DAΦNE OPERATING EXPERIENCE

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Abstract

Commissioning of the DAΦNE Φ-factory without experimental apparatus ended last November, when the construction of KLOE detector was complete. KLOE is presently being installed and operation with beam will resume next April for physics runs. We report in the following the DAΦNE performance achieved during the first phase of operation for single beam and colliding beams.

1 INTRODUCTION

The first commissioning phase of DAΦNE was concluded for the installation of the KLOE [1] detector (Fig. 1). The main results obtained in ~ 6 months of beam time are presented in the following.

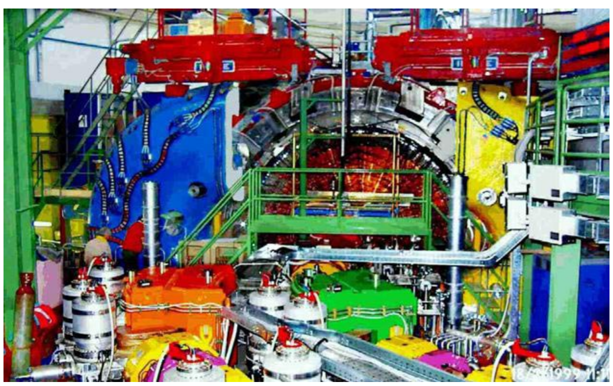

Figure 1: The KLOE detector during installation.

The strategy of the commissioning phase aimed at tuning the machine for collisions and optimizing the single bunch luminosity before KLOE's installation. This should guarantee that, after correcting the perturbation introduced by the KLOE solenoidal magnet, the machine is ready for two beams operation.

Single beam commissioning of the two rings, in single bunch mode, is completed: electron and positron currents larger than twice the design value (110 mA reached, 44 mA design) have been stored without instabilities and machine parameters have been measured and found in good agreement with the predictions of theoretical models. In particular, a machine coupling much smaller than the design value has been obtained.

Multibunch feedback systems have been put into operation and currents of 0.54 A of electrons and 0.56 A of positrons have been stored, only limited by vacuum.

A maximum single bunch luminosity of 1.6 10^{30} cm^{-2} s^{-1} has been so far obtained, while in multibunch collision, less extensively tested, a luminosity value of ~ 10^{31} cm^{-2} s^{-1} in 13+13 bunches configuration has been achieved.

2 GENERAL DESCRIPTION

The main DAΦNE [2] design parameters are summarized in Table 1, while the magnetic layout is shown in Fig. 2.

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 PEPII [3] and KEKB[4]. 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). 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.

DAΦNE's design allows 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 30 bunches and the main effort of the next machine shifts will be devoted to improve by a factor two single bunch luminosity and beam current in a reliable way.

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Once this target is obtained, in parallel with physics runs, the accent will be put to progressively tune the machine systems for higher currents and increase the number of bunches. To operate with 120 bunches further investment on the longitudinal feedback and additional work on the cures of the parasitic crossings effects will be needed.

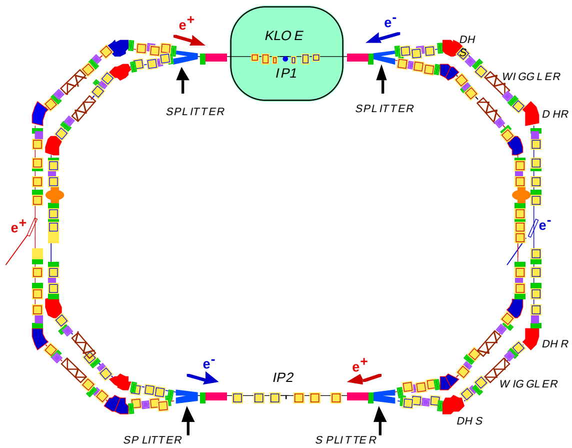

Figure 2: Main Rings magnetic layout (March 99).

3 SINGLE BEAM PERFORMANCE

3.1 Main Rings Optics

For commissioning purposes two temporary interaction regions (*day-one* IR), consisting of seven normal conducting quadrupoles, have been used to tune the optical functions. The first order transfer matrix and the β functions at the IP are the same for the *day-one* IR and the KLOE one, in order to match the same optical functions in the arcs, while the optical functions inside the IR and the quadrupole layouts are different.

The β functions along the ring have been measured in each quadrupole and used for lattice modeling. This model takes into account the fringing fields of dipoles and quadrupoles (non negligible because of the short lengths and large apertures of the magnetic elements), all the focusing effects in the wigglers and the off-axis trajectory in the IR quadrupoles.

The closed orbit before correction was inside the ring aperture in both rings. The sources of closed orbit are alignment errors, compensation of the trajectory in the wigglers and, since the two rings are very close, the stray fields from high field elements of the other ring. After closed orbit correction a coupling of the order of κ ~.002 has been obtained, much smaller than the design value (κ = .01), also when sextupoles are 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, it is nearly proportional to square root of the coupling. The minimum achieved coupling, well below the synchrotron light monitor resolution, has been tuned by measuring the beam lifetime as a function of the strength of a skew quadrupole.

The horizontal emittance measured by the synchrotron light monitor (see Fig. 3) is in good agreement with the design value for both rings.

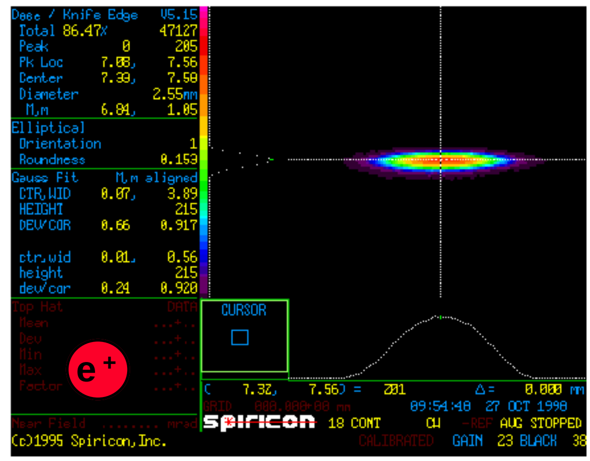

Figure 3: Beam image from the synchrotron light monitor at design coupling κ = .01.

The chromaticity has been measured and corrected using the same sextupole strengths in both rings and the behavior of the tunes versus the relative energy deviation, shown in Fig. 4 for the positrons, is the same for 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 beam 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 [5].

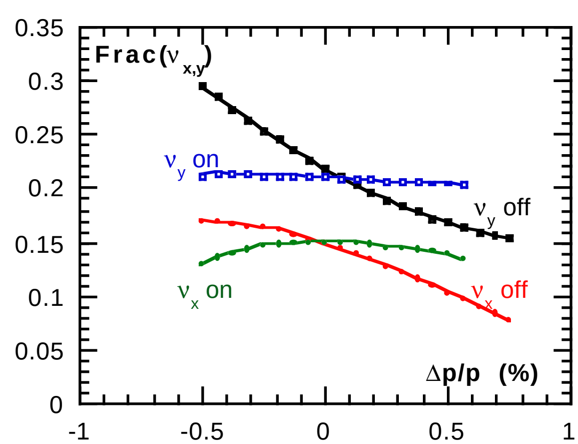

Figure 4: Betatron tunes versus relative energy deviation with sextupoles on and off for e^+ ring.

3.2 Principal subsystems

Special RF cavities, with low impedance parasitic high order mode (HOM) content, have been developed to allow stable high current-multibunch operation [6]. The cavities, one per ring, are normal conducting copper single cells, with a system of HOM damping waveguides which couple out and dissipate the HOM energy induced by the beam on external 50 Ω loads. The HOM shunt impedance has been reduced by up to three orders of magnitude. No evidence of arcing or multipacting effects due to the loading waveguides has been observed and the performance of the damped cavities under high beam loading is quite satisfactory.

A longitudinal bunch-by-bunch feedback system [7], implemented in collaboration with the SLAC/LBL PEP II group, is operational in both rings. It consists of a time domain system employing digital techniques. A damping time faster than ~ 200 μsec has been demonstrated in the positron ring with 30 bunches.

The specially designed arc vacuum chambers [8] and the Ti sublimation pumps have been very effective and the static gas pressure in the arcs was in the 10^{-10} Torr range. At the moment no baking of the arc chambers is needed and further improvement of the vacuum is expected by beam conditioning of the vacuum chamber, very effective due to the high emission of synchrotron radiation. The vacuum in the *day-one* IRs was very poor since they were not baked, in view of replacing them with the final ones. The bad IR vacuum, specially under high beam loading, was a limit for high current operation.

During the winter shutdown some operations to substantially improve the vacuum of the rings straight sections have been performed. Two special designed NEG pumps capable of a pumping speed for CO of 2000l/s have been installed in the KLOE IR, the distributed ion pumps inside the splitter magnets have been activated and the straight sections vacuum chambers adjacent to the IRs have been baked out.

3.3 Beam Dynamics

The maximum current stored in single bunch mode, 110 mA in both rings, largely exceeds the design value of 44 mA. The bunch length has been measured as a function of bunch current in the positron ring and found in very good agreement with numerical simulations based on machine impedance estimates [9]. According to these data the normalized coupling impedance |Z/n| is below 0.6 Ω. The transverse impedance is very low, as confirmed by the high threshold of the head-tail instability without sextupoles (13 mA in a single bunch).

Ion trapping effects have been observed in the electron ring, due to the poor vacuum of the commissioning IRs, even in single bunch mode above 20÷30 mA. Clearing electrodes [10] have been successfully tested. Although only partially powered, they helped in reducing the tune spread and shift due to the ions in the electron beam. In multibunch operation different filling configurations with a gap have been tested.

3.4 Multibunch operation

In the multibunch mode (all 120 bunches filled) 0.3 A in the positron beam and 0.23 A in the electron one have been stored without feedback. With the longitudinal feedback system on, up to 0.54 A of electrons have been stored in 25 bunches with a spacing of four RF buckets and an ion clearing gap of 5 consecutive bunches. With the positron beam 0.56 A have been stored in 30 uniformly spaced bunches. The uniformity of the stored current in the different bunches is quite satisfactory for both beams. These currents correspond to half the design value for 30 bunches and seem limited by vacuum and ion trapping.

4 COLLIDING BEAMS

Maximum beam overlap is the preliminary condition to obtain high luminosity in a two rings collider. For this purpose a careful adjustment of the longitudinal timing and of the orbits at the IP has been performed.

The longitudinal overlap of collisions at the nominal IP has been optimized by monitoring the distance between the combined signals of the two beams on two sets of symmetric BPMs on each side of the IP. The RF phase of one of the two beams is shifted to bring them into collision at the low-β point. Fine tuning is performed by looking for the maximum counting rate of the luminosity monitor at high currents.

The vertical distance between the two beams at the IP has to be small with respect to a vertical beam size $\sigma_y = 20\ \mu m$. The position in the IR is measured for each single beam in the same seven BPMs, canceling therefore any monitor offset. A BPM at the IP, installed for this purpose in the *day-one* IR, has been helpful during the initial set-up of orbit and timing for collisions. Averaging over 100 readings, a measurement of the beam position in the IR with an rms deviation better than 10 μm is obtained. Closed orbit bumps in the IR with four correctors are used to adjust angle and displacement at the IP to equalize the orbit of the two beams in the vertical plane and set the crossing angle at the design value $\theta = 25$ mrad. Fine tuning of the vertical orbit is performed by changing the position at the IP in steps of 5 μm and looking for maximum luminosity monitor signal. Tuning the horizontal position and vertical angle is not necessary because the orbits are set with more than enough precision with respect to the beam size ($\sigma_x = 2.1$ mm) and to the angles inside the beam ($\sigma'_y = 0.47$ mrad).

The minimum of the vertical beta function β_y^* has to be the same for the two rings and to coincide with the crossing point. As the IP is not a symmetry point of the machine, symmetric beta functions with the same β_y^* at the IP for both rings have been obtained by iterating the measurement and tune of β functions in the IR.

The beams were brought into collision in one IP only, while kept vertically separated in the other one. A vertical orbit bump separated the beam centers by Δy = 4 mm corresponding to nearly $2\sigma_x$ and 200 σ_y.

After the initial operation on the working point (5.11, 5.07) it was decided to run on the one (5.15, 5.21) farther from integers and sextupolar resonances. On this point the machine is less sensitive to closed orbit distortion, the dynamic aperture is larger and the lifetime longer.

Beam-beam simulations [11] predict for this working point, with a single interaction point, a luminosity of 2.2 10^{30}cm^{-2}s^{-1} with a beam-beam tune shift parameter $\xi_{x,y}$ of 0.03 and good lifetime. A brick-wall plot of the relative luminosity predicted by simulations in the tune diagram around 5.15, 5.21 is shown in Fig. 5.

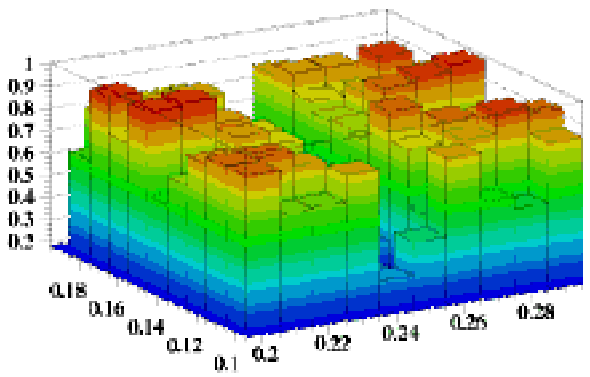

Figure 5: Relative luminosity predicted by simulations in the tune diagram.

During injection in collision mode the intensity of the injected beam saturated below the current of the already stored beam. The longitudinal and transverse oscillations of the bunch at injection cause crossings out of the nominal IP during a time comparable with the radiation damping one and produce particle losses. At present injection with the vertical separation bump is not very effective because the correctors are not synchronized and produce orbit distortions while turning off the separation.

To overcome this limitation a 'RF fast phase jump' procedure was implemented [6]. Injection is made on non interacting buckets and then the RF phase of one beam is rapidly shifted towards the collision phase. If the phase shift is performed with a fast ramp (~ 600 μsec) the bunch follows the RF phase. This procedure proved to work also in multibunch mode, shifting by two buckets 400 mA in 30 bunches without any beam loss.

During the November shifts, when the highest luminosity has been obtained, the positron beam has been injected two buckets apart from the colliding one and then brought in collision by means of the RF fast phase jump. This procedure has been also useful for luminosity tune-up, comparing beam sizes and lifetimes in and out of collision; moreover it makes gas background subtraction for the luminosity monitor easier and more accurate.

The single bunch luminosity measurements are shown in Fig. 6 as a function of the product of the electron and positron currents; the line represents the luminosity calculated with the design parameters for the same currents.

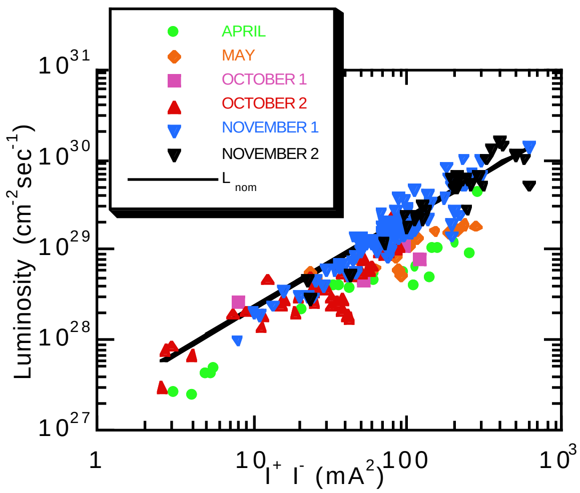

Figure 6: Luminosity versus the product of the e^+ and e^- currents.

After careful tuning of the collision parameters the measured luminosity is in good agreement with predictions, showing that a good beam overlap and a vertical beam size as low as the design value have been achieved. Due to the excellent result obtained for the minimum coupling, when the current in the interacting bunches is less than design, it is possible to improve the luminosity by squeezing the vertical beam size. The maximum single bunch luminosity (1.6 10^{30} cm^{-2} s^{-1}) has been obtained with I^+ = 19 mA, I^- = 21 mA (assuming equal tune shifts for the two beams this corresponds to ξ_y ~ .03). This is in good agreement with the predictions of beam-beam simulations with one IP on this working point. A tune scan around the working point has been performed, showing a qualitative behavior in agreement with the simulations [12].

Only two days were dedicated to multibunch luminosity measurements. Using the RF fast phase jump procedure a luminosity of the order of 10^{31} cm^{-2} s^{-1} has been obtained with 13+13 bunches.

A short time has also been dedicated to luminosity measurements with two interaction points. In this case there is a luminosity degradation (~ 40%) in agreement with simulations. Since the lattice is asymmetric with respect to the IP, the beam experiences different phase advances going from IP1 to IP2 and back. The beam-beam behavior depends on the machine tunes but also on the phase advance difference between the two IPs.

In the future, luminosity measurements with two IPs will be done on the optimum value of the phase advance difference predicted by the simulations.

5 KLOE IR

The KLOE detector consists of a cylindrical drift chamber surrounded by a lead-scintillating fiber electromagnetic calorimeter and immersed in the .6 T magnetic field of a 2.5m radius superconducting solenoid.

In order to leave the maximum free solid angle around the IP, SmC permanent magnets low-β quadrupoles, built by Aster Enterprises, have been adopted. They are confined inside a 9° cone around the IP and the solid angle available for the detector is 99%. There are three of these quadrupoles on each side of the IP, supported by the detector.

The high integrated field of the KLOE solenoid (2.4 Tm) is a strong perturbation for the low energy DAΦNE beam (510 MeV). It rotates the beam by ~ 45° in the transverse plane and it is the main source of machine coupling. A compensation scheme, the Rotating Frame Method [13], has been adopted to cancel this coupling. This scheme requires two compensating solenoid in a position symmetric to the main solenoid and a rotation of the low-β quadrupoles.

The three quadrupoles are carefully aligned and rigidly connected as shown in Fig. 7. After installation each triplet can be rigidly moved with 5 degrees of freedom (displacement and tilt in the x and y plane and rotation around the axis) by means of a cam system.

Figure 7: One of the KLOE low-β triplets on the alignment bench.

The beam pipe around the IP has to be as transparent as possible for the outcoming particles. In order to avoid K_S^0 regeneration, it is required that the K_S^0 decay before hitting the pipe. In order to have a large enough fiducial volume for the K_S^0, the cylindrical pipe around the IP is welded to a 500 μm thick sphere with a 10 cm radius. A 50 μm thick Be cylindrical shield is welded inside the sphere to provide RF continuity of the beam pipe.

The chamber, built by BrushWellman is made with a Be-Al alloy (AlBeMet, 68% Be, 32% Al). The chamber, before the insertion in the KLOE detector, is shown in Fig. 8.

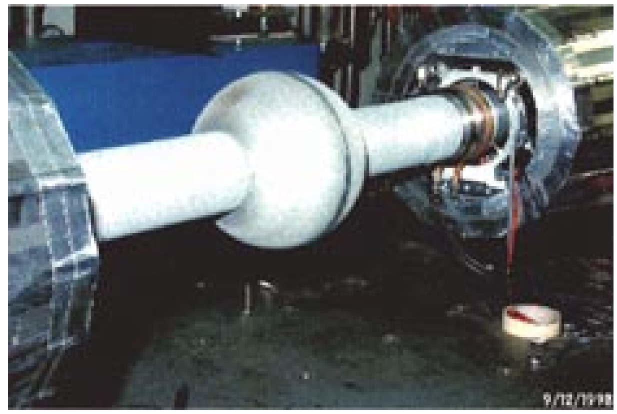

Figure 8: The KLOE vacuum chamber.

6 CONCLUSIONS

The performances of the DAΦNE Φ-Factory in single beam mode and the results of colliding beams have been described.

At present the shutdown for the installation of KLOE is concluded. The cool down of the KLOE solenoid is in progress, energization is expected in few days and operation with beam will resume right after.

7 ACKNOWLEDGMENTS

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8 REFERENCES

[1] The KLOE collaboration, KLOE a general purpose detector for DAΦNE, LNF-92/019(IR), April 1992.

[2] G. Vignola, and DAΦNE Project Team, DAΦNE, The Frascati F-factory, Proc. of PAC '93, Washington.

[3] J.T. Seeman, Commissioning Results of B-Factories, these Proceedings.

[4] K. Oide, The KEKB Commissioning Team, Commissioning of the KEKB B-Factory, these Proceedings.

[5] M.E. Biagini et al., Chromaticity Correction in DAΦNE, DAΦNE Technical Note BM-4, March 1999.

[6] R. Boni et. al., Operational Experience with the DAΦNE Radio-frequency Systems, these Proceedings.

[7] M. Serio et. al., Multibunch Instabilities and Cures, Proceedings of EPAC '96, Sitges, June '96.

[8] V. Chimenti et al., An UHV Vacuum System for DAΦNE, Proceedings of EPAC'96, Sitges, June '96

[9] C. Biscari et al., Single and Multibunch Beam Dynamics, these Proceedings.

[10] C. Vaccarezza, Ion Trapping Effects and Clearing in the DAΦNE Main Electron Ring, DAΦNE Note G-38, March '96.

[11] M. Zobov et al., Beam-Beam Interactions at the Working Point (5.15; 5.21), DAΦNE Technical Note G-51, March 1999.

[12] M.E. Biagini et. al., Optimization of Beam-beam Performance, these Proceedings.

[13] M. Bassetti et. al., The Design of the DAΦNE Interaction Region, Proc. of PAC '93, Washington.