OPERATING THE DIAMOND STORAGE RING WITH REDUCED VERTICAL EMITTANCE

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Abstract

In a synchrotron radiation light source, a reduction in vertical emittance can potentially increase the source brightness, reduce the spot size for microfocus beam lines or increase the vertical transverse coherence of the photon beam. With this aim, the target vertical emittance for the Diamond storage ring has been recently reduced from 27 pm.rad to 8 pm.rad (0.3% coupling). In this paper we discuss the main impacts of this reduction, along with the steps that have been taken to stabilise the coupling at the new value.

INTRODUCTION

The Diamond Light Source has been operated in user mode since January 2007 [1]. As part of the continual efforts to improve the scientific potential of the facility, the operational vertical emittance has been reduced from 27 pm.rad to 8 pm.rad. Trials of this mode were initially confined to machine development periods, but following a successful two week trial during user time in October 2012, it was adopted as the standard operating mode from March 2013.

Benefits of the reduction in vertical emittance for the X-ray beamlines include an increase in the brightness and vertical transverse coherence, and a reduction in the spot size for microfocus beamlines. However, the change has also had several adverse consequences on the storage ring performance. Firstly, small perturbations in vertical emittance caused by insertion device (ID) gap changes, tune variation and long-term drift have a larger proportionate impact on storage ring performance than was previously the case, prompting the introduction of a vertical emittance feedback. Secondly, the lifetime has reduced close to the 10h ‘soft’ minimum lifetime limit defined for top-up operation. Lastly, whilst the absolute stability remains unchanged, the electron beam motion in proportion to the vertical beam size has increased. In this paper we present details of these issues, along with their solutions.

EMITTANCE MEASUREMENT

The horizontal and vertical electron beam sizes are measured at two locations in the Diamond storage ring using x-ray pinhole cameras [2]. From these, the horizontal emittance ($\epsilon_x$), vertical emittance ($\epsilon_y$) and energy spread ($\sigma_E$) are extracted by inverting the relationship

\[
\begin{pmatrix} \sigma_{x1}^2 & \sigma_{x2}^2 \\ \sigma_{y1}^2 & \sigma_{y2}^2 \end{pmatrix} = \begin{pmatrix} x_1 & \beta_{y1} & \eta_{z1} \\ 0 & \beta_{y2} & \eta_{z2} \\ 0 & \beta_{y2} & \eta_{y2} \end{pmatrix} \begin{pmatrix} \epsilon_x \\ \epsilon_y \\ \sigma_E^2 \end{pmatrix}
\]

where $\sigma_{z,n}$ are the electron beam sizes extracted from the pinhole camera images, and $\beta_{z,n}$ and $\eta_{z,n}$ are the beta functions and dispersion at the image source points.

The vertical emittance found using this method is particularly sensitive to the vertical dispersion at the source point; to ensure the emittance calculation is using up to date values the dispersion is routinely measured after each injection. Values for $\beta_{z,n}$ are extracted from the machine model.

VERTICAL EMITTANCE CONTROL

Control of $\epsilon_y$ is achieved starting from a correction of the linear optics using LOCO [3], for which all 96 skew quadrupoles are used (4 per cell). This correction defines a vector of skew quadrupole strengths, $\mathbf{K}_{skew0}$, and a single iteration of LOCO is usually sufficient to bring $\epsilon_y$ below 3 pm.rad. From this point, $\epsilon_y$ is increased to the target value by applying a constant offset $\delta$ to $\mathbf{K}_{skew0}$, with the magnitude of $\delta$ calculated by inverting the model response matrix $R$, where

\[
\Delta\epsilon_y = R\delta
\]

Note that $\epsilon_y$ varies quadratically with $\delta$ [4], so the model response matrix $R$ should be measured at the target $\epsilon_y$ to ensure predictable gain for the feedback (see Fig. 1).

The above method for $\epsilon_y$ control, whilst simple in concept, is found to be very efficient at increasing $\epsilon_y$ through vertical dispersion only. This separates control of $\epsilon_y$ from the betatron coupling, reducing beam losses on narrow-gap vessels and minimising the residual beam tilt.

Feedback Implementation

The $\epsilon_y$ feedback algorithm uses the same principle as the initial correction, keeping the LOCO correction vector $\mathbf{K}_{skew0}$ constant but varying the magnitude of $\delta$. The feedback runs at 5 Hz (matched to the frequency at which $\epsilon_y$ is measured), and applies only a fraction $f$ of the calculated change at each iteration. To minimise the impact of noise, an Infinite Impulse Response (IIR) filter with coefficient $\alpha$ is used to smooth the instantaneous value of $\epsilon_y$. The correction applied by the feedback at iteration $n$ can therefore be written as

$$
\Delta \epsilon_y[n] = \alpha \Delta \epsilon_y[n-1] + (1-\alpha) \epsilon_y[n]
$$

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Operational Performance

An earlier implementation of the feedback aimed to stabilise the emittance coupling ratio $\chi$ rather than $\epsilon_y$. This version was first enabled during user operations in March 2013, one week after $\epsilon_y,\text{target}$ was set to 8 pm.rad (see Fig. 3). However, it soon became clear that this method was sensitive to changes in the horizontal beam size caused by beta-beat driven by ID gap changes, rather than true variation in $\epsilon_x$ or $\epsilon_y$. Additionally, the application used a mean value of $\chi$ averaged over 20 samples rather than the instantaneous value, limiting the feedback frequency to 0.2 Hz. This was sufficient to correct for long-term drift in the coupling value, but allowed significant, transient deviations in $\chi$ from the target value to appear on ID gap change.

The switch to feeding back on $\epsilon_y(n)$ rather than $\chi,\text{mean}$ was made at the beginning of Run 2 in April 2013. This change has had the effect that transient deviations of $\Delta \epsilon_y$ are now kept to a minimum, and substantially reduces the step-changes in lifetime that occur during ID gap and phase changes. An example showing the effectiveness of the feedback in stabilising $\epsilon_y$ during one such change is shown in Fig. 2.

Conservative feedback parameters of $f = 0.15$ and $\alpha = 0.25$ are currently in use, as these have been identified to allow stable and reliable operation of the feedback, as well as maintaining the ability to react to ID changes on a reasonable timescale. With these settings, variations in $\epsilon_y$ during ID gap and phase changes are in general below the noise floor of the $\epsilon_y$ reading (measured to be 0.12 pm.rad). The exception to this is the in-vacuum device I02, for which transient deviations in $\epsilon_y$ of up to ~0.6 pm.rad are observed, with the total deviation lasting for less than 5 seconds. Over a typical 10 minute period, $\epsilon_y(n)$ is stabilised to a mean value of 8.00 ± 0.13 pm.rad, with r.m.s. changes in $\delta(n)$ of the order 0.7 mA. Note that the variations in $\epsilon_y$ with feedback running are comparable to the natural fluctuations in the $\epsilon_y$ reading.

LIFETIME OPTIMISATION

The lifetime in the Diamond storage ring is dominated by Touschek scattering. Since the scattering rate varies in proportion to the vertical beam size, the reduction in $\epsilon_y$ has led to a drop in lifetime of 45%. To combat this, renewed efforts to increase the storage ring momentum acceptance via sextupole tuning have been made. These include a model sextupole optimisation using a multi-objective genetic algorithm tied to ELEGANT [5], followed by an online suppression of the sextupole resonance driving terms [6]. A comparison of the lifetime before and after this tuning is shown in Fig. 4.

BEAM STABILITY

The reduction in vertical beam size has brought the beam stability marginally above the target value of 10% of beam size in the 1-1000 Hz bandwidth in the vertical plane, as...
CONCLUSIONS

A vertical emittance feedback application is now in use on the Diamond storage ring. The feedback aims to stabilise $\epsilon_y$ directly rather than the emittance coupling, removing any dependance of the vertical beam size on fluctuations in $\epsilon_x$ (real or otherwise). With feedback enabled, $\epsilon_y$ is maintained at a value of $8.00 \pm 0.13$ pm.rad, with the variations limited by noise on the emittance monitor value.

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REFERENCES