Synchrotron Radiation Monitor For DAΦNE

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Abstract

The Synchrotron Radiation Monitor for both electrons and positron beams of DAΦNE, the LNF Φ-Factory, is described. The most important measurements the monitor needs to provide are: beam transverse dimensions, bunch length, beam transverse density, vertical and horizontal tunes. The source points are in two bending magnets, one of each rings, placed in a zero dispersion region. The collected radiation, in the visible range, is sent through two optical transfer lines to the same measurement bench placed in a dedicated laboratory outside the DAΦNE hall. The complete layout of the measurement bench and a detailed description of the detectors employed are presented.

INTRODUCTION

The DAΦNE accelerator complex (1), which is being built at LNF, consists of two storage rings and an injector for topping-up at 510 MeV. The stored positron and electrons beams circulate in opposite directions, intersecting in two interaction points. The first interaction point is dedicated to CP violation experiments, while the other one to hypernuclei experiments.

The synchrotron radiation monitors design for the DAΦNE storage rings is presented.

MEASUREMENT RESOLUTION OF A SYNCHROTRON RADIATION MONITOR

Horizontal Resolution and Source Length

In the hypothesis of gaussian beams, the horizontal resolution Δx can be calculated by the square root of the quadratic sum of three different errors, the *curvature error* Δx_C, the *diffraction limit error* Δx_D and the *depth of field error* Δx_{DF} (2).

Figure 1 shows the essential geometry of a light source in a constant magnetic field area (dipole magnet case). The curvature error is due to the finite size of the finite size and to the curvature of the particles trajectory within this length. It can be expressed by (3):

$$\Delta x_C = x - x_0 \tag{1}$$

with

$$x = \frac{l^2 R - a(R+x_0)^2 - \sqrt{l^2 (R+x_0)^2 \left(a^2 - 2aR - x_0^2 - 2Rx_0 + l^2\right)}}{(R+x_0)^2 - l^2} \tag{2}$$

where x_o is the half horizontal size of the beam, while the meaning of the others symbols may be derived from Fig.1. Equation 2 holds for small angles θ and ϕ.

The diffraction limit and the depth of field errors can be evaluated using (4,5):

$$\Delta x_D = \frac{\lambda}{2\,\upsilon} \qquad\qquad \Delta x_{DF} \approx \frac{\delta z}{2}\,\upsilon \tag{3}$$

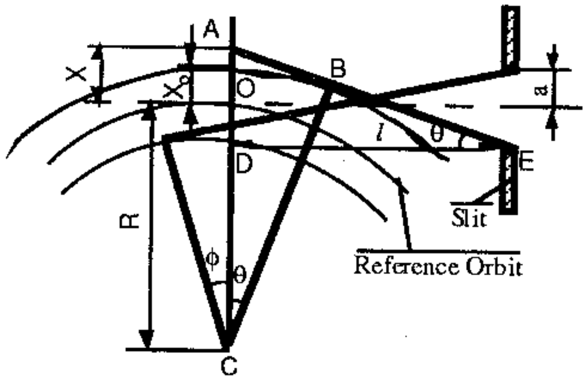

Figure 1. Typical Source Area Top View.

where λ is the wavelength measurement, $\upsilon = arctan\ (a\ /l\ ) \approx a\ /l$ is the half aperture angle of the system source+slit and δz is the longitudinal extent (length) of the source (3):

$$\delta z = (\ \phi + \theta\ )\ R \approx 2\theta R \tag{4}$$

where

$$\theta \approx tan\ \theta = (x + a\ )\ /\ l \tag{5}$$

Vertical Resolution

In the vertical case we still have the *diffraction limit error* Δy_D and the *depth of field error* Δy_{DF}, but no more the curvature error:

$$\Delta y_D = \lambda\ /\ (\ 2\vartheta\ ) \qquad\qquad \Delta y_{DF} = \delta z\ \vartheta\ /\ 2 \tag{6}$$

The quantity δz is given by Eq.4 where ϑ is the *total angular half-aperture of the photon beam* :

$$\vartheta\ =\ \left(\psi_{beam}^2 + \psi_{typ}^2\right)^{1/2} \tag{7}$$

with

$$\psi_{beam} = \left(\gamma_y\ \varepsilon_y\ \right)^{1/2} = \left(\frac{1 + \alpha_y^2}{\beta_y}\ \varepsilon_y\right)^{1/2} \qquad\qquad \psi_{typ} \approx \frac{1}{\gamma}\left(\frac{\lambda}{\lambda_c}\right)^{1/3} \tag{8}$$

ψ_{beam} is the electron beam divergence and ψ_{typ} is the typical opening angle of the emitted photon beam. The quantities β_y , α_y , γ_y are the vertical Twiss parameters at the source point, ε_y is the beam vertical emittance (zero vertical dispersion has been assumed), λ_c is the critical wavelength (4) and γ the energy in rest mass units. The expression for ψ_{typ} holds if $\lambda \gg \lambda_c$.

A routine, called Synch1_2, which applies the theory previously described, has been developed (3). Its output file, with the DAΦNE parameters, is shown in Fig.2.

DAΦNE MAIN RINGS SYNCHROTRON RADIATION MONITOR

Source Area

Table 1 shows the relevant DAΦNE parameters and Table 2 the optical characteristics at the selected source point.

Two sources, one per beam, are foreseen. They are 18.5 deg inside the parallel face dipole magnets in the shorter DAΦNE ring half section (see Fig.4).

The geometry , which is the same for both of them, is shown in Fig.3. A water cooled Al with 35 mm diameter, placed 0.8 m downstream the source point, vertically deflects the photon beam, through a vacuum window, onto a slit 1.065 m far away from the source point. A window on the photon beam axis, upstream the source point, allows the alignment of the optical line and the calibration of the transverse dimension measurement using a laser in place of the synchrotron ligth.

Table 1. DAΦNE General Parameters.

Energy	510 MeV
Ring Length	97.69 m
Dipole Bending Radius	1.4 m
Natural Emittance	10^{-6} m rad
Natural Relative Energy Spread	3.97×10^{-4}
Particles/Bunch	9×10^{10}
Max Number of Bunches	120
r.ms. Natural Bunch Length	8.1×10^{-3} m
r.m.s. Anomalous Bunch Length	3.0×10^{-2} m

Table 2. Characteristics at Source Point (1% Coupling)

β_x	6.46 m
β_y	7.87 m
α_x	0.468
α_y	0.165
Dispersion	~ 0 m
Horizontal Dimension (rms)	2.5×10^{-3} m
Vertical Dimension (rms)	2.8×10^{-4} m

For what concerns resolution, an important choice is the working wavelength. We decided to work within the visible range (~ 400 ÷ 600 nm) in order to use the wide variety of commercial optical components and to have the optical channels in air. The vertical resolution, which is the more critical in DAΦNE, is still good enough with such a choice. The Synch1_2 output file in Fig. 2 shows that, with a maximum wavelength of 600 nm and a slit half aperture of 1 mm, the relative error on the vertical measurement is less than 3 %. In the same file all the others meaningful quantities of the DAΦNE monitors are given.

Optical Channel and Instrumentation Hall

Figure 4 shows the optical channels top and side views. The Synchrotron Radiation Monitor Instrumentation Hall is outside the concrete wall of the main rings hall, in a room at an higher level with respect to the machine plane. This feature makes the hall a radiation safe area, where it is possible to stay when the beams are stored. Each of the two optical channel starts from a beam expander downstream the slit, (see Fig.3), this is an achromatic system of lenses with focus in the source point. A set of matching mirrors transports the light from the source area to the optical table in the Instrumentation Hall. The first of these mirrors is visible in Fig.3, the other two will be placed in the Instrumentation Hall. The optical line, which is ~ 20 m long, has to be surrounded by an opaque black pipe to prevent distortions due to thermal effects in air and to avoid noise caused by environmental stray lights.

Synch 1.2 (400 - 600 nm) ; PARALLEL FACE DIPOLE ; 0.01 coupling

LINE	
l0 (m)	: 0.5653
d (m)	: 0.2656
Slit Half Aperture (m)	: 0.1000E-02
RING PARAMETERS:	
Energy (MeV)	: 510.0
Relative Energy Spread	: 0.3970E-03
Natural Emittance (m rad)	: 0.1000E-05
Coupling	: 0.1000E-01
Bending Radius (m)	: 1.400
Revolution Frequency (Hz)	: 0.3068E+07
Number of Bunches	: 120.0
Charge/Bunch (C)	: 0.1442E-07
Bunch Length (sigma) (m)	: 0.3000E-01
BEAM OPTICAL FUNCTIONS @ SOURCE:	
Beta x (horizontal) (m)	: 6.457
Alpha x (horizontal)	: 0.4679
Eta x (horizontal) (m)	: 0.0000E+00
Deta x (horizontal)	: 0.0000E+00
Beta y (vertical) (m)	: 7.872
Alpha y (vertical)	: 0.1648
INTEGRATION PARAMETERS:	
Lambda Start (nm)	: 400.1
Lambda Stop (nm)	: 600.0
Lambda Number Int. Steps	: 2000
Ksi Number Int. Steps	: 50
CALCULATION RESULTS:	
Total Average Current	: 5.309 (A)
Cut Off Lambda	: 5.881 (nm)
Source Magnet Edge Angle	: 0.3230 (rad)
l: Source-Slit Distance	: 1.065 (m)
Single e- Emitted Power	: 0.3030E-11 (watt)
Normal/Parallel Power Ratio	: 0.3142
Single Bunch Radiated Power	: 0.2727 (watt)
Total Radiated Power	: 32.73 (watt)
Source Length	: 0.9299E-02 (m)
Single Bunch Accepted Power	: 0.2883E-03 (watt)
Total Accepted Power	: 0.3460E-01 (watt)
One Turn One Bunch Ac. Ener.	: 0.9397E-10 (joule)
Single Bunch Peak Power	: 0.3746 (watt)
# of Accepted Photons/bunch	: 0.2365E+09
Photon Average Lambda	: 500.0 (nm)
Electron Beam x dim (sigma) (m)	: 0.2529E-02
x Measurement Error (sigma) (m)	: 0.3196E-03
x Measurement Relative Error	: 0.7955E-02
x Curvature Error (m)	: 0.7735E-05
x Depth of Field Error (m)	: 0.4367E-05
REMARK: In the following part the largest lambda has been used	
x Diffraction Limit Error (m)	: 0.3194E-03
Electron Beam y dim (sigma) (m)	: 0.2792E-03
y Measurement Error (sigma) (m)	: 0.6773E-04
y Measurement Relative Error	: 0.2901E-01
Diffract./Depth of Field Error Ratio	: 2.949
Photon Beam Divergence (rad)	: 0.4677E-02

Figure 2. Synch 1_2 Output File: DAΦNE Light Source.

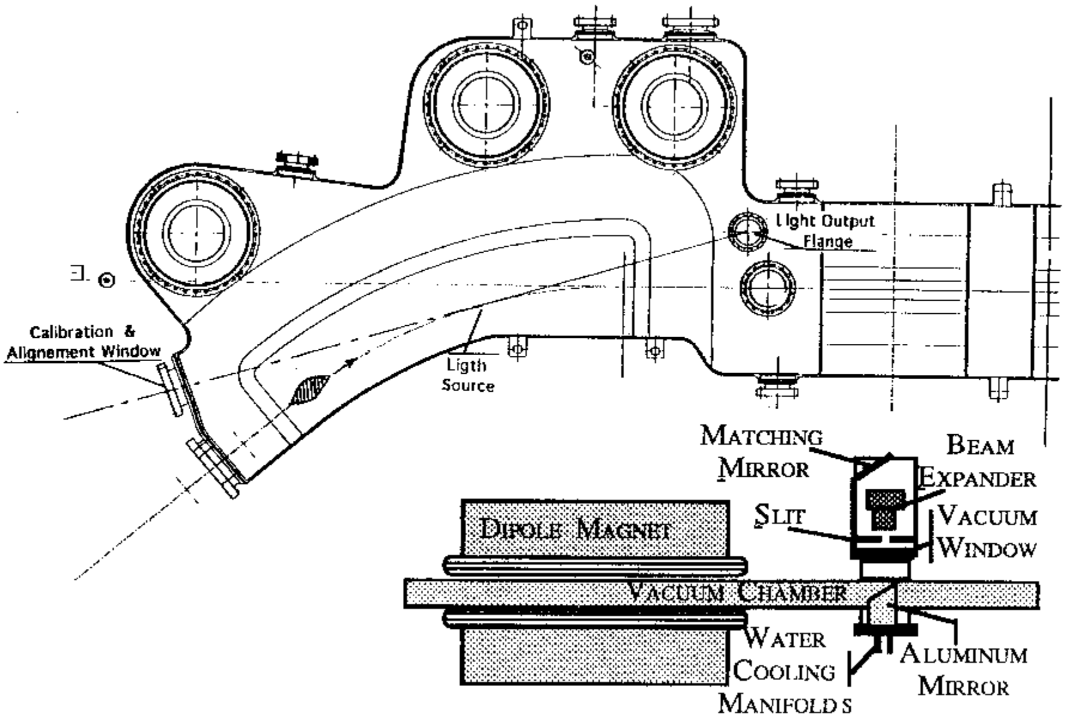

Figure 3. Source Area Layout.

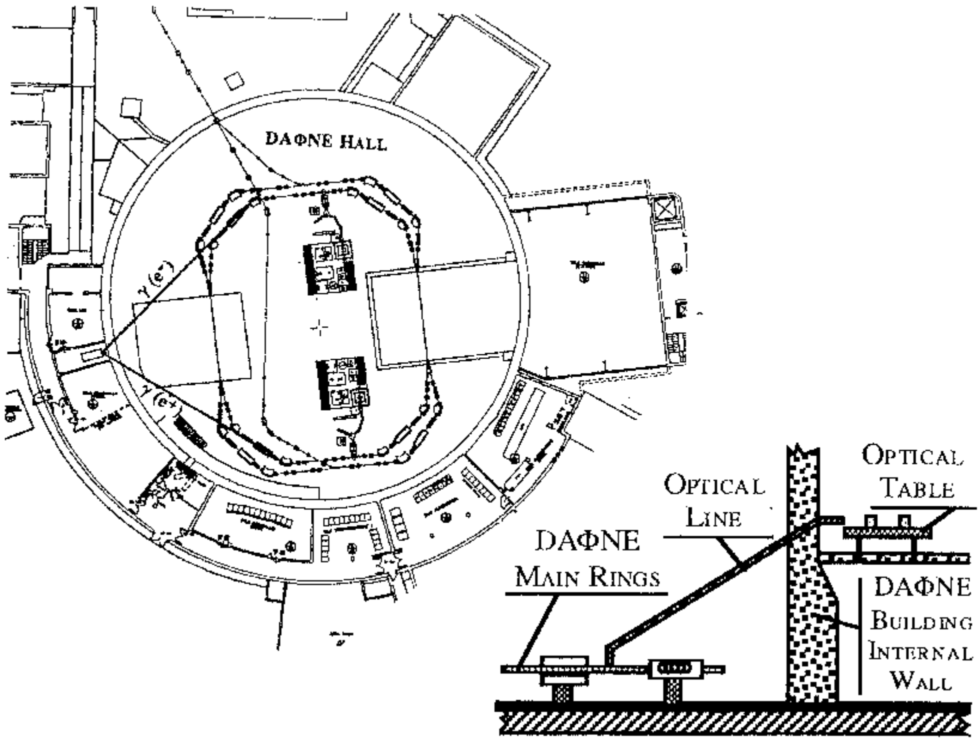

Figure 4. Optical Channels Lay-out. Side and Top View.

MEASUREMENTS

Figure 5 shows the optical table layout. By using splitters and two independent lines, all the measurements will be independently and simultaneously available for both beams.

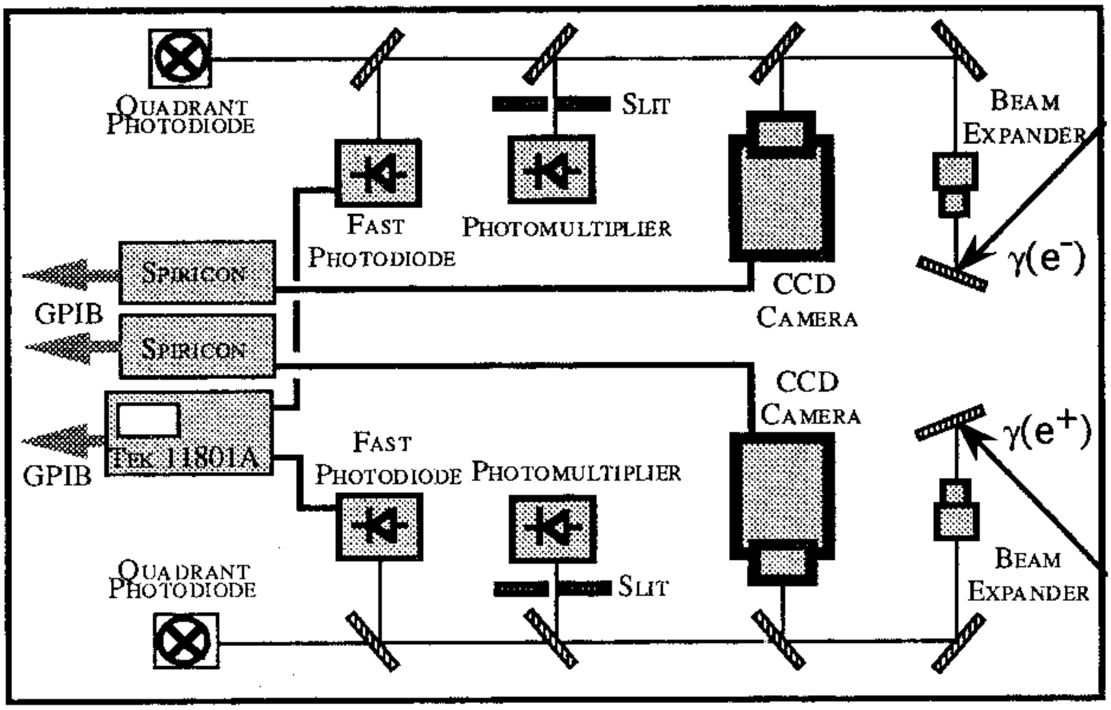

Figure 5. Optical Table Lay-out.

Transverse Dimensions

The measurement system is composed by a CCD camera and an image analyzer. The camera, a PULNIX TM 6 has a 752 × 582 video matrix with a pixel dimension of 8.6 × 8.3 μm^2. A zoom objective in front of the camera permits to vary the overall magnification (optimum magnification ~ 0.5).

The image analyzer is the SPIRICON LBA 100A which is able to capture, display and analyze the camera image with repetition rates up to 15 Hz.

It is worth to mention that, because of the zero dispersion, the beam emittances can be measured (this measurement implies the knowledge of the ring optical functions at the source point).

Bunch Length

The bunch length is measured by a fast detector+large bandwidth oscilloscope system. The New Focus 143-4 photodiode ensures DC-25 GHz bandwidth and 17 psec rise time. The coupling between radiation and the photodetector active area (25 μm diameter) is provided by a single mode fiber optic with a GRIN lens collimator. The detector output is directly connected to the digital oscilloscope TEKTRONIX 11801A (50 GHz bandwidth and 200 KHz sampling rate).

Assuming gaussian beams with σ=100 psec, the estimated measurement error is ~ 0.3%. The oscilloscope sampling rate and record length imply that about 8000 turns are needed to sample the whole beam pulse.

The system sensitivity makes the measurement possible with stored currents as low as 2 mA. This feature should permit the study of the turbulent bunch lengthening in DAΦNE.

Beam Transverse Density and Tunes

Figure 5 also shows a slit+photomultiplier system for the beam transverse density measurement, whose set-up is shown in Figure 6. The beam is transversely excited by a sweeping oscillator+kicker system. The slit, horizontal for the vertical measurement and viceversa, selects the photons around the peak of the light distribution allowing a measurement of the density around this position. The effect of incoherent oscillations on the beam is to decrease this density (7). In this way the existence of non-linear phenomena (read beam-beam interaction, lattice non-linearities, ion trapping, etc) leading to incoherent oscillations, can be detected and measured (8).

Replacing the slit-photomultiplier assembly with a quadrant photodiode, the previous set-up can be used to simultaneously measure the horizontal and vertical machine tunes. The quadrant photodiode, which is sensitive to the photon beam center of mass position, is also used for the alignment of the line on the optical table (see figure 5).

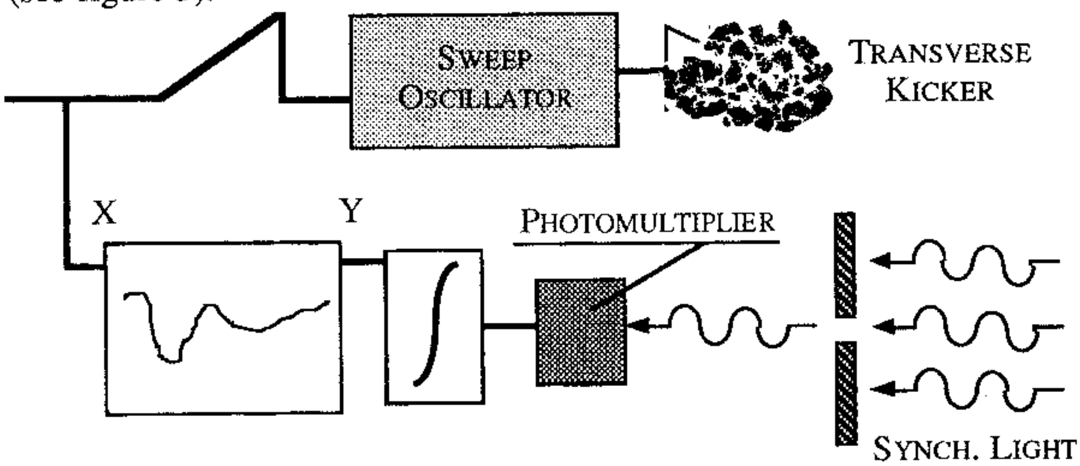

Figure 6. Density Measurement Set-up.

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