OPTICAL BEAM DIAGNOSTICS FOR THE LNLS SYNCHROTRON LIGHT SOURCE*

R.H.A. Farias, L.C. Jahnel, Liu Lin and P.F. Tavares

Laboratório Nacional de Luz Síncrotron - Caixa Postal 6192 - 13083-970 Campinas SP - Brazil

Abstract

An optical characterization bench for the electron beam in the LNLS storage ring using visible synchrotron radiation is described. Preliminary measurements at injection energy (120 MeV) and at operation energy (1.37 GeV) are presented. The system includes a high frame rate (up to 400 Hz) CCD camera and a fast photodiode (7 ps FWHM) for longitudinal measurements.

1 INTRODUCTION

The Brazilian Synchrotron Light Source (LNLS) is based on a 1.37 GeV electron storage ring with a 120 MeV injector Linac. Commissioning of the storage ring [1] at low energy started on May 1996 and presently, an year later, we can store 120 mA at 120 MeV and ramp more than 75 mA to 1.37 GeV. The availability of a real time image of the beam in the control room proved to be very useful both during commissioning and normal operation of the ring. In addition, measurements of the stored electron beam transverse and longitudinal profiles yield information about the beam emittance and bunch length. Both quantities are affected to first order by lattice functions, and to higher order by current dependent collective effects. The ability to measure these quantities accurately is, thus, a very important tool to asses both the lattice focusing properties and the effects of collective phenomena, such as ion trapping and beam instabilities.

Several means of producing an image are described in the literature, including pinholes to collimate X-rays [2,3] or lenses to focus the visible part of the spectrum [4,5,6]. The LNLS UVX storage ring operating at injection energy (120 MeV) does not produce detectable X-ray intensities and the present beam characterization bench is set for visible light observation. The achieved resolution of about 70 µm, limited by diffraction due to the natural radiation opening angle, is well suited for the injection energy, where the large beam size is dominated by intra-beam scattering effects. At high energy, however, we expect difficulties to measure the small vertical beam size as well as the vertical emittance, since the latter is calculated from the beam size and the knowledge of the beta functions. In our case, the vertical emittance resolution is about 0.26 nm.rad.

2 THE OPTICAL BEAM DIAGNOSTICS BEAMLINE

The UVX optical electron beam characterization bench uses visible radiation produced at dipole ADI01 at a 4 degree low dispersion port. A schematic layout is shown in Figure 1. The high energy synchrotron radiation power is absorbed by a sapphire filter attached to a water cooled copper radiation mask. The visible light is then extracted into air through a sapphire vacuum window and guided by two mirrors (86 and 90 degree deflection) to the experimental hall. Two borosilicate plano-convex lenses form an image of the electron beam on the surface of a CCD sensor. A variable aperture is placed in front of the radiation exit port to define the horizontal-vertical optical acceptance of the line and consequently control diffraction and geometrical curvature effects. The visible radiation is monochromatized by a 10 nm bandpass interference filter to reduce chromatic aberrations. A set of two polarization filters is used to polarize and control beam intensity on the CCD sensor. The filters are placed near the detector to minimize potential errors due to their surface irregularities. The first mirror, located behind the shielding wall, is mounted on a platform which allows remote angular adjustments about the horizontal and vertical axes. The polarization filters can be commanded from the control room in order to adjust the beam intensity level at the CCD.

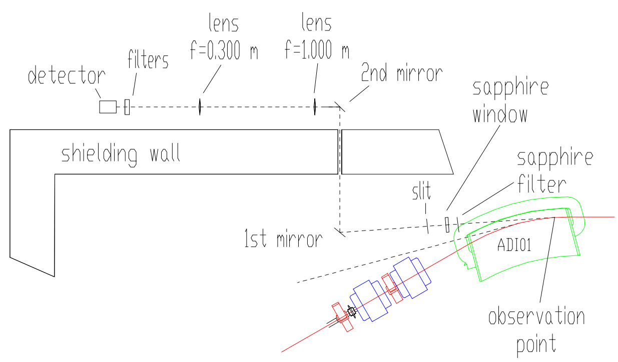

Figure 1: The LNLS UVX optical characterization bench.

The main line CCD camera (EEVCAM17-46), with 512x512 square pixels 15x15 µm in size, will be able to operate up to 400 Hz frame rate, allowing measurements of phenomena which occur in time scales as short as 10 ms such as beam damping at high energy. Meantime,

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while the EEV camera is not operational, we have installed a common CCD video camera to perform the preliminary measurements.

A broadband dielectric beamsplitter divides a fraction of the light to a second branch of the characterization bench where a calibrated photodiode is used to monitor beam current and beam current decay variations for lifetime measurement purposes.

A second beamsplitter separates a fraction of light from the second branch to a third one. Here an ultrafast commercial photodetector (Picometrix PX-D7) with 7 ps FWHM response time will be used to measure single shot bunch length.

2.1 Optical resolution

The synchrotron light accepted by the aperture of the optical bench comes from an arc along the electron orbit. The longer the arc the greater the apparent transverse and longitudinal sizes of the source. If the aperture is made smaller, the limit to resolution from diffraction becomes worst. The optimum aperture is thus a compromise between these effects. In the case of visible synchrotron radiation, the natural diffraction limit imposed by the angular width of the emitted radiation is usually dominant. The optimum aperture should, thus, be approximately equal to the natural radiation opening angle as the diffraction limit will not improve by increasing the aperture but the apparent source size will. For UVX running at 1.37 GeV, the width of the radiation cone for 550 nm is ±3.6 mrad. The calculated resolution of 70 µm is dominated by diffraction, as expected. A bandpass filter with 10 nm FWHM is used to eliminate the long wavelength light which would degrade the diffraction limited resolution. The calculated parameters for UVX standard operation mode are given in Table I. The large value for the natural emittance at 120 MeV is due to intra-beam scattering effects. The transverse spatial resolution of 70 µm corresponds to emittance resolutions of 0.26 nm.rad and 3.5 nm.rad for the vertical and horizontal planes respectively. The principal limitations are expected in the vertical plane at 1.37 GeV whenever coupling coefficients are less than approximately 0.3%.

Table I: Parameters at the UVX beam diagnostics line.

Injection energy	120	MeV
Operation energy	1.37	GeV
Horizontal beta	1.4	m
Vertical beta	18.9	m
Natural emittance		
at 1.37 GeV	99.8	nm.rad
at 120 MeV	≈ 900	nm.rad

3 EXPERIMENTAL RESULTS

3.1 Emittance Measurements

A conventional CCD video camera has been installed at the main beam line to perform static beam emittance measurements. The beam image is captured using a frame grabber and the beam sizes are calculated by fitting gaussian functions to the horizontal and vertical beam profiles.

Beam transverse profiles have been measured as a function of current for the injection and operation energies. Figure 2 shows the beam image seen at the monitor in the control room.

Figure 2: Beam images from dipole ADI01 4 degree exit port corresponding to E=120 MeV (left) and E=1.37 GeV (right).

Figure 3 shows the fitted gaussian curves for an horizontal and a vertical beam profile. Figures 4a and 4b show the beam sizes (one standard deviation) measured as a function of beam current for 1.37 GeV and 120 MeV. Figures 5a and 5b show the natural emittance and coupling factor for both energies. The vertical emittance and coupling at 1.37 GeV are lower than 0.3 nm.rad and 0.3 %, respectively, and are limited by the measurement resolution. The measured natural emittance is in good agreement with the theoretical value at 1.37 GeV indicating that the linear optics of the machine is close to the calculated one. The slight increase in vertical beam size for low currents is probably due to a slow drift in the electron beam orbit which defocus the image on the CCD sensor, since the automatic orbit correction system was not activated during the measurements. At 120 MeV, the measured emittance at low currents is close to the value predicted from intra-beam scattering calculations. For higher currents we have measured an enormous increase in beam emittance. This is probably due to the fact that high current measurements need to be performed right after injection, when the beam is not yet damped (the damping time is 10 s).

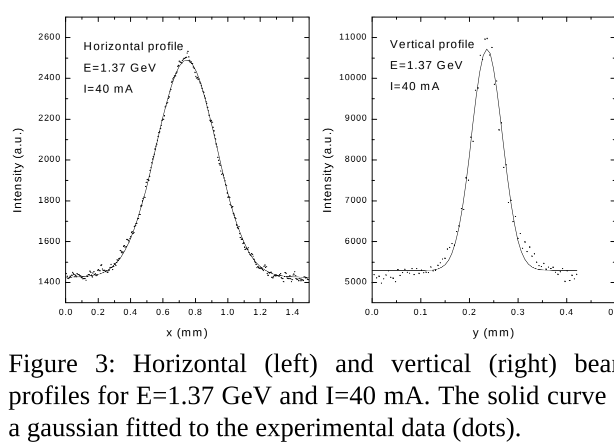

Figure 3: Horizontal (left) and vertical (right) beam profiles for E=1.37 GeV and I=40 mA. The solid curve is a gaussian fitted to the experimental data (dots).

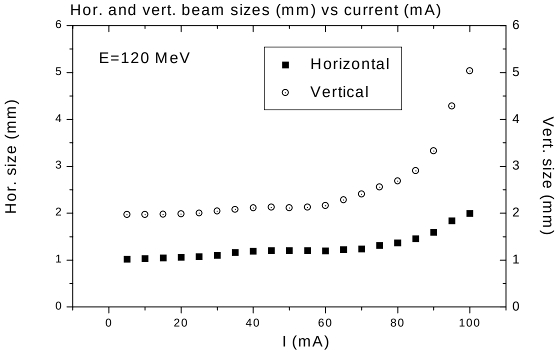

Figure 4a: Horizontal and vertical r.m.s. beam size as a function of beam current for E=120 MeV.

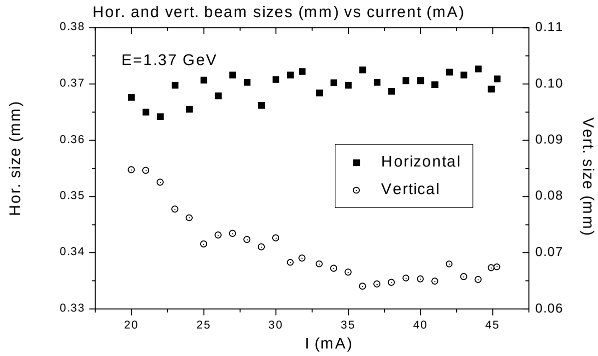

Figure 4b: Horizontal and vertical r.m.s. beam size as a function of beam current for E=1.37 GeV.

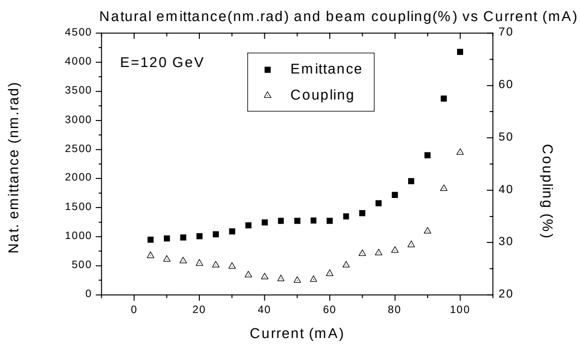

Figure 5a: Natural emittance and coupling as a function of beam current for E=120 MeV.

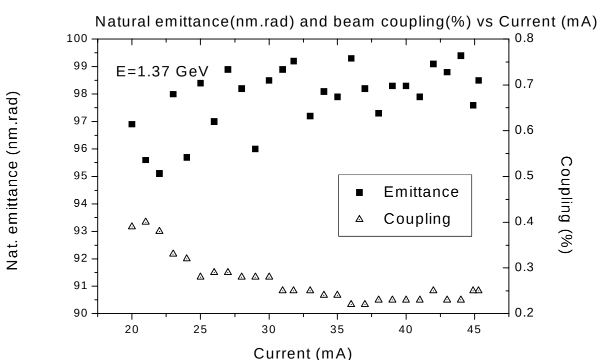

Figure 5b: Natural emittance and coupling as a function of beam current for E=1.37 GeV.

3.2 Observation of ion trapping

Effects of ion trapping have been observed in the storage ring at the synchrotron light monitor in the control room. Ion effects have been detected as a vertical expansion of the beam when a kicker is excited. The vertical enlargement of the beam persists even when the excitation is turned off. The beam can be made flat again by applying appropriate voltages to the clearing electrodes. Figure 6 shows two images of the beam at 900 MeV corresponding to the cases before and after a kicker excitation.

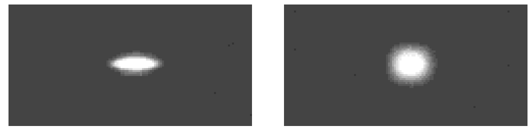

Figure 6: Images showing a vertical enlargement of the beam after excitation with a kicker.

4 CONCLUSIONS

The LNLS optical beam diagnostic line using visible synchrotron radiation has been described. Although not fully operational, some transverse beam size and emittance measurements have been carried out. The installation of the fast photodetector and the high frame rate CCD camera will allow measurements in the longitudinal plane as well as analysis of damping in the transverse plane.

The emittance measurements show that the system resolution is adequate for analysis at injection energy but is limited for measurements in the vertical plane at nominal operation energy. The results show, however, a vertical emittance lower than 0.3 nm.rad at 1.37 GeV, or coupling coefficient lower than 0.3 %, indicating a careful alignment of the magnets.

Some improvements in the beamline are in progress including a system for remote focusing of the beam image and modification of the beam extraction scheme. The new scheme will use a refrigerated mirror in the vacuum chamber in place of the sapphire filter, which has become darkened by radiation.

The limitation to resolution comes from inherent diffraction effects, so resolution improvement imply decreasing the wavelength towards X-rays. The idea of a new line using X-ray imaging is also being considered.

REFERENCES

[1] A.R.D.Rodrigues et al, ‘Commissioning and Operation of the Brazilian Synchrotron Light Source’, these proceedings.
[2] C.Bovet and E.Rosa, Workshop on Advanced Beam Instrumentation, KEK, 1991.
[3] E.Tarazona and P.Elleaume, Rev Sci.Inst. 66, Feb 95.
[4] A.Hofmann, IEEE Tran.Nuc.Sci., NS-28,No.3, 1981.
[5] Åke Andersson, Juri Tagger, Nuclear Instruments and Methods, A 364 (1995) 4-12.
[6] R.J.Nawrocky, J.Galayda, L.H.Yu and D.M.Shu, IEEE Trans. Nuc. Sci., NS-32, No. 5, 1985.