Vertical Undulator Emittance Measurement: A Statistical Approach (TUPF18)

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Abstract

Direct measurement of low vertical emittance in storage rings is typically achieved via interferometric techniques. Proof of low vertical emittance is demonstrated by the measurement of a null radiation field, which is also the crux of the vertical undulator emittance measurement. Here we present strategies to improve the sensitivity to low vertical emittance beams. We move away from photon spectrum analysis to a statistical analysis of undulator radiation, showing the measured increase in signal-to-background. Reproducing simulations of previous work, we demonstrate that photon beam polarisation extends the linearity of the technique by several decades in emittance. These statistical and polarisation improvements to the signal-to-background allow realistic measurement of smallest vertical emittance.

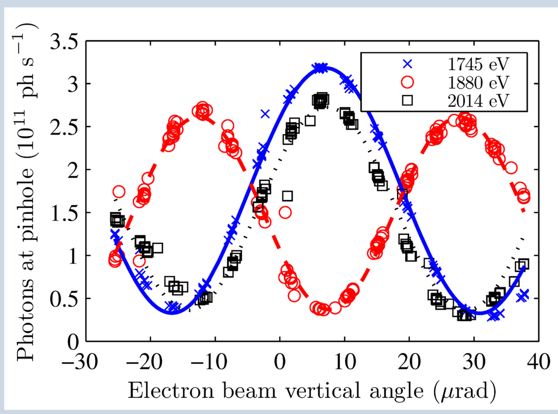
Orbit bumps

One of the most significant systematic uncertainties in this flux measurement is the size and transverse position of the pinhole mask. In particular, the technique is sensitive to vertical transverse offsets of the pinhole [1, 2].

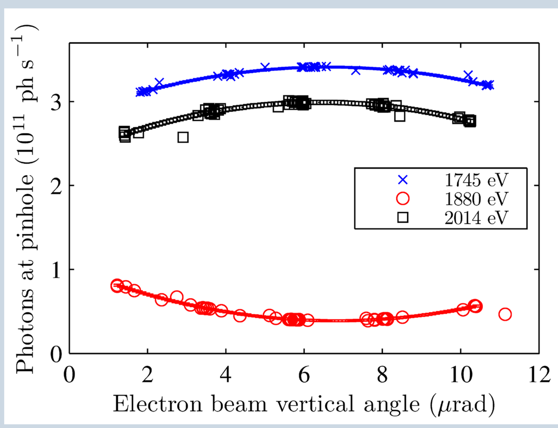
Previously, we aimed to simultaneously minimise the size and centring of the pinhole formed by closing four white beam blades. Instead in this work the blades are closed to the minimum possible aperture, and transverse orbit bumps are performed of the electron beam through the insertion device to optimise centring.

As an approximation, the angular distribution of undulator radiation can be fitted by the double-slit diffraction distribution [3],

$$I(\theta_y) = I(0)\,\mathrm{sinc}^2\left(\frac{2\pi\sigma_y\theta_y}{\lambda R_1}\right)\times\left[1+\gamma\cos\left(\frac{2\pi\sigma_r\theta_y}{\lambda R_1}+\phi\right)\right]$$



Measured and fitted pinhole flux for orbit bumps through ID.



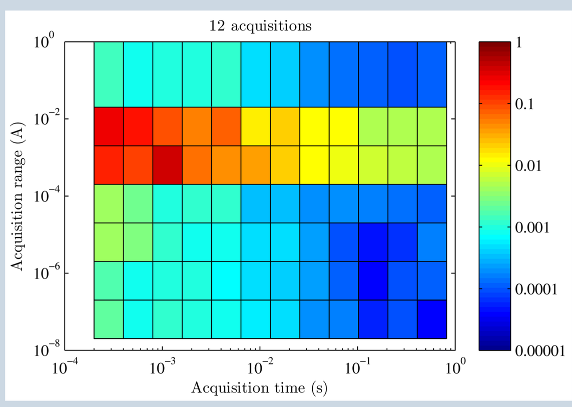
Measured and fitted pinhole flux for orbit bumps through ID, central lobe.

Repeated acquisitions

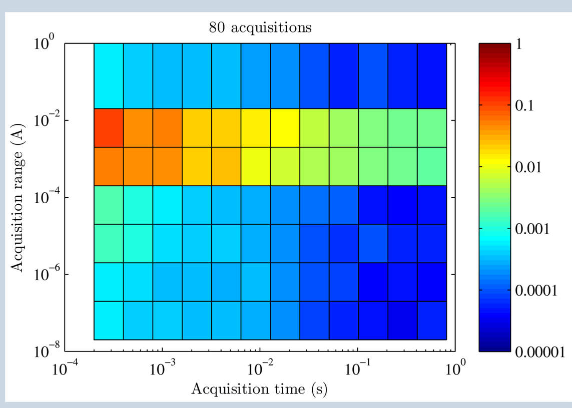
Statistical uncertainty in a measurement can be minimised by making repeated independent measurements of a single quantity [4]. We aim to measure the photon flux passing through a pinhole, for a given stored electron beam current. To compensate for the decaying electron beam current, the quantity measured here is photodiode drain current, normalised to a nominal 200 mA stored beam current by the measured DCCT current. For *n* repeat measurements Gaussian-distributed about some mean value μ, the standard uncertainty in the estimate of the mean δμ is given by [4]

$$\delta\mu = \frac{\sigma}{\sqrt{n}},$$

The interpretation of this statement is that as the number of samples *n* is increased, the measured mean converges toward the true mean of the distribution. For comparison, in the figures at right, the measured relative standard deviation is shown for 12 and 80 acquisitions, over various acquisition ranges and times.

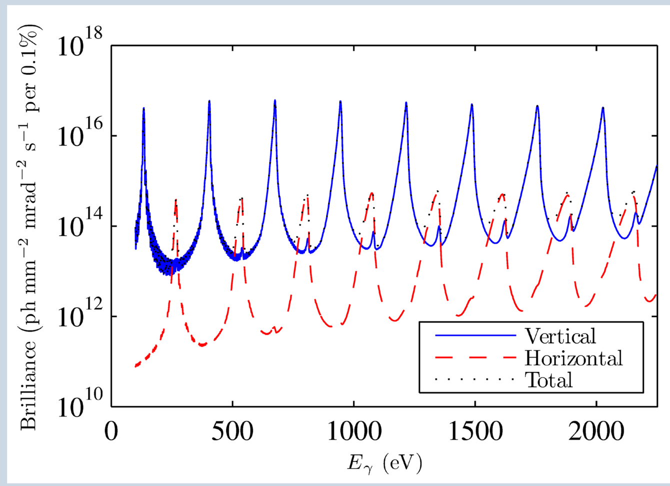


Relative standard uncertainty measured for 12 acquisitions

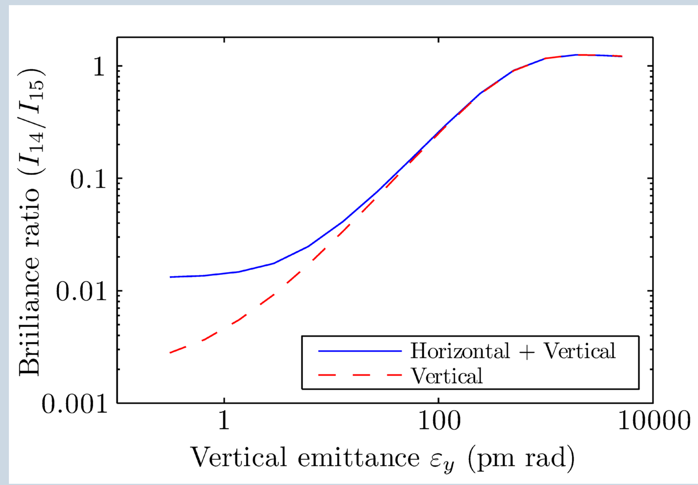


Relative standard uncertainty measured for 80 acquisitions

Photon polarisation



SPECTRA [8] simulation of spectral brilliance assuming an ideal undulator field.



Simulation of flux ratio of adjacent undulator harmonics, for total flux and vertical polarisation alone.

One approach in the minimisation of systematic uncertainties is by selective observation of the polarisation components of the photon beam flux. This was first outlined for a proposed SPring-8 vertical undulator measurement of vertical emittance [5]. The intensity of horizontal I_x and vertical I_y linear polarised light is described in terms of the Stokes parameters [6], where the Stokes parameters are defined in terms of the intensity of light with respect to polarisation orientations [7].

We have undertaken simulations of the undulator brilliance using the SPECTRA code [8]. The code returns several polarisation parameters which can be used to calculate the intensities of horizontally and vertically polarised light.

It can be seen that the measurement of the vertically polarised component of undulator radiation extends the linearity of the measurement technique to lowest vertical emittances.

Discussion

Fitting for the undulator radiation distribution, the angle of the electron beam through the insertion device can be varied to recover the angular distribution of undulator radiation. Repeat acquisitions highlight that over appropriate choices of acquisition range, statistical uncertainty in the measured pinhole flux can be an insignificant contribution to the uncertainty in measured pinhole flux.
The next stage of investigation will be to repeat these polarisation brilliance calculations with measured magnetic fields of the insertion device, to account for phase errors of a real device.

Conclusion

The measurement of a null radiation field is the crux of this vertical emittance measurement. Techniques are presented to minimise sources of statistical and systematic uncertainty. To reconstruct the angular distribution of undulator radiation, transverse orbit bumps of the electron beam are promising, as is the rejection of horizontal polarised photons for the measurement of lowest vertical emittance.

References

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