DAΦNE Beam Instrumentation

A. Ghigo, C. Biscari, O. Coiro, G. Di Pirro, A. Drago, A. Gallo,
F. Marcellini, G. Mazzitelli, C. Milardi, F. Sannibale, M. Serio,
A. Stecchi, A. Stella, G. Vignola, M. Zobov

INFN Laboratori Nazionali di Frascati
00044 Frascati (Roma), Italy

Abstract. DAΦNE, the Frascati Φ-Factory, is now under commissioning. The accelerator complex is composed of a linac, an accumulator-damping ring, and two separate main rings, one for electrons and the other for positrons, with two interaction regions in which the experiments will be placed. In order to achieve the luminosity goal, high performance instrumentation and beam diagnostics have been installed. Some of the relevant beam measurements performed are: beam emittance, transverse and longitudinal dimensions, beam positions and tunes, overlap in the interaction points, and luminosity. An overview of the diagnostic instrumentation of the accelerator complex is given together with measurement examples and discussion of operational experiences.

INTRODUCTION

DAΦNE, the Frascati Φ-Factory (1) now under commissioning, is an electron-positron collider designed to produce very high luminosity at 1020 MeV center of mass. The main aim of the machine is to permit the observation of CP violation through the measurement of ε'/ε in the K^0 decay with the KLOE detector; a smaller detector for the spectroscopy of Lambda hypernuclei will be installed in the second DAΦNE interaction region.

In order to achieve the high luminosity needed for precision measurements (about two orders of magnitude larger than the highest luminosity achieved so far at this energy), the strategy adopted was to increase the collision frequency, operating in multibunch mode, maintaining the beam dimensions and the tune shift parameter at reasonable values. This operation mode implies storing very high current distributed in many bunches (up to 120). In order to minimize the parasitic crossings, two separate rings, one for electrons, the other for positrons, with two common interaction regions have been built. In the IR the two beams collide at a full horizontal angle of 25 mrad in the waist of a vertical low beta function (flat beam). Table 1 summarizes the DAΦNE main rings parameters.

TABLE 1. DAΦNE Main Rings Design Parameters

Energy (GeV)	0.51
Maximum luminosity [$cm^{-2}s^{-1}$]	5.3×10^{32}
Single bunch luminosity [$cm^{-2}s^{-1}$]	4.4×10^{30}
Trajectory length (each ring) [m]	97.69
Emittance, $\varepsilon_x/\varepsilon_y$ [mm·mrad]	1/0.01
Beta function, β_x/β_y [cm]	450/4.5
Transverse size σ_x/σ_y [mm]	2/0.02
Beam-beam tune shift, ξ_x/ξ_y	0.04/0.04
Crossing angle, θ_x [mrad]	± 12.5
Betatron tune, ν_x/ν_y	5.09/6.07
rf frequency, f_{rf} [MHz]	368.25
Number of bunches	120
Minimum bunch separation [cm]	81.4
Particles/bunch [10^{10}]	8.9
rf voltage [MV]	0.250
Bunch length σ_Z [cm]	3.0
Synchrotron radiation loss [keV/turn]	9.3
Damping time, τ_ε/τ_x [ms]	17.8/36.0

To achieve and maintain high average luminosity, a very efficient full energy injector, able to top up the beam current, was realized. The injector consists of a 550MeV (e^+)/800MeV (e^-) linac and an accumulator-damping ring.

The electron and positron beams travel from the linac to the accumulator and, after damping and extraction, to the main rings. A sizable fraction of the transfer lines are traversed in opposite directions by the linac and accumulator beams.

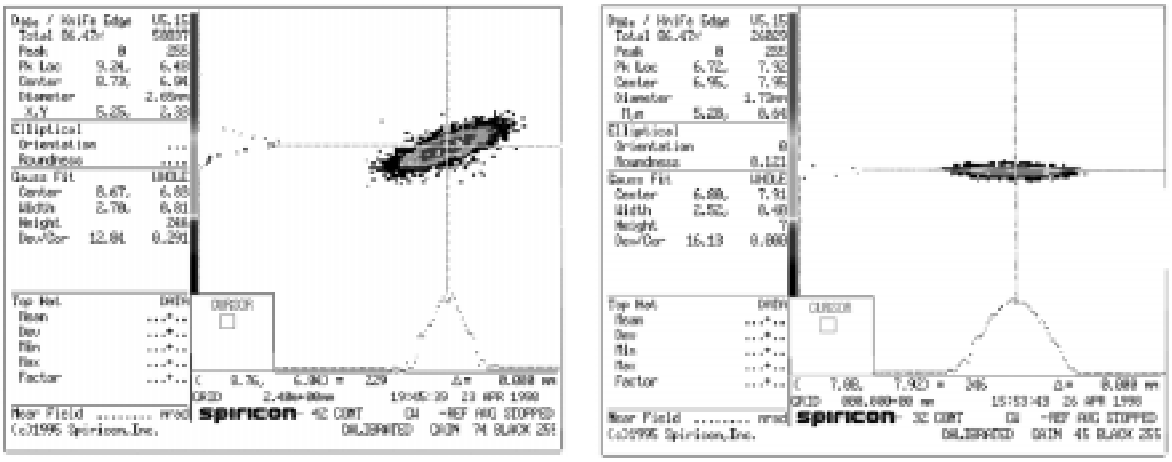
The main purpose of the DAΦNE beam instrumentation (2, 3) is to measure the beam parameters, to help to understand the machine behavior during the commissioning phase and to maintain the luminosity performances during operation (see Table 2).

TRANSVERSE DIMENSIONS

The Synchrotron Light Monitor (4) is used extensively in this first part of commissioning to measure the transverse beam sizes. The synchrotron radiation in the visible range produced from the beam passing through a dipole magnet is extracted from the vacuum chamber by a 45° tilted aluminum mirror through a fused-silica window. The beam image is focused with a lens system, after slit selection, on a commercial Philips VCM6250 CCD camera and processed by a frame grabber (Spiricon LBA-100A).

TABLE 2. DAΦNE Beam Instrumentation Summary Table

		Storage Rings		Interaction Regions		
Type	**Tr. Lines**	**Acc.**	**e^+/e^-**	**Day One**	**KLOE**	**FINUDA**
Secondary Emission (SEM) Hodoscope	1					
Faraday Cup	1					
Fluorescent Flag	18	2	1/1			
Slit/Scraper	4		3/3			
Toroidal Current Monitor	9	1				
Wall Current Monitor		1	1/1			
DC current Monitor		1	1/1			
Beam Position Monitor - Stripline	23	4		8		
Beam Position Monitor - Button		8	33/33	26	10	10
Beam Position Monitor - Special			3/3			
Transverse Kicker - Stripline pair		2	2/2			
Synchrotron Light Monitor		2	1/1			
Transverse Tune Monitor/Tr. Feedback		2	2/2			
Synchr. Tune Monitor/Long. Feedback		1	1/1			
Beam Loss Monitor		1	8/8	8	4	4
Luminosity Monitor				2	1	1



a) b)

FIGURE 1. Beam images from the synchrotron light monitor a) before, b) after correction of coupling.

The beam transverse emittances were directly evaluated from horizontal and vertical dimension measurements since the position of the point source is in a zone with vanishing value of the dispersion function.

The coupling and the rotation due to the beam's vertical displacement in the sextupoles, to the off axis passage in the interaction regions quadrupoles and to tilted quadrupoles was measured and corrected to the design value of 0.01, as shown in Figure 1. The beam-beam blow-up is easily observable.

BUNCH LENGTH

The bunch length in DAΦNE is measured by processing the beam signal from a broad band button electrode (5), connected with a low attenuation cable (Andrew FSJB-50B), 9 m long, to a sampling oscilloscope Tektronix 11801A, equipped with a sampling head SD-24 with a rise time of 17.5 psec and an equivalent bandwidth of 20 GHz. Stability of the waveform, even in the presence of longitudinal oscillations, has been achieved by using the signal from a stripline electrode as trigger. The waveform is sent via a GPIB interface to the control system for storage and off-line reconstruction after correcting for the (small) cable distortion and the pick-up transfer impedance.

Figure 2 shows the comparison between the bunch length vs. bunch current and the numerical simulations at two different rf voltages. From these bunch lengthening measurements it has been possible to evaluate the vacuum chamber impedance. We find $Z/n \approx 0.6\ \Omega$ (below the design value of 1Ω). the bunch length at the design bunch current is $\sigma_z < 3$ cm.

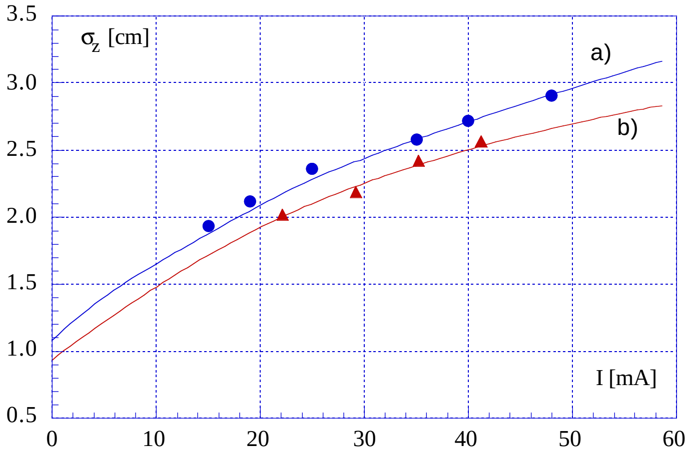


FIGURE 2. Bunch length vs bunch current in DAΦNE Main Ring; measurement results (dots) and numerical simulation (solid line) a) V_{rf} = 150 KV, b) V_{rf} = 200 KV.

TRAJECTORY AND CLOSED ORBIT

The Beam Position Monitor (BPM) is the most important diagnostic system in DAΦNE (6). Two different kinds of BPM are used in the accelerator complex: striplines, which have higher sensitivity and are used in single-pass measurements in the transfer lines, and during the accumulator and main ring injection; and button monitors, which are more numerous and permit accurate measurements on the stored beam with the advantage of little contribution to the machine impedance.

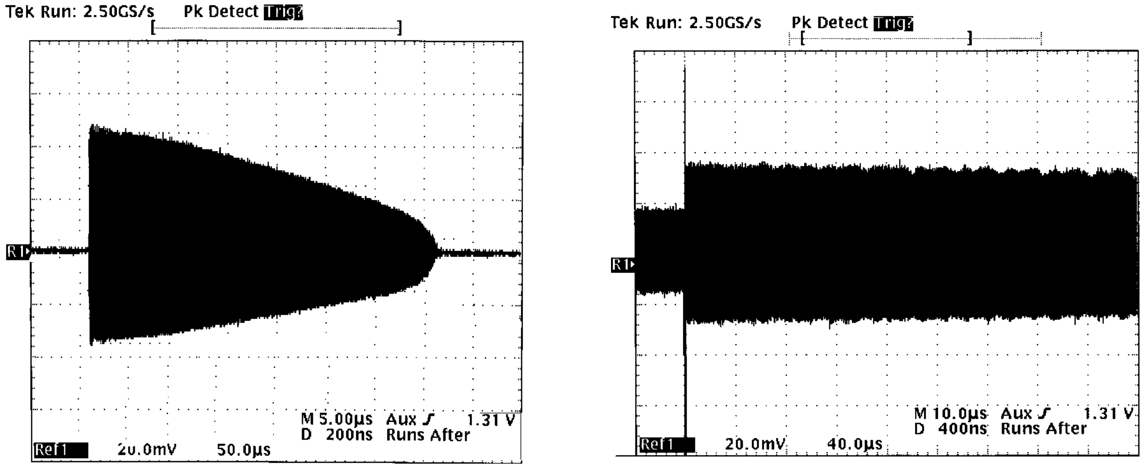
In order to measure the stationary closed orbit in the Main Rings, 35 button BPM have been installed in each ring and 26 in the interaction regions. Several different monitor configurations have been realized because of the differing vacuum chamber shape along the accelerator. For each monitor configuration, a calibration procedure with numerical and bench measurements has been accomplished, to obtain an accurate determination of the beam position.

The BPM detector was developed by Bergoz Beam Instrumentation System for DAΦNE: it consists of a superheterodyne receiver which converts the 240th harmonic (twice the rf frequency) of the beam induced signals down to an intermediate frequency if = 21.4 MHz before amplitude detection. At the circuit output, two voltages, which are software processed to obtain horizontal and vertical beam positions, are provided.

The acquisition system has been developed in the VME standard. The signals are multiplexed and measured with HP E1352A FET Multiplexers and HP E1326B Digital Multimeters controlled by dedicated CPUs.

The higher level of DAΦNE control system collects from these peripheral units the position data to be used in the high-level orbit reconstruction and analysis programs. The whole closed orbit of the main rings is acquired at a rate of 5 per second.

The main rings striplines have been very useful during the commissioning phase, indeed, the high sensitivity permits the injected beam to follow turn-by-turn and they are used to measure and correct the orbit in the first turns and help in the injection kicker setting. One optimization criterion was to achieve the number of turns permitted by the spiralization due the synchrotron radiation loss with the rf cavity off; a hardcopy of the striplines signal at injection, digitized by an oscilloscope (Tektronix 644B), is shown in Figure 3. The peak intensity decreases because the debunching effect broadens the pulse shape; when the rf cavity is switched on, the previously injected beam is stored in the ring.



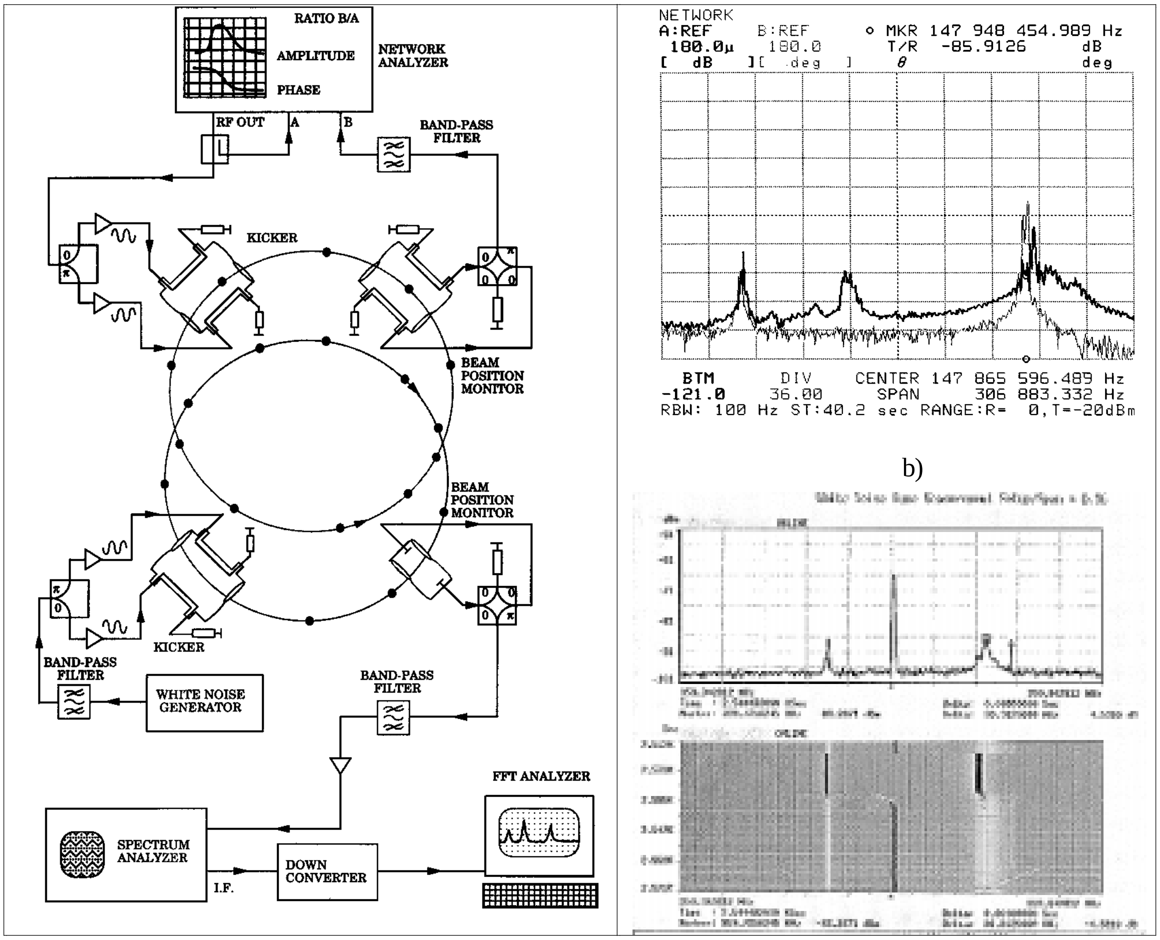
a) b)

FIGURE 3. a) The injected beam in the main ring detected by a stripline monitor with rf cavity off b) the stored beam with rf cavity on.

TUNE

The fractional parts of the horizontal and vertical betatron tunes are measured by exciting the beam at rf frequency with transverse stripline kickers and measuring the beam response in the excitation plane with a transverse pick-up.

Two different sets have been adopted to perform the tune measurements. In the first, the Network Analyzer HP 4195A (10 Hz–500 MHz) rf output, amplified up 100 W by class A amplifiers, provides the sweeping excitation. The horizontal and vertical coherent beam response is picked-up by stripline pairs. The signal is combined in hybrid junctions and detected with the Network Analyzer. In the second system the other beam is excited with white noise and the oscillation signal is extracted by broad-band button electrodes and sent to the spectrum analyzer (HP 70000 system) operating in detector (zero span) mode. The spectrum analyzer if output is down-converted with an HP 89411A module and processed by a real time FFT anlyzer, HP model 3587S.



a)

b)

c)

FIGURE 4. a) Tune measurement systems layout; b) swept measurement on the electron beam: lighter line out of collision, darker line during collision; c) white noise measurement on positron beam during collisions, below the spectrogram representation.

In Figure 4 a layout of the two measurement sets, together with the results of two simultaneous tune measurements in the two rings are shown. The horizontal and vertical signals are combined so that they appear in the same trace, horizontal at lower frequency and vertical at the higher. In the upper picture, the swept measurement performed on the electron beam shows clearly the tune split on the horizontal tune (the two peaks at lower frequency) during the beam collisions (darker line), in comparison with the tune measurement out of collision at low current (lighter line).

Below (Figure 4c), the measurement with the white noise performed on the positron beam is shown, using a spectrum representation, in which the tune split appears in the horizontal and vertical planes and the spectrogram, in which the time evolution (downwards) of the tune peaks shows two distinct phases: no interaction and collisions.

The two measurement systems have been largely used during this commissioning phase to tune the machine working point and to observe the beam-beam effects during the collisions.

BEAM CURRENT

The direct measurement of the beam current throughout the DAΦNE accelerator complex is crucial in order to maintain the best integrated luminosity.

In the injection system nine toroidal integrating current transformers by Bergoz have been placed to measure the transfer efficiency from the linac to the accumulator and from the accumulator to the main rings. In the accumulator a toroidal current monitor is used to measure the injected current in each linac pulse.

In the accumulator, the stored current is measured by a DC current monitor (made by Bergoz). A control program, based on this measurement, permits the injection to stop at a pre-set current value, ready for extraction into the main rings, in order to equalize the bunch currents.

Similar DC current monitors have been also installed in each main ring. The usual ceramic gap has been shunted by an array of parallel resistors in order to strongly reduce the resonant impedances of the monitor structure. The voltage developed across the resistive by-pass is picked up at four locations and used as a longitudinal monitor. The current value is continuously acquired and stored by the control system in order to perform lifetime measurements and to keep a log of the integrated current.

LUMINOSITY

The DAΦNE luminosity monitor (7) is based on the measurement of the photon production in the single bremsstrahlung electromagnetic reaction at the interaction point during the collisions. The luminosity value is given by the single bremsstrahlung photon-counting rate multiplied by the reaction cross section.

Because of the high counting rate of the single bremsstrahlung, the monitor has a fast response. This feature proved very useful during the machine tune-up.

Two monitors are placed at both ends of the two interaction regions, where the common vacuum chambers are split into separate rings by means of split-field magnets. At these positions, thin aluminum windows permit the photons to escape the chambers, hitting the detectors.

The detector is a proportional counter composed of a sandwich of lead-scintillating fiber with photomultiplier read-out. The integral of the signal coming from the detector is proportional to the incoming photon energy. The energy analysis and photon counting is provided by NIM-VME electronics.

The most important contribution to the measurement error is the photon production in gas bremsstrahlung reactions; this background is subtracted measuring the counting rate with the two beams kept separated.

The evaluations of the luminosity from the tune split measurement, described before, at the nominal machine parameter values and the direct measurements with the luminosity monitor are in good agreement.

ACKNOWLEDGMENTS

The authors wish to thank C. Marchetti and D. Pellegrini for highly professional and continuing technical support and P. Possanza for editing this paper.

REFERENCES

[1] Vignola, G., and the DAΦNE Project Team, “DAΦNE, the First Φ-factory,” *Proceedings of the Fifth European Particle Accelerator Conference,* Sitges, Spain, June 1996, p. 22.

[2] Serio, M., DAΦNE Team, “Operational experience with the DAΦNE beam diagnostic system,” *Proceedings of the 3RD European Workshop on Beam Diagnostics and Instrumentation for Particle Accelerators DIPAC97*, Frascati, Italy, October 1997, p. 138, LNF-97/048.

[3] Biagini, M. E., et al., “Overview of DAΦNE Beam Diagnostic,” *Proceedings of the Fifth European Particle Accelerator Conference London*, UK, July 1994, p. 1503.

[4] Ghigo, A., Sannibale F. and M. Serio, “Synchrotron Radiation Monitor for DAΦNE,” *AIP Conference Proceedings No. 333 of the Beam Instrumentation Workshop*, Vancouver, Canada, October 1994, p. 238.

[5] Marcellini, F., Serio M., A. Stella and Zobov M., “DAΦNE Broad-Band Button Electrodes,” *Proceedings of the 3RD European Workshop on Beam Diagnostics and Instrumentation for Particle Accelerators DIPAC97*, Frascati, Italy, October 1997, p. 106, LNF-97/048.

[6] “Beam Position Monitor System of DAΦNE,” these Proceedings.

[7] Di Pirro, G., et al., “The DAΦNE Luminosity Monitor,” these Proceedings.