ELECTRON BEAM PROFILE, POSITION SYSTEMS AND MEASUREMENTS ON THE DARESBURY SRS

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Measurements of electron beam profile and position have been carried out on the Daresbury SRS. A beam profile monitor based on photodiode array detectors has assessed the emittance coupling coefficient to be < 3 %. A high magnification X-ray pinhole camera has similarly been used to measure beam profile. The paper describes the development of the diagnostic facilities and the achieved performance, including a comparison between the visible light and X-ray systems.

Introduction

During early 1987, the electron beam emittance on the Daresbury Synchrotron Radiation Source (SRS) was reduced tenfold by the installation of a higher brightness magnet lattice. Knowledge of the electron beam size and position is therefore fundamental to the successful operation of this dedicated synchrotron storage ring. These beam parameters are monitored on the SRS using synchrotron radiation from two of the sixteen main dipole bending magnets.

The horizontal and vertical beam dimensions have been measured by imaging visible synchrotron flux from dipole 13 onto a pair of linear photodiode arrays. An error analysis has successfully modelled diffraction and depth of field effects observed in the data. A two-dimensional position sensitive detector on the same radiation port provides high resolution information on any electron beam movements in the storage ring. A high magnification X-ray pinhole camera on dipole 5 has also measured beam profile and experiments carried out have investigated the limitations of this technique.

Beam Profile Monitor System

The availability, flexibility and simplicity of visible synchrotron light flux makes it a very suitable candidate for use in electron beam diagnostics. Sufficient flux was available over the entire SRS energy range (0.6 to 2.0 GeV) and average current range (25 μA to 400 mA) to offer good dynamic detection range. The expected beam profile dimensions in the reduced emittance SRS were on the order of 1.0 mm horizontally and 0.15 mm vertically, RMS gaussian. This very small expected vertical beam size meant that the spatial resolution in that plane had to be < 10 μm.

The overall system design chosen for the beam profile monitor (BPM) was similar to one used successfully elsewhere[1]. With one diagnostic arm for each beam dimension (horizontal and vertical) it was possible to optimise the image space for each. The optical system consisted of a single focusing lens for each diagnostic arm with the optical magnification (OM) limited by the minimum distance between that lens and the source. The radiation port used for the BPM was a multi-diagnostic facility which meant that this minimum distance was disadvantageously large thus limiting the OM. A long focal length lens was essential for the vertical diagnostic in order to offer a reasonably large image size and obtain the required resolution. The detectors were commercially-available linear photodiode arrays[2] with high aspect ratio (13 μm by 2.5 mm) making the array suitable for measurements performed at low beam current with minimal flux. The centre to centre spacing of the photodiodes was 25 μm. The length of array chosen for each diagnostic arm was matched to the expected image space.

Optical aberrations, diffraction and depth of field effects were expected with the BPM system which would all contribute to an apparent widening of the source. Spherical aberration resulting from the focusing lens was substantially eliminated by choosing a high quality lens of fused silica (see ref.[1] for an analysis). Chromatic aberration can similarly be minimised with the use of small bandwidth chromatic filters. Limiting the system acceptance angle θ causes diffraction whilst also reducing the depth of field. By understanding the two effects, it is possible to optimise θ and so provide a compromise situation between the two competing effects. This understanding is of more consequence to the vertical BPM measurements where widening contributions will be of the same magnitude as the expected source size. Small effects like finite electron beam divergence have been omitted from this analysis.

By geometrical optics, it can be shown that the image enlargement dS_1 due to depth of field is given by :

$$dS_1 = D\rho\theta^2 \tag{1}$$

where θ is the whole-angle acceptance, ρ is the dipole magnet bending radius (5.572m for the SRS), and D is a proportionality factor of order 1/3 obtained by integrating along all points of the trajectory acceptance arc. This arc length effect is equally important for the vertical resolution where the horizontal beam and system components play an important role . The image enlargement dS_2 due to diffraction is given by :

$$dS_2 = \frac{F\lambda}{\theta} \tag{2}$$

where λ is the system central wavelength and F is the diffraction correction factor of order 0.5 (see ref.[1]) corresponding to a gaussian intensity distribution and a circular limiting aperture. Examination of expression (2) shows that the system wavelength should be minimised whilst still providing adequate detector response. This parameter value is physically dictated by the chromatic filter and was chosen to be 500 nm (7.0 nm FWHM). Combining expressions (1) and (2) it can be seen that:

$$\sigma_m^2 = \sigma_s^2 + dS_1^2 + dS_2^2 \tag{3}$$

where σ_m and σ_s are the measured and deconvoluted RMS dimensions, respectively.

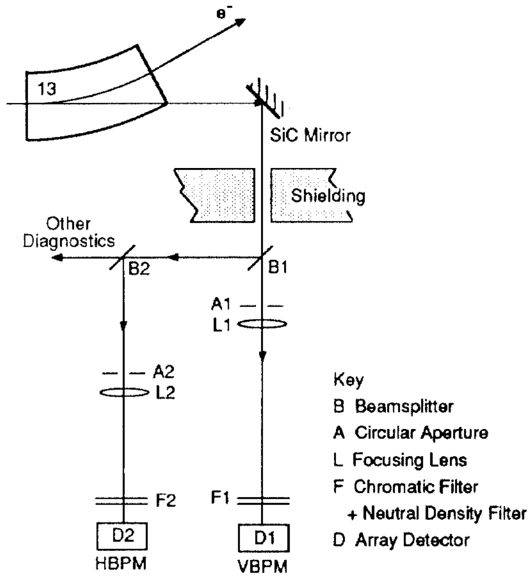

Fig.1. Schematic layout of beam profile system.

Figure 1 shows the layout of the BPM system schematically. A water-cooled silicon carbide mirror reflected the visible light and absorbed the X-ray radiation. The optics and detectors, outside the main shield wall, were supported on a heavy steel table and clamped with magnetic bases. Three-axis (X,Y,Z) adjustment was available on both detector mounts, with micron resolution in the focal (Z) plane. Ultra-thin pellicle beamsplitters were used to distribute the light, with neutral density filters attenuating the light in order to maximise the dynamic ranges of the detection systems. The beamsplitters and neutral density filters produced negligable image deterioration. The evaluation circuitry necessary to process the detector video signals required low-noise power supplies (< 0.5 mV pk to pk) in order to minimise the dark level noise. Saturation voltage levels, dynamic ranges and beam current operating ranges for the two systems are given in Table 1. It was also important to optimise the array integration times to avoid the misinterpretation of beam positional jitter as profile growth whilst at the same time maintaining a reasonable dynamic range.

Table 1. Summary of BPM dynamic and beam current ranges.

	Saturation Level (V)	Noise (mV)	Dynamic Range	SRS Current Range (mA)
VBPM	5.15	20	260	400 - 0.02
HBPM	3.00	15	200	400 - 0.35

Typical video signals from the BPM are shown in Figure 2. In order to correlate the measured image size with the actual electron beam size in the machine , it was necessary to measure the conjugate ratios to high accuracy : 0.342 and 0.099 for the VBPM and HBPM, respectively.

In line with the theoretical model summarised in eq.(3), the image size was measured as the acceptance angle was varied.

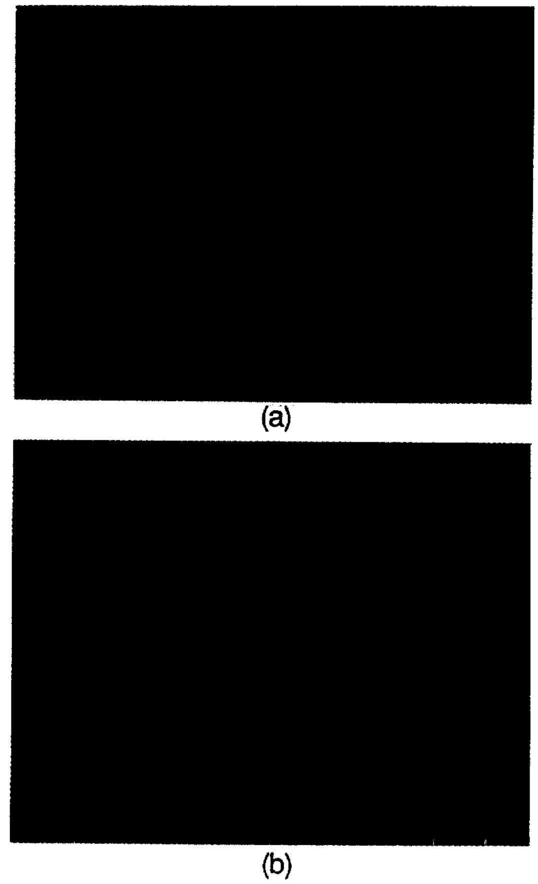

Fig.2. Typical video signals from (a) VBPM, and (b) HBPM. Scope settings:20 μsec/div.,0.2 V/div

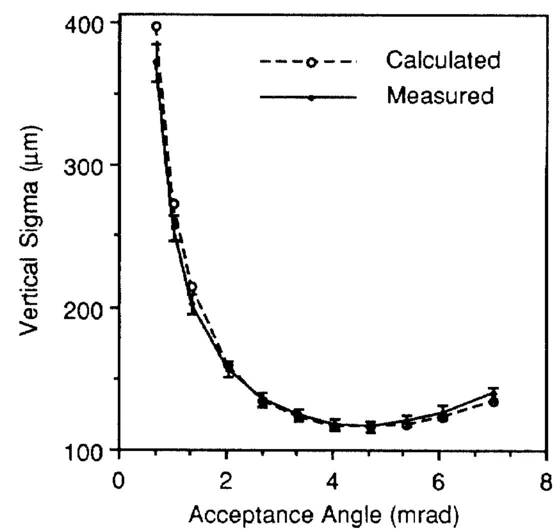

Fig.3. Variation in measured and calculated vertical RMS source size with acceptance angle.

Figure 3 shows the results for the VBPM, with the model showing good agreement assuming σ_S = 93 μm. In the new SRS lattice,this value of vertical σ_S corresponds to a coupling coefficient of 2.5 %. Differentiation of eq. (3) w.r.t. θ to find the optimum value of acceptance angle, gives θ = 4.6 mrad, agreeing well with the observed data.

Table 2: Summary of BPM measurements performed at 2 GeV, 200 mA. The predicted values correspond to a coupling of 2.5%.

	VBPM σ_V (μm)		HBPM σ_H (mm)	
Wiggler	Measured	Predicted	Measured	Predicted
OFF	93 ± 4	93	1.09 ± 0.04	1.06
ON (5T)	118 ± 5	121	1.23 ± 0.05	1.19

Table 2 summarises some of the beam profile measurements made with the VBPM and HBPM. The profiles were recorded under normal SRS operating conditions : 2 GeV, 200 mA. The error contributions have been subtracted and the resulting beam dimensions indicate a coupling of 2.5 %.There is a 5 T superconducting wiggler on the SRS which increases both beam dimensions when energised, and these measurements are also included for completeness. For the measured profile widths quoted in Table 1, the resolutions of the VBPM and HBPM are approximately 4 μm and 40 μm, respectively.

X-ray Pinhole Camera

A pinhole camera (PC) was constructed to utilise a portion of the X-ray flux from dipole 5 in the SRS lattice. The conjugate ratio was extended to 4.1 in order to provide high magnification for beam profile measurements. High energy X-rays passed through a water-cooled aluminium window placed in front of the 74 μm diameter pinhole. The resulting X-ray image was viewed on a high resolution fluorescent screen aligned 8.5 m from the pinhole. A low-light level vidicon camera fitted with a high magnification TV lens could then either provide a direct image for immediate dimensional analysis, or pass the image to a 2D framestore. The stored images were subsequently transferred and analysed with a graphics program on a VAX computer. The fluorescent screen was engraved with a graticule pattern with 2 mm line separation, useful for ensuring optimum focusing of the vidicon monitoring system and accurate beam size calibration in the image plane.

Early measurements of beam profile at low coupling coefficient (< 5 %) showed reasonable agreement (within 10 %) with the expected horizontal beam size.

Comparison of Electron Beam Size Estimates obtained with the Profile Monitor and the Pinhole Camera

An experiment was performed to compare the vertical beam size estimates obtained with the BPM and the PC. The machine coupling coefficient was increased by reducing the frequency split between the vertical and radial betatron tunes. Figure 4 is a plot of the data from the two measuring systems with the VBPM showing vertical beam size growth corresponding to a coupling increase from 3.0 % to 60.0 % for the 270 kHz tune split reduction. Simultaneous measurements on the PC showed the coupling to increase from 4.0 % to only 10.5 %. As the coupling increases, the horizontal beam size is expected to decrease, with percentage reductions of 16.0 % and 2.5 % for the coupling increases observed with the VBPM and PC, respectively. Simultaneous measurements of horizontal beam size with the HBPM showed a reduction of 16.5 %, demonstrating good correlation with theory between the two planes. The conclusion is that the BPM system gives a more realistic estimation of the magnitude of beam size variations than the PC.

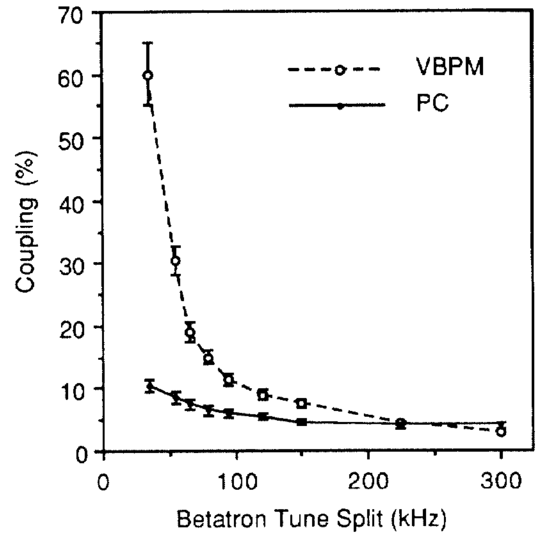

Fig.4. Variation in derived coupling with betatron tune split for the VBPM and pinhole camera.

Beam Position Detector

Testing of a commercially-available[3] two-dimensional position sensitive detector (PSD) has commenced on the same radiation port as that used for the BPM system. Previous work using a similar device as an X-ray PSD has been undertaken elsewhere[4]. The SRS system uses a portion of the visible flux focused onto the detector active area (4 mm by 4 mm). The device consists of a voltage-biased silicon slab with associated amplification stages. Voltages produced are proportional to the distance between the beam profile centroid and the electrodes on the detector surface. The amplified voltages from each of the two electrodes (i.e. two for each dimension) are then summed and differenced with additional processing amplifiers. Minimisation of bias supply noise and amplification noise is vital in order to extract the maximum position sensitivity. By using two detectors in tandem it should be possible to distinguish between positional and angular variations at the source tangent point. Resolutions of < 0.01 mrad (angular) and < 0.05 mm (positional) are expected, coupled with the ability to observe high frequency transient beam jitter. Results are preliminary at this stage and will be reported at a later date.

Acknowledgements

I gratefully acknowledge the help of all the other members of the SRS machine physics group.

References

[1] R.J. Nawrocky, et al, "A beam profile monitor for the NSLS VUV ring employing linear photodiode arrays", IEEE Trans. Nucl. Sci., NS-32, pp.1893-1895, October 1985.

[2] EG&G Reticon, Sunnyvale, California.

[3] SiTek Laboratories, Partille, Sweden.

[4] A.L. Hanson, et al, "The use of a SiTek PSD for synchrotron radiation beam monitoring and alignment", Nucl. Instrum. and Meth., A260, pp.529-533, 1987.