

Overview of DAΦNE Beam Diagnostics

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Abstract

A general overview of the diagnostics designed for each part of the DAΦNE complex is given. The relevant beam measurements we need to provide are: emittance, energy and energy spread in the Linac, longitudinal and transverse dimensions, beam position and tunes in the Accumulator and in the double ring collider, where overlap of the two beams at the interaction point has to be optimized and controlled.

1. INTRODUCTION

DAΦNE is a high luminosity electron-positron double ring collider [1], designed to serve as a Φ-factory (1020 MeV c.m.), now under construction at the INFN Frascati National Laboratory; its commissioning is foreseen in fall 1996.

The average luminosity must be improved by two orders of magnitude with respect to existing facilities in the same energy range to fulfill the requirements of the experiments, based on high precision measurements of CP violation related parameters. To achieve this goal, up to 120 bunches will be stored in each ring, collisions taking place in two low-β interaction points (IP), where the experimental detectors (KLOE [2] and FINUDA [3]) are installed. The ultimate total beam current is ≈2x5 A (≈10¹³ particles in each ring).

A full energy injection system, consisting of a 550 (e⁺) / 800 (e⁻) MeV Linac and an intermediate booster (Accumulator), provides topping-up capability. Injection from scratch of both beams will take place in 5+10 minutes, while half this time is expected in the topping-up mode. Transfer Lines drive the beam from the Linac to the Accumulator, and, after damping, from the Accumulator to the Main Rings.

The primary role of beam diagnostics is to make performance optimization easy. The stringent requirements of a high average luminosity collider call for careful control of life-time, beam sizes, coupling, storage rings optics, closed

orbit distortion and stability of the interaction points. This can be accomplished only with extensive, redundant and general-purpose beam instrumentation.

Diagnostic devices will also be used for the initial commissioning of machine components and, in routine operation, to measure beam parameters at the boundaries between the injection chain elements, to check and optimize injection, extraction and transfer efficiency, and accumulation rate. This is very important in view of the fast filling rate required.

The table below summarizes the various types of beam instrumentation in the DAΦNE accelerator complex.

2. LINAC AND TRANSFER LINE INSTRUMENTATION

The DAΦNE Linac [4], is an electron/positron accelerator delivering 10 ns FWHM macropulses with nominal peak current of 40 mA (e⁺) and 150 mA (e⁻) at 50 pps. The diagnostic devices along the LINAC are sensitive to 1 mA.

The main parameters to be checked are emittance, central energy and energy spread of both beams.

Beam emittance is measured with the *three gradients method* [5]. The beam width is measured as a function of the gradient in a quadrupole of the Linac/Transfer Line matching section, by letting the beam strike a chrome-doped alumina flag downstream the quad. The emitted light, proportional to beam density, is collected by a CCD camera + frame grabber system and processed by the Main Control System to derive the horizontal and vertical emittances and optical functions at the quadrupole.

Energy measurements are performed by a spectrometer system [6], consisting of a small angle pulsed dipole magnet and a 60° DC dipole, with a secondary emission monitor (SEM) in its focus, made of 34 tungsten bars (90x2.7x2.7 mm³ each) grouped to form a 24 channels hodoscope. Resolution is δ(ΔE/E) = ±0.07% (e⁻), ±0.18% (e⁺).

DAΦNE Beam Instrumentation Summary Table

Type	Tr.Lines	Storage Rings		Interaction Points		
		Acc.	e+/e-	DAY-1	KLOE	FINUDA
Secondary Emission (SEM) Hodoscope	1					
Faraday Cup	1					
Fluorescent Flag	18	2	2/2			
Slit/Scraper	4		3/3			
Beam Stopper	3					
Toroidal Current Monitor	9	1				
Wall Current Monitor		1				
DC current Monitor			1/1			
Beam Position Monitor - Stripline	23	4+1		12	4	4
Transverse Kicker - Stripline		1	2/2			
Beam Position Monitor - Button		8	36/36	13	6	6
Synchrotron Radiation Monitor		2	1/1			
H/V Tune Monitor/Tr. Feedback		2	2/2			
Synchrotron Tune Monitor/Long. Feedback		1	1/1			
Luminosity Monitor				2	1	1

The low repetition rate and intensity of the beam in the Transfer Lines require high sensitivity of the beam position monitors (BPM). Stripline monitors are used in the Transfer Lines and in the Accumulator to perform the measurement of the relatively weak and long current pulses entering the Accumulator from the Linac and the low repetition rate (~1 pps), high peak-current pulses from the Accumulator into the Main Rings.

The BPMs consist of four 50Ω strip electrodes, placed on opposite sides of the vacuum chamber horizontally and vertically (at 45° in the Accumulator), short circuited at one end inside the vacuum chamber. The strip length is ~0.15 m, with a response broadly resonating at 500 MHz. The output voltage is a doublet of pulses of opposite polarity, reproducing the longitudinal beam density, spaced by 1 nsec. Each electrode is separately connected through a good quality, high-frequency cable to the measuring electronics, thus allowing true single-pass acquisition of the beam position.

The detector is self-triggered and can be armed by the Master Trigger Generator to gate any selected single bunch passage, or used in free-run mode for stored beam measurements in the Accumulator.

The position detection is based on the amplitude to phase modulation-demodulation technique, where the amplitude ratio of two opposing electrodes, carrying the position information, is converted by means of a quadrature hybrid junction into a phase difference between two equal-amplitude signals. The BPM pulses are fed to a broad-band (~20 MHz bandwidth) band-pass filter ringing at 368 MHz (5-th harmonic of the Accumulator RF frequency). The pseudo-sinusoidal signals are then amplified and clipped by fast comparators. The phase difference is measured by an exclusive-OR circuit, whose average (low-pass filtered) DC output is proportional to the beam position.

The main advantages of such a detector are that it is self-normalizing, thus allowing a wide intensity range, and that it can be used both in single-pass and stored beam modes.

The intensity of the bunches injected into and extracted from the Accumulator is monitored by high performance toroidal current monitors [7].

Flags of fluorescent material (Beryllium Oxide) can be inserted in the vacuum pipe to intercept the beam at an angle of 45°. These screens are used to monitor the beam size and position, during the Transfer Lines set up, but they are not compatible with injection at full rate. A couple of them is provided in the injection/extraction septa of the Accumulator and the Main Rings.

In the Transfer Lines, slits can be inserted towards the center of the pipe, to reduce the aperture. They are used at suitable points to cut any portion of the beam outside the acceptance limit in order to prevent distributed beam spills.

3. ACCUMULATOR AND MAIN RINGS

3.1 Beam position

The beam position monitors are the primary diagnostic system in the Accumulator and Main Rings. The BPM system is based on the stripline monitors mentioned above and on electrostatic button monitors. Special BPMs, buttons and directional striplines are envisaged in the Interaction Regions to monitor the separation and crossing of the beams.

Other stripline electrodes are used as longitudinal monitors and in the transverse feedback and tune monitor systems.

The highest precision and reproducibility are required in the Main Rings, where the monitors consist of four button electrodes mounted flush with the vacuum pipe. This design helps in maintaining coupling impedance and parasitic losses within acceptably low values in spite of the large number of units required. Three different designs, with different sensitivities and scale factors are present because of the varying cross-section of the vacuum chamber.

The BPM detector electronics is under development at LNF. It is a VXI board including an RF detector module and a digital section with two 12-bit ADCs and a DSP processor to compute the beam position. The last 2000 measurements are stored in a RAM memory on-board.

Two modes of operation are foreseen: single pass and stored beam. In both each button electrode is sequentially connected to the same RF detector by means of a PIN diode multiplexer. Therefore, four subsequent beam pulses are necessary to measure a single-pass position. A fast GaAs switch provides the capability to gate a particular bunch.

The voltage induced in each electrode is measured by heterodyning and detecting at an IF of 10.7 MHz the response of a tuned filter resonating at the RF frequency with a bandwidth of ~10 MHz. The IF signal goes to two separate circuits and is detected with synchronous demodulators. One part of the signal is low-pass filtered ($f_c \sim 20\text{KHz}$) prior to digitization for stored beam measurements; in the single pass mode, the detected IF signal is sampled and held in synchronism with the desired bunch passage, then digitized.

The beam position is computed from the cross-differences of the induced voltages normalized to the sum, to remove the current intensity dependence. The measurement rate is 1000/sec with the possibility of averaging over several subsequent passages of the stored beam, to improve resolution. Our goal is <2 mm*mA rms in the single passage and <0.01 mm in the stored beam mode (with 46 mA/bunch).

3.2 Beam current

In the Accumulator the total beam charge is monitored by an integrating toroidal current transformer [5]. It consists of a ceramic gap in the vacuum pipe, surrounded by a torus of high-frequency, high- μ ferrite. A conductive screen shielding the monitor prevents radiated noise. The monitor response is a ~70 ns long pulse, largely independent of the transverse beam size and position and of the bunch duration, which can vary from ~10 nsec (Linac beam) to ~0.1 nsec (stored beam).

The pulse peak amplitude is proportional to the bunch charge and is measured by means of a sampler module [SRS, model SR255]. The charge measurement in the Accumulator is used to stop injection when a preset limit is reached, in order to evenly fill the Main Rings.

A DCCT is used in the Main Rings to yield a precise absolute measurement of the total circulating current.

3.3 Tune monitor

In the storage rings the fractional part of the betatron tunes ΔQ_x , ΔQ_y is measured by transversely exciting the beam at RF frequency with a pair of stripline kickers and measuring the (coherent) resonant beam response of the beam in the plane of excitation with a transverse pick-up and the (coherent and incoherent) beam enlargement with the SR monitor.

The sweeping excitation is provided by the RF output of a network analyzer, boosted to ≤ 100 W with a power amplifier; the coherent beam response is detected with the network analyzer or with the synchrotron radiation monitor.

The betatron tune monitor is part of the transverse feedback system, whereby the detected signal of a coherent beam oscillation is amplified and fed back with the appropriate phase to the beam by stripline kickers, to damp any transverse instability of the beam. The synchrotron tune is measured by phase-modulating the RF cavity and observing the longitudinal beam response with a longitudinal monitor.

Residual oscillations can also be observed with the same instrumentation. Both longitudinal and transverse Beam Transfer Functions (BTF) are measurable with these monitors.

3.4 Synchrotron Radiation Monitors

Both the Accumulator and the Main Rings are equipped with two synchrotron radiation monitors, one for each beam, used to measure the transverse and longitudinal beam size (the rms bunch length at full current is 30 mm).

In each one of the Main Rings the source point is in one of the parallel face dipole magnets [1], where the dispersion vanishes and the beam horizontal and vertical rms sizes are 2.5 mm and 0.28 mm respectively.

Measurements are performed within the visible range (400-600 nm) because it is possible to use high quality commercial optical components and detectors, maintaining a diffraction limit which sets the vertical resolution to 0.08 mm (4% error in the vertical beam width measurement).

The light from the beams is driven through two channels onto a common optical bench placed outside the Main Rings hall, to reduce to a minimum the number of remotely controlled adjustments. The transverse profiles are measured by means of a CCD camera and an image analyzer [8], GPIB connected to the Main Control System. The beam emittance is calculated from the measured widths and knowledge of the optical functions. The length of any individual bunch is measured with a 25 GHz photodetector [9], directly connected to a sampling oscilloscope, and averaged over ~ 8000 turns.

The betatron tune distribution is also measured by exciting the beam and detecting the light through a slit with a photodiode [10]. This method is used to measure the incoherent contributions due to nonlinear forces in the rings such as ion trapping and beam-beam interaction.

3.5 Interaction point

An *absolute* luminosity measurement will be performed at both IPs by measuring the rate of single beam-beam bremsstrahlung [11]. A special vacuum chamber in the splitters [1] leaves enough free space for the γ rays to reach a thin window at the end of the magnets, within a cone of 3 mrad full aperture. Downstream the window a proportional counter, made of thin lead layers interleaved with scintillating fibers collects the photons and provides energy discrimination. Luminosity is calculated by dividing the measured counting rate by the theoretical integrated cross section. The photon flux, at the full DAΦNE design luminosity, is several MHz, so that the luminosity can be monitored continuously with high statistical precision. However, this measurement is not likely to be used as a feedback signal for the two beams overlap, since the luminosity is flat around its optimum.

A good probe for beam overlap optimization is instead the beam-beam deflection [12]: when the two beams cross at the IP with a vertical displacement between the two centers of mass, they are deflected towards each other. Figure 1 shows the deflection angle at the IP as a function of the distance between the two beams for the nominal DAΦNE parameters.

The beam-beam induced deflection propagates in the whole rings and can be measured at any BPM. In practice, it is convenient to leave a gap in one of the two beams in such a way that one can measure the difference in position between interacting and non interacting bunches. For the maximum foreseen deflection this difference ranges between ± 150 μm . By taking all BPMs in the ring one can improve the sensitivity of the measurement. At the design sensitivity it is possible to detect an overlap corresponding to a tune shift ten times smaller than the nominal one. This method can be exploited in a luminosity feedback system, since the beam deflection changes sign at the optimum overlap with a slope proportional to the linear beam-beam tune shift.

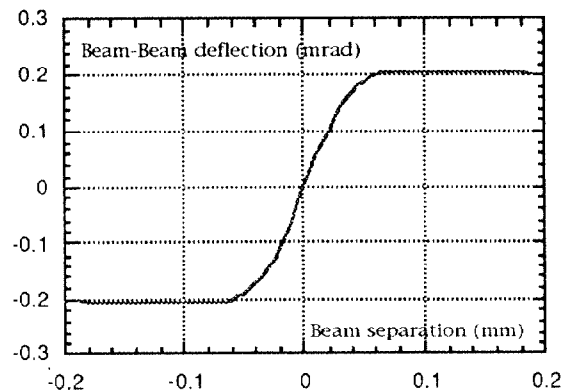


Figure 1. Beam-beam deflection angle.

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