STATUS REPORT ON DAΦNE PERFORMANCE

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Abstract

Commissioning of the Φ-factory DAΦNE with two temporary interaction regions was successfully concluded in November 1998 proving the reliability of all machine systems. After the roll-in of the experimental detector KLOE, the commissioning resumed and the beam was stored in this configuration at the end of March 1999. The first physics events were already observed in mid April 1999. Since then, the collider shares its time between experimental shifts and machine physics runs. The main efforts have been dedicated to push up the luminosity by improving the single bunch collision luminosity and increasing the current in multibunch operations. We describe the results achieved so far, discuss the difficulties encountered on the way to high luminosity and the actions undertaken to improve collider performance.

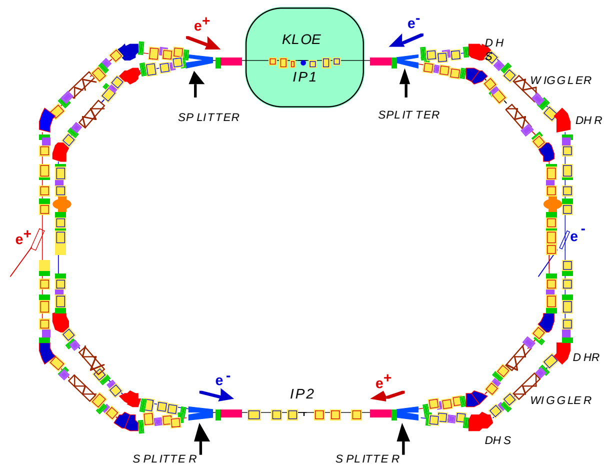

Figure 1: Main Rings magnetic layout.

1 INTRODUCTION

DAΦNE, the Frascati 1.02 GeV c.m. electron/positron Φ-factory [1], is now in operation at Frascati Laboratories of Italian National Institute of Nuclear Physics. The main DAΦNE design parameters are listed in Table 1, while the magnetic layout is shown in Fig. 1.

Table 1: DAΦNE Design Parameters

Energy [GeV]	0.51
Trajectory length [m]	97.69
RF frequency [MHz]	368.26
Harmonic number	120
Damping time, τ_E/τ_x [ms]	17.8/36.0
Bunch length [cm]	3
Emittance, $\varepsilon_x/\varepsilon_y$ [mm·mrad]	1/0.01
Beta function, β^*_x, β^*_y [m]	4.5/0.045
Particles/bunch [10^{10}]	8.9
Single bunch luminosity [$cm^{-2}\,s^{-1}$]	$4.4\,10^{30}$

High current, multibunch and flat beam approach has been adopted for DAΦNE, similar to that of PEP-II [2] and KEKB [3], to reach high luminosity. Electron and positron beams, stored in two separate rings, travel in a common vacuum chamber in the Interaction Regions (IR) and collide at two Interaction Points (IP). Crossing at a horizontal angle of 25 mrad minimizes the effect of parasitic collisions and allows to store many bunches, increasing the luminosity by a factor equal to the number of bunches. The DAΦNE design accepts a maximum number of 120 bunches and all the critical subsystems (injector, RF, vacuum system, diagnostics) are dimensioned to cope with a stored current of ~ 5 A.

The Phase I luminosity target is 10^{32} $cm^{-2}\,s^{-1}$ with ~1A of average current stored in each colliding beam. Once this target is obtained, in parallel with physics runs, we will progressively tune the machine systems for higher currents and increase the number of bunches, and consequently the luminosity. In order to achieve this ultimate goal further investment on the longitudinal feedback and additional work on the cures of the parasitic crossings effects will be needed.

The DAΦNE commissioning with two provisional interaction regions without experimental detectors ("Day-one" IRs) was concluded successfully in November 1998 (see [4] for details). After the KLOE detector [5] installation the first beam was stored at the end of March 1999. Since then, the commissioning efforts have been dedicated to the compensation of the perturbation introduced in the machine optics by the experimental detector solenoid, to the optimization of beam parameters at the interaction point in order to improve the single

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bunch collision luminosity and to increase the beam current in multibunch operation.

In this paper we give a brief description of the DAΦNE collider with the KLOE interaction region (IR), describe the results of the machine optics modelling and coupling correction, discuss beam dynamics in single and multibunch operation and analyse the data obtained in beam-beam collisions with the experimental detector.

2 GENERAL DESCRIPTION

The DAΦNE magnetic layout is shown in Fig. 1.

The circumference of each ring is about 100 m: this length is imposed by the need to have two 10 m long IRs. In each ring two sections connect the IRs: an outer one called Long and an inner one called Short. Each of these two sections is made of two arc cells with an utility straight section in between. The Short straight section is dispersion free and it is used for RF cavity, feedback kickers and diagnostics. The Long straight section is used for injection and diagnostics.

Particular care has been taken in the design to make the damping times as short as possible in order to counteract possible instabilities at the DAΦNE low energy. Small bending radius in the dipoles and four high field wigglers in each ring produce large energy loss. The energy radiated in the wigglers is about as much as that radiated in the bending magnets.

One of the parameters required to increase the luminosity is high emittance. The arc cell (BWB: bending-wiggler-bending) with two bendings and a wiggler in between them 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 correction sextupole is placed on each side of the wiggler. One of the dipoles has parallel end faces allowing better separation of the optical functions at the sextupoles. By varying the dispersion function in the wiggler the emittance can be tuned over a wide range.

3 KLOE IR

The KLOE detector consists of a cylindrical drift chamber surrounded by a lead-scintillating fiber electromagnetic calorimeter and immersed in the 0.6 T magnetic field of a 2.5 m radius superconducting solenoid. In order to leave the maximum free solid angle for the experiment the low-β triplets, which are embedded inside the detector on either side of the IP, are realized with permanent magnet quadrupoles. The three quadrupoles of each triplet are confined inside a cone of 9° half-aperture and the free space around the IP is ±0.45 m thus providing a solid angle of 99% available for the detector.

The integrated field of the KLOE solenoid is ~ 2.4 Tm: this is a strong perturbation to the machine optics at the DAΦNE energy which corresponds to a rigidity of $B\rho$ = 1.7 Tm. The KLOE solenoid rotates the normal modes of oscillation in the transverse plane by an angle of 41.5°. This is the major contribution to the coupling between radial and vertical oscillations.

The correction of such a large coupling is obtained by two compensating solenoids plus rotated permanent magnet quadrupoles: the rotation introduced by the solenoidal field of KLOE is neutralized by the two superconducting compensating solenoids of equal but opposite integrated field and symmetrically placed on each side of the detector. The low-β quadrupoles inserted in the detector solenoid do not affect the coupling correction provided they are tilted by an angle equal to the rotation angle due to the solenoid.

4 LATTICE MODEL

DAΦNE optics modeling is not a simple task due to the high complexity of the magnetic layout including wigglers and experimental detector solenoids as an integral part, the absence of periodicity and the close vicinity of the two rings, leading to substantial crosstalk. The machine model is based on magnetic measurements of all the elements, measurements of the optical functions and Response Matrix (RM) analysis.

The present optical model takes into account:

- Splitter and dipole magnet fringing fields.
- Wiggler fringing fields and focusing on the trajectory due to the quadratic term in the vertical field.
- Longitudinal solenoid field distribution of KLOE detector and compensator solenoids.
- Longitudinal behavior of the gradient of the permanent magnet quadrupoles in KLOE low beta insertion, which, due to the small ratio between the gap and magnetic length, is not well represented by the step model.
- Tilt of these quadrupoles which compensate the transverse rotation introduced by the KLOE solenoid.

The model reproduces the beta functions within 5% accuracy, the tunes within 0.01 (0.2% of the absolute value), the dispersion function within few cm, the emittance within 10% and the momentum compaction within 1%.

The present optics model allows to correct the vertical dispersion down to 100 μm, thus removing this coupling source, gives a possibility to explore wide tune areas during luminosity tune up without changing the model parameters, to tune the emittance and momentum compaction, helps to adjust the optics functions at the sextupole positions in order to obtain more efficient chromaticity correction and to improve the dynamic aperture.

As the result of the modeling the DAΦNE optics has been optimized. Now the magnet currents of both rings are similar and the orbits, beta functions, dispersions and momentum compaction are almost equal in the two rings.

The small tune difference in the two rings of the order of 0.05 is due to the stray fields of the transfer line magnets, which introduce an asymmetry between the two ring lattices, and to the ion clearing electrodes in the electron ring.

5 COUPLING CORRECTION

The coupling correction is an important issue for DAΦNE since:

- Coupling must be reduced down to 1% in order to provide the design vertical beam size.
- Coupling may affect single ring transverse dynamics, in particular, the dynamic aperture.
- If not properly corrected, coupling may lead to luminosity degradation, inducing vertical size blow up and relative tilt angle between colliding bunches.

At the commissioning stage without solenoids it was demonstrated that the design tolerances on all the magnet alignments are well satisfied achieving coupling value of 0.4 %.

The coupling correction with the experimental solenoid is more complicated since it requires precise matching between low-beta quadrupole tilts, detector and compensator solenoids fields and the beam energy.

Survey measurements on the low-beta triplets done during the last winter shutdown showed a tilt misalignment of the order of 1^0, which therefore prevents the exact coupling correction.

Another source of coupling is in the second IR, where the beams are presently vertically separated and pass off-axis in the stray field of the splitter magnets. Fortunately, the phase of this perturbation is such that coupling can be controlled adjusting the KLOE IR parameters. Tuning the KLOE IR solenoid fields and the beam separation at the second IP can therefore optimize the coupling correction. In this way coupling has been corrected down to the values of 0.2% in the positron ring and 0.3% in the electron one without using any skew quadrupole.

The relevant improvement in the coupling correction was confirmed by beam size measurements at the synchrotron light monitor and observing correlated reduction in the beam lifetime that in DAΦNE is essentially dominated by the Touschek effect.

More information about coupling has been obtained from RM measurements. The average ratio between vertical and horizontal displacement caused by all horizontal steering magnets at each BPM is taken as a measurement of the average amount of horizontal oscillation transferred to the vertical plane, i.e. proportional to the tilt angle introduced by coupling sources along the machine.

Figure 2 compares this value before and after the coupling correction.

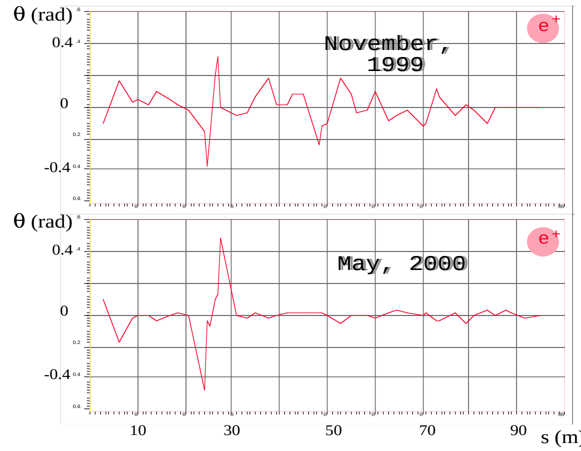

Figure 2: Transverse tilt measurements in the positron ring by response matrix analysis.

6 BEAM DYNAMICS

6.1 Single Beam Dynamics

Before the detector installation the maximum current stored in single bunch mode in both rings was 110 mA, i.e. by a factor of 2.5 higher than the design value of 44 mA. No destructive single bunch instability was observed.

The bunch length as a function of bunch current has been measured in the positron ring using a signal from the broad-band button pick up [6]. A very good agreement with numerical simulations based on machine impedance estimates has been found. According to these data the normalized coupling impedance |Z/n| is below 0.6 Ω. Recently, the measurements were repeated in both rings with a streak camera. The results agree well with those obtained with the button for the positron ring. In the electron ring bunches are measured to be about 20-30% longer than positron bunches since the electron ring impedance is higher, presumably due to the presence of several clearing electrodes.

After the experimental IR installation, an unstable quadrupole mode was detected in both rings. It has been found that the mode threshold is very sensitive to the bunch length. In particular, the threshold was higher for lower RF voltages and higher momentum compaction. Moreover, the instability disappeared by increasing the bunch current above a certain threshold. Perhaps, this can be explained by a modification of the impedance at high frequencies where the quadrupole mode spectrum has a maximum. An increase of the bunch length shifts the mode spectrum to lower frequencies and the current instability threshold increases.

The instability problem has been fixed by increasing the momentum compaction and by applying HOM damping antennas in the injection kickers [7].

At present, no sign of microwave instability is observed at different RF voltages up to a single bunch current of 140 mA. No dedicated measurements were carried out to estimate the exact value of the transverse impedance since some observations have shown that it is low. In particular, a head-tail instability threshold as high as 13 mA with sextupoles off has been achieved after an accurate orbit correction. Moreover, the observed vertical tune shift is a small fraction of the synchrotron tune in the whole current range from zero to the nominal value, indicating that the DAΦNE operating point is quite far from the transverse mode coupling threshold.

6.2 Multibunch operation

So far no major problems for multibunch operation in DAΦNE have been encountered. The maximum stored currents have exceeded 1 A in both the positron and the electron rings. Further current increase is limited by bad vacuum after a vacuum accident in April 2000 when cooling water from a synchrotron light copper absorber penetrated into the vacuum chamber. We expect to reach higher currents when vacuum is improved.

Figure 3 shows the DCCT record for the positron ring. The current of about 1050 mA was stored in 60 equidistant bunches. The beam was stable at that point even without a transverse feedback. However, sometimes we observe transverse dipole coherent oscillations in the positron beam at lower currents. The instability does not represent a serious danger for the beam since the coherent oscillations are damped in beam-beam collisions due to Landau damping.

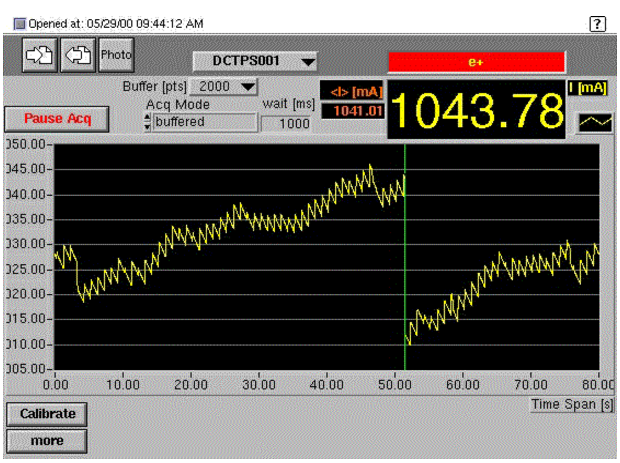

Figure 3: DCCT current record in the positron ring.

In order to reach higher currents and to improve beam stability additional investments are being made in feedback systems. Recently, a new filter was implemented in the longitudinal feedback system, allowing to overcome the 0-mode instability. A prototype transverse feedback system has already been installed in the positron ring and has proven to perform well.

7 BEAM-BEAM INTERACTION

7.1 Collision point optimization

In order to achieve high luminosity the longitudinal and transverse positions of the two beams must be adjusted to provide maximum overlap at the IP. Moreover, the waists of the vertical beta functions of the two rings should coincide with the crossing point.

The longitudinal overlap of colliding bunches at the nominal IP has been synchronized by monitoring the distance between the combined signals of the two beams on two sets of symmetric BPMs on either side of the IP. The final precise longitudinal timing has been achieved by varying the RF phase of one of the two beams in order to maximize the luminosity monitor signal.

The beam orbit measurements in the IRs are performed by six BPMs distributed along each IR. Since the position of both beams is measured by the same monitors, monitor offsets cancel out. Averaging over 100 BPM readings provides precise beam position measurements in the IRs with a standard deviation below 10 µm. Closed orbit bumps in the IR with four correctors are applied to adjust angle and displacement at the IP and overlap the beams. Orbit bumps have been also used to separate vertically the beams in one of the IRs when colliding in only one IP.

At present the optimization of the beam collision parameters is performed by measuring the luminosity as a function of calibrated vertical and horizontal bumps at the IP. The fit of these dependencies gives us the mean geometric rms beam sizes ($\Sigma_{x,y}$) at the collision point which have to be minimized.

Figure 4 shows the luminosity as a function of the vertical bump at the IP measured by the luminosity monitor.

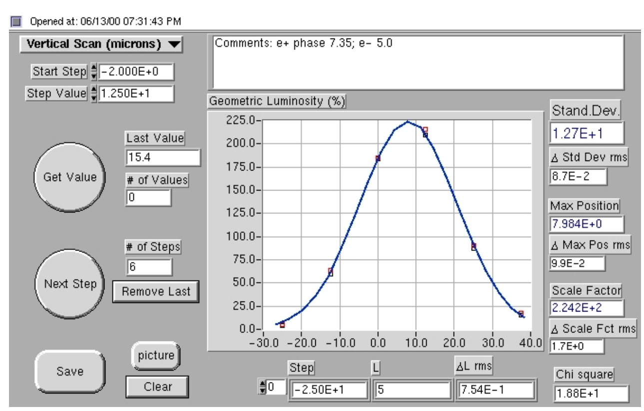

Figure 4: Σy measurement by luminosity scan.

By optimizing the coupling in the best case we have reduced the vertical capital sigma Σ_y down to 13 µm, while the nominal value is more that twice higher (30 µm).

7.2 Experimental results

After KLOE detector installation it was decided to exploit the same working point as we had used during "Day One" commissioning since quite satisfactory luminosity in single bunch collisions of 1.6E30 $cm^{-2}s^{-1}$ was obtained [8]. Working on that point in December 1999 allowed us to deliver to the KLOE experiment data taking runs with lifetime of 1 hour and initial luminosity of 4.5E30 $cm^{-2}s^{-1}$ with about 300-400 mA stored in 30-40 bunches and to collect an integrated luminosity of ~2.5 pb^{-1} during approximately 1 month of physics runs.

Further luminosity improvement was limited by the maximum achievable luminosity in single bunch collisions which at that time was at the level of 1-2E29 $cm^{-2}s^{-1}$.

One possible explanation of this limit is the imperfect correction of coupling. Indeed, as the numerical simulations show, beam blow up depends strongly on coupling and, in particular, on how and where in the ring it is created. In the collider configuration with the KLOE detector there are new sources of coupling such as rotation errors of the KLOE IR permanent quadrupoles. Furthermore, it has also been found that the coupling depends on the beam separation bump at the second IP.

Another possible reason could be stronger sextupolar nonlinearities in the lattice with the KLOE IR due to necessity to correct a higher natural chromaticity. Crosstalk between beam-beam effects and machine nonlinearities is one of the subjects presently under study.

After a collider shut down in January-February 2000 the main efforts are dedicated to improve the single bunch luminosity. By adjusting the collision point parameters and decreasing the coupling we have managed to increase the single bunch luminosity up to 5-6E29 $cm^{-2}s^{-1}$.

In multibunch operation the luminosity scales linearly with the number of bunches.

Figure 5 shows the luminosity measured by the detector for different number of bunches. The maximum luminosity of 1.0E31 $cm^{-2}s^{-1}$ has been achieved in 30 bunch configuration with about 350 mA per beam. Unfortunately, because of the recent vacuum accident we could not use more bunches to push the luminosity up since the residual gas pressure increases too much at higher currents.

Our present activity is aimed at improving the single bunch luminosity performance by exploring new tune areas, performing careful coupling correction and collision point optimization. In parallel, we use high current beam vacuum chamber conditioning in order to reduce the residual gas pressure allowing high current multibunch luminosity collisions.

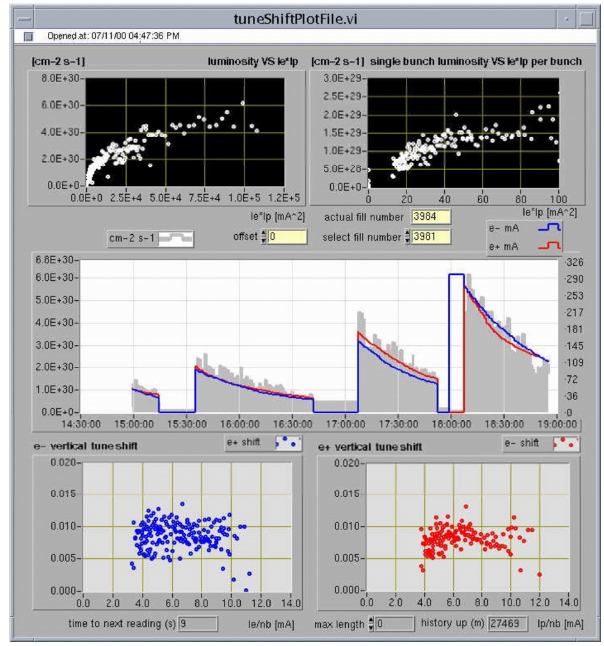

Figure 5: Luminosity measurement for 6, 10, 20 and 29 bunches per each beam, respectively (with 10 mA per bunch).

8 ACKNOWLEDGMENTS

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