STELLAR INTERFEROMETRY VS DIRECT IMAGING FOR SYNCHROTRON RADIATION PROFILE MEASUREMENTS

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Abstract

At Elettra light source we are investigating different techniques for improving the resolution of the transverse beam profile measurements. Since 1994, a transverse beam profile monitor based on direct imaging is in operation. As well known, in this scheme, the spatial resolution is limited by the diffraction and the depth of field effects. The vertical beam size in the 3rd generation synchrotron light sources being very small, in the range of tens of microns, the resolution of the direct imaging may not be enough for its accurate measurement. A different technique, based on stellar interferometer scheme, has been used by other groups for beam size measurement and reported to improve sufficiently the resolution of the measurement. In this paper, we present preliminary results of measurements of both the horizontal and vertical beam sizes at different beam conditions that confirm better performance of the interferometric technique. Some of our results indicate that diffraction effects and beam instabilities may influence the vertical beam size measurement.

1 INTRODUCTION

The stellar interferometer (SI) technique allows the determination of the size of a spatially incoherent source by measuring the spatial distribution of the degree of coherence after propagation. The method, first applied by Michelson for measuring angular dimensions of stars, is based on the Van Cittert–Zernike theorem, which states that there is a Fourier transform relation between the intensity distribution of an incoherent object and the complex degree of coherence measured in the far field. A complete description of the underlying theory and derivation of the theorem can be found e.g. in [1].

The application of SI to synchrotron radiation beam profiling was first proposed and demonstrated by Mitsuhashi (see [2] and refs there). The main motivation of applying this method instead of direct imaging is that it should allow better resolution and permit to measure beam size down to several microns [2]. In addition, as suggested in [3], by using cylindrical optics it is possible to perform the measurement in one plane (e.g. horizontal) by using only a selected part of the beam and thus avoiding strongly distorted parts of the image. In [2], there is a lot of useful information and discussions concerning the experimental set-up and some of the error sources. However, there are still several open questions, e.g. what is the influence of diffraction at intermediate slits and apertures on the measurement, factors limiting resolutions etc.

In this work we present preliminary results of the application of SI for beam size measurement at Elettra. We found that the method provides better resolution than the conventional imaging. In addition, it allows the selection of less deformed regions on the first mirror and thus considerably reduces the error in high-energy regimes. However, there are indications that diffraction from slits introduces a modulation of the degree of coherence and may limit the resolution.

If it is assumed that synchrotron light is emitted by a thin layer of independent emitters with a Gaussian spatial distribution σ_{PH}, and the Van Cittert-Zernike theorem is applied, the complex degree of coherence of the light field at a distance L from the source can be shown to be a Gaussian function of the distance between the sampling points having a width of (see e.g.[2]):

$$\sigma_j = \frac{\lambda L}{2\pi\sigma_b} \quad (1)$$

where λ is the central wavelength. It is worth noting here, that only the amplitude of the complex degree of coherence gives useful information in this measurement and the phase (indicated by the exact transversal position of the fringes) will not be considered.

The spatial distribution of the degree of coherence, denoted below by j, can be obtained by using a two slit (or pinhole) interferometer. The procedure involves a measurement of the visibility V of the interference fringes

$$V = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} \quad (2)$$

at different distances between the pinholes, and then the calculation of the degree of coherence at each distance using the relation:

$$j(d) = 2\frac{\sqrt{I_1 I_2}}{I_1 + I_2} V(d) \quad (3)$$

Here we denote by I_1 and I_2 the intensities of the beams coming from each pinhole.

2 MEASUREMENT SET UP

The synchrotron light port used for the interferometer experiment is the same used for the Synchrotron Radiation Profile Monitor (SRPM), installed at ELETTRA in 1994 [4]. The radiation from a bending magnet is extracted to an optical laboratory located in the

Experimental Area. The source point is a low dispersion point on the electron orbit in order to minimize the energy effects on the measured beam size.

The SRPM optical system [4] includes an in-vacuum extraction mirror followed by a quartz UV grade optical window. A second mirror deflects the light outbound to the optical laboratory. A long focal length lens L1 (f=2070mm) focuses the light onto the CCD camera used for the SRPM operation.

As the in-vacuum mirror is the most critical part of the system, due to the deformation induced by the X-rays (up to 100W on the mirror surface), a visual inspection has been carried out during the last shutdown to check the vacuum mirror surface. No permanent macroscopic damage has been observed: as a proof of this fact, transverse beam profiles acquired at low (1GeV) showed little deformation whereas at 2GeV the mirror bends in the mid-plane giving origin to two separate images.

The interferometric scheme requires small modifications of the original optical scheme. The imaging lens (L1) is removed and the beam is left to propagate to the optical rail in the monitor room (about 7 m from the source). Then, a holder for the screen (S) with the pinholes, and a doublet lens (L2) of 46cm focal distance are placed. The screens were interchangeable solid frames (6x6 cm), containing thin metal foil with two 0.75mm diameter holes with specified separation. The fringes obtained at the focal plane of the first lens were magnified about 10 times by an aberration-corrected lens (L3), and the CCD camera was placed in the back image plane of the latter. In this way we ensure that even the finest fringes are well resolved by the camera without decrease of the fringe visibility. A combination of filters (F) centered at 520nm (360nm for direct imaging) limiting the bandwidth to 30nm FWHM and a polariser (P) are inserted in front of the camera.

Clearly, both the pinholes and the filters reduce significantly the amount of signal, so for precise recording of the interferograms it is essential to use a very sensitive (and still linear) detection.

For this reason we installed a digital CCD developed at CARSO [5] for space imaging applications. The CCD sensor is manufactured by EEV (type CCD02-06); it is a frame-transfer CCD with an Image region area 8.5x6.3mm large, corresponding to 385x288pixels. The pixel pitch is 22x22um. The CCD elements are read-out using the correlate-double-sampling technique using a 10-bit A/D converter. The images are acquired on a PC digital Frame Grabber and post processed using LabView™ IMAQ™ image analysis Library.

3 RESULTS

The vertical and horizontal beam sizes have been measured both with the Interferometer and with direct Imaging (SRPM). A set of interferograms obtained at E=2.4GeV, I=120mA, k=1% is shown in fig. 2. The fringe visibility decreases with the pinhole distance as expected. The values extracted from the interferograms are plotted in fig. 3 together with their Gaussian fittings.

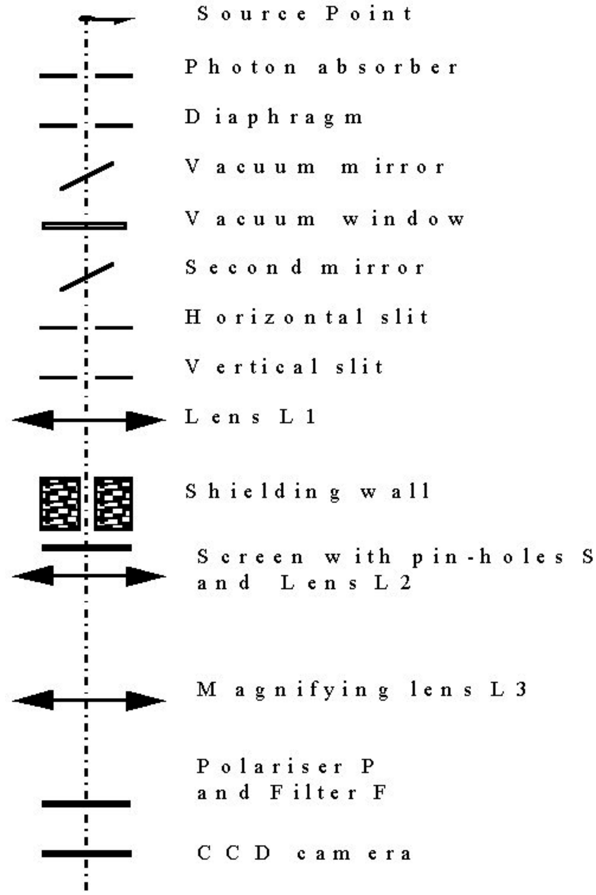

Figure 1: Optical system schematic

The theoretical sizes of the electron beam (σ_B) have been estimated taking the theoretical calculated linear betatron functions at the source point, the theoretical equilibrium emittance and r.m.s. energy spread, while the dispersion is evaluated at the source point from the measured values at the upstream and downstream BPMs. The vertical emittance is estimated using the coupling extracted from measured vertical dispersion [6]. The

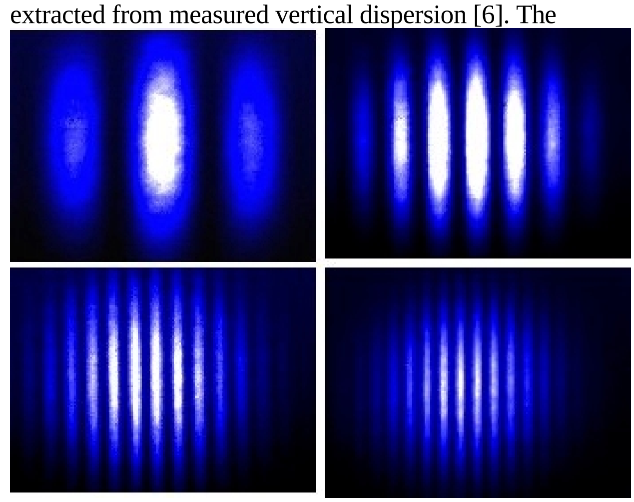

Fig.2: interferograms taken at 2.4GeV with slit distance varying from 2.5mm (top left) to 10mm (bottom right).

theoretical photon beam sizes (σ_{PH}) have been estimated taking into account both diffraction and depth of field effects, according to: $\sigma_{PH}=(\sigma_B^2+\sigma^2_{diff}+\sigma^2_{dof})^{1/2}$. In Table 1 we report the measured photon beam sizes computed from the acquired data at different beam conditions and we compare them to the theoretical estimated values.

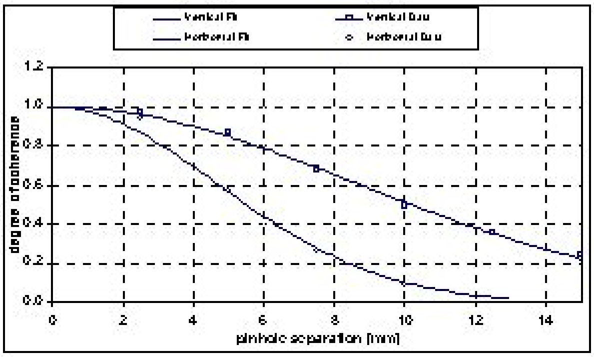

Fig.3: degree of coherence vs. pinhole separation from the vertical (squares) and horizontal (circles) data plotted with the gaussian fits

Table 1: comparison of beam sizes in the vertical and horizontal planes: SI data, Direct Imaging and Theoretical Estimation.

	E	2.4 GeV	2.4 GeV	2.0 GeV
	k	1%	0.5%	0.5%
Interferometric Measurement	σ_{jV} [mm]	8.62	8.67	6.6
	σ_{jH} [mm]	4.82	4.70	5.19
	σ_{PH-V} [μm]	72	67	93
	σ_{PH-H} [μm]	138	141	126
Direct Imaging	σ_{PH-V} [μm]	-	170	-
	σ_{PH-H} [μm]	-	143	-
Theoretical estimation	σ_{PH-V} [μm]	47	39	39
	σ_{PH-H} [μm]	149	149	124
	σ_{BV} [μm]	36	25	21
	σ_{BH} [μm]	146	146	121

The following comments can be made:

- Both the interferometric and the direct imaging measurements of the *horizontal* beam size agree with the theoretical estimations.
- The *vertical* beam size measured by direct imaging is considerably larger than that obtained by the SI and from theory. This can be attributed to the strong image distortion introduced by the vacuum mirror. We note that the reported values are obtained after optimising the vertical slit opening with respect to both distortion and diffraction broadening
- The discrepancy between the estimated and the SI measured vertical beam sizes is larger at 2GeV than at 2.4 GeV. In our opinion this can be attributed to transversal fluctuations of the beam position indicated also by other measurements at 2 GeV.

Here we note that the accuracy of the SI measurement is affected by the deformation of the extraction mirror and by beam diffraction on the intermediate slits and apertures. We observed that the visibility of the fringes at fixed pinhole separation decreases if measured close to the beam edges. Therefore, the results of Table 1 were obtained by performing the measurement with the pinholes close to the center of the beam.

4 CONCLUSIONS

The preliminary results reported here show that in our conditions the application of the SI method allows an improvement of the resolution of the vertical beam size measurement.

However, the measurement procedure is longer and more complex and it appears to be more sensitive to beam transverse position fluctuations.

Furthermore, we note the need of deeper investigations of the fundamental resolution limits of this method since some peculiarities of the synchrotron light are not completely taken into account in the existing literature.

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