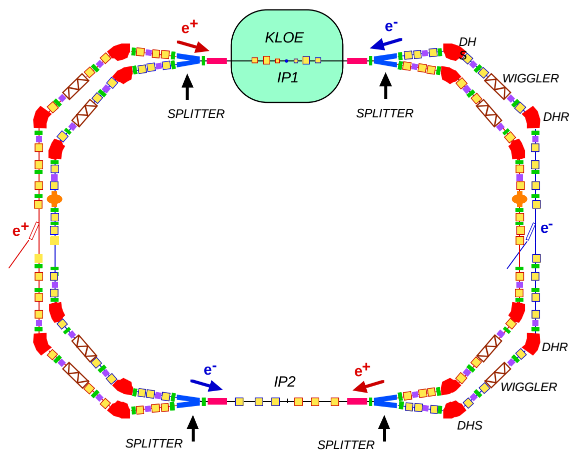

Figure 1: Main Rings Magnetic layout.

The *Short* straight section is dispersion free and is used for RF, feedback and diagnostics. The *Long* one is used for injection and diagnostics. In the *Long* straight section a non zero dispersion function is used to control the value of the momentum compaction to reduce instabilities.

2.1 The Arc Cell

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. The wigglers double the energy radiated in the bending magnets.

One of the parameters required to increase the luminosity is a high emittance. The arc cell (BWB) with two bendings and a wiggler in between has been designed to increase the emitted radiation and tune the emittance. The cell is a double bend achromat with three quadrupoles (DFF) and a wiggler inside; a chromaticity correcting sextupole is placed on each side of the wiggler. One of the dipoles has parallel end faces and allows a better separation of the optical functions at the sextupoles. By varying the dispersion function in the wiggler, the emittance can be tuned in a large range.

2.2 The Interaction Regions

A peculiar feature of the lattice is the interaction region 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 and corrector dipoles allows to change the crossing angle so that the effect of parasitic crossings can be finely tuned. The beams are 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 optical functions inside the IR are symmetric with respect to the IP.

Four different IR lattices have been designed: three for the experiments and one for commissioning without the detectors. The total IR first order transport matrix is almost the same for all configurations, thus allowing to interchange the four IRs with small adjustments of the optical functions in the arc.

The *day-one IR*, used for machine commissioning, housed seven electromagnetic quadrupoles to help tuning the optical functions, with a quadrupole placed at the Interaction Point (IP) to reduce the chromaticity. A Beam Position Monitor (BPM) at the IPs allowed to align the two beams for the collision configuration.

At the beginning of 1999 the KLOE IR, described in section 3, has been installed in IR1. DEAR, placed in IR2, is a slight modification of the *day-one IR* obtained by removing the central quadrupole at the IP.

3 THE KLOE IR

KLOE is a large detector equipped with a longitudinal field solenoid. To leave the maximum free solid angle for the experiment, the low-β triplets, embedded inside the detector, are realised with permanent magnet quadrupoles.

The three quadrupoles are confined inside a cone of 9° half-aperture, the free space around the IP is ±.45 m and the solid angle available for the detector is 99%.

The optical functions and beams trajectories in the KLOE IR are shown in Fig. 2. The high integrated field of the KLOE solenoid (BL = 2.4 Tm) is a strong perturbation to the machine optics at the relatively low DAΦNE energy ($B\rho$ = 1.7 Tm). It rotates the normal modes of oscillation in the transverse plane by an angle $\theta_R \sim 45°$, with θ_R defined by:

$$\theta_R = \frac{1}{2B\rho}\int B_z(s)ds\,.$$

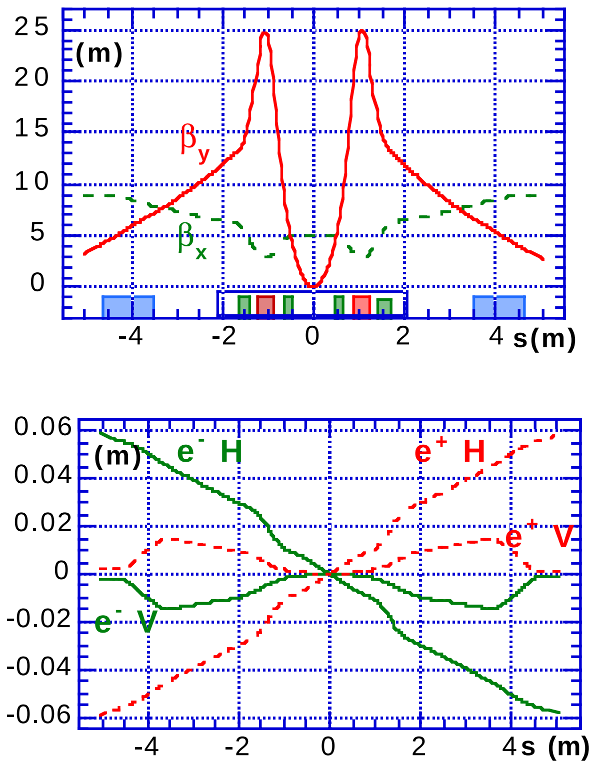

Figure 2: a) Optical funtions in IR1, b) Beam trajectories in IR1.

This is the major contribution to the coupling and it has to be compensated to obtain the very flat beam ($\kappa \leq .01$) required for high luminosity.

To cancel the coupling at the IP and at the ends of the IR it is sufficient to make the matrix of each half-IR block diagonal by using four skew quadrupoles. This method cannot be applied to DAΦNE for lack of space and for the excessively high strengths required for the skews.

To correct such a large coupling we have adopted a scheme [2] consisting of antisolenoids plus rotated quadrupoles, that we call Rotating Frame Method (RFM).

The rotation introduced by the solenoidal field of KLOE is neutralised by two superconducting compensating solenoids, of equal but opposite integrated field, symmetrically placed on each side of the detector.

The RFM allows to insert the low-β quadrupole triplet between the main and the compensating solenoids without affecting the coupling correction. This is based on a property of the solenoid matrix that can be written as the product of two matrices $\mathbf{R}(\theta_R)$ and $\mathbf{F}$, which commute. $\mathbf{R}(\theta_R)$ is a rotation and $\mathbf{F}$ is a block diagonal matrix equivalent to a quadrupole focusing in both planes with strength $K=(\theta_R/L)^2$.

The half IR matrix consisting of half the detector solenoid plus the compensating one can be written as:

$$\mathbf{M}_H = \mathbf{F}_C\, \mathbf{R}(-\theta_R)\, \mathbf{R}(\theta_R)\, \mathbf{F}_D.$$

A quadrupole inserted between the detector and the compensator does not introduce coupling, provided it is tilted by the solenoid rotation angle θ_R.

In fact when a quadrupole, represented by the matrix $\mathbf{Q}$, is tilted by the angle θ_R its matrix becomes:

$$\mathbf{Q}_R = \mathbf{R}(\theta_R)\, \mathbf{Q}\, \mathbf{R}(-\theta_R).$$

When inserting $\mathbf{Q}_R$ in the matrix $\mathbf{M}_H$, between the detector and the compensating solenoid, the rotations are cancelled out and $\mathbf{M}_H$, being the product of block diagonal matrices, is block diagonal itself.

In the KLOE IR the low-β quadrupoles are immersed in the detector solenoid. Exact application of RFM implies that each quadrupole should be continuously rotated as an helix.

In practice the quadrupoles are rotated by the angle corresponding to their longitudinal midpoint. The resulting half IR matrix has a small residual coupling which is corrected by slightly adjusting four parameters: three additional rotations of the low-β quadrupoles and a correction of the compensating field.

4 OPTICS MEASUREMENTS

To have a large lattice flexibility all magnetic elements have independent power supplies. This allows to measure the beta functions at all quadrupoles.

The β functions measured along the ring are shown in Fig. 3, compared with the lattice model.

Due to the high beam emittance the machine aperture is large; for this reason and because of the short length of the magnetic elements the effect of the fringing fields is not negligible and corrections have been applied to the dipoles, which account for a change of almost 0.5 in the vertical tune.

The model also takes into account the focusing effects in the wigglers.

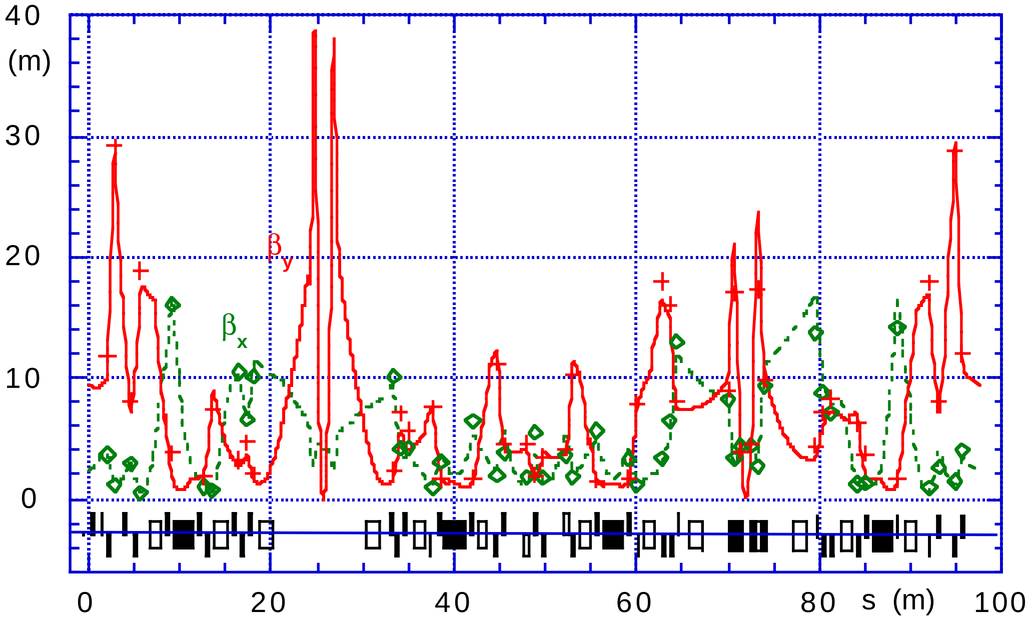

Figure 3: Horizontal and vertical β functions in the e^+ ring.

In the KLOE IR short slices of solenoid interleaved by thin lens quadrupoles account for the overlap and for the longitudinal variation of the fields. In addition, in order to better fit the measured beta functions, few free parameters have been used as variables.

An independent check of the model can be obtained by using the information of the ring response matrix, measured by recording the closed orbit displacements produced by unit variations of the dipole correctors. A procedure to derive the optical functions from the response matrix, reducing the influence of calibration errors of monitors and correctors, is in progress. This check of the model is specially important for the KLOE IR , where a direct measurement of the optical functions cannot be performed by varying the quadrupole currents, because they are made of permanent magnets.

The closed orbit before correction was inside the ring aperture in both rings. Since the two rings are very close to each other, the stray fields from high field elements produce orbit changes on the nearby ring. 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. Four methods to correct the closed orbit have been implemented:

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

Orbit bumps in the IRs, with four or six 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 the beams only in the other one.

During commissioning with the *day-one IR*, after closed orbit correction, a coupling of the order of $\kappa \sim .002$ has been obtained, much smaller than the design value ($\kappa = .01$), also with sextupoles turned on.

Coupling has been estimated from the synchrotron light monitor and by the closest tune approach distance. Another sensitive measurement of the relative variation of the coupling is the beam lifetime which is essentially determined by the Touschek effect and therefore it is inversely proportional to the beam density and, for small coupling, nearly proportional to square root of the coupling. The minimum coupling has been found by measuring the beam lifetime as a function of the strength of a skew quadrupole.

The horizontal emittance measured by the synchrotron light monitor is in agreement with the value calculated by the model.

The chromaticity has been measured and corrected using the same sextupole strengths in both rings. The sextupole strengths have been tuned in order to improve the energy acceptance of the ring and therefore the beam lifetime. Indeed the lifetime depends on the physical and dynamic aperture for the betatron and synchrotron oscillations.

The design value of the energy acceptance has been reached by powering only the eight sextupoles located in the arcs arranged in four families.

4.1 KLOE Solenoid Compensation

The rotation angles of the quadrupoles in the triplets with respect to each other have been set first, then the two triplets as a whole have been aligned with respect to their mechanical supports. After installation each triplet can be moved rigidly with five degrees of freedom (horizontal and vertical angle, displacement and rotation angle). The alignment of each triplet has been measured looking at four reference points. In the horizontal plane the alignment is quite satisfactory, while the vertical displacement of one triplet and the rotation angle of both need further correction. This operation requires a machine shutdown with the KLOE end-caps opened.

At this stage the effects of the misalignment errors are compensated by adjusting the field of the detector and compensating solenoids and by means of eight skew quadrupoles in each ring.

Figure 4a) shows the synchrotron light monitor of the positron beam at the first start-up of the ring with KLOE. The same image after tuning the optical functions, orbit correction and coupling compensation is shown in Fig. 4b).

The measured coupling corresponds to the design value $\kappa = .01$ and is obtained only by adjusting the fields of KLOE and of the compensating solenoids. For the electron ring we have used also two skew quadrupoles and the obtained coupling is slightly higher ($\kappa \sim .02$).

a) b)

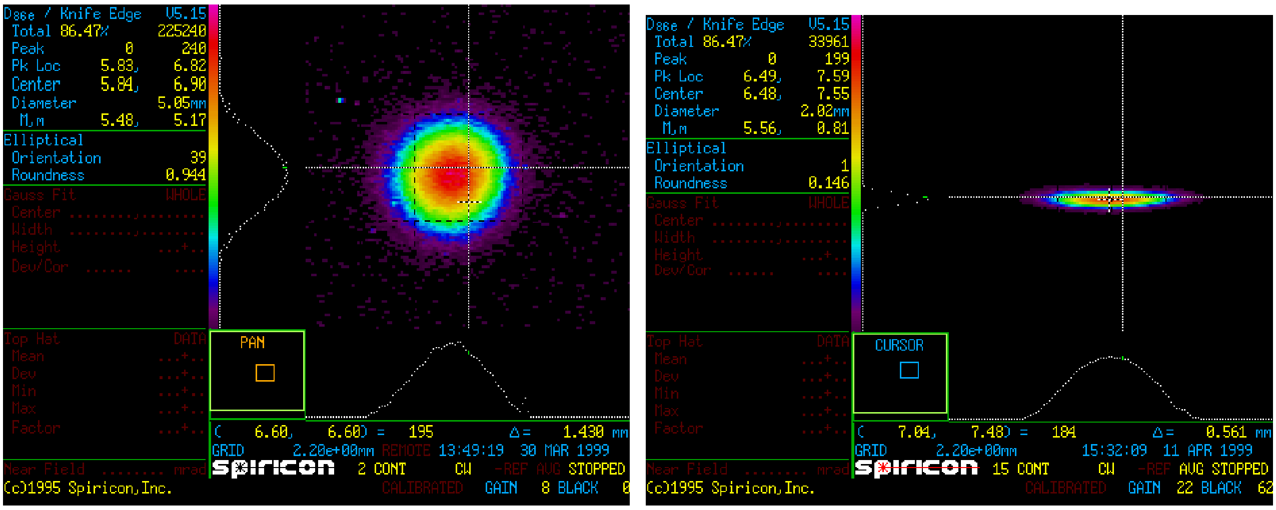

Figure 4: Beam image from synchrotron light monitor
a) before optics correction, b) after coupling compensation.

5 CONCLUSIONS

The optics of DAΦNE has some features common to higher energy colliders, together with a very compact design.

During commissioning, before KLOE installation, all the design values of the optics parameters have been achieved. Although the KLOE IR is a strong perturbation to the optics, after some tuning, the lattice parameters are again near to the design values.

6 REFERENCES

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