FURTHER REDUCTION OF EMITTANCE COUPLING

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The emittance coupling is defined as the ratio of the vertical emittance to the horizontal and should be as low as possible. It has recently been reduced at the ESRF by nearly a factor of three, achieving a record of less than 0.25%, thanks to new strategies based on response matrix modelling and x-ray pinhole measurements, introduced in this report.

One of the major performance enhancements to third-generation light sources such as the ESRF is the achievement of smaller transverse beam sizes, namely emittances, by orders of magnitude when compared with the previous generation. This comes from the fact that the brilliance of the photon beam is inversely proportional to the electron beam emittances. In the horizontal plane, in which the bending radiation occurs, the beam must be strongly focused to fight against the emittance growth due to the recoil of the photon emission. The focussing is obtained using a combination of quadrupole and sextupole magnets, called the "optics". These optics, which started by generating 7 nm•rad horizontal emittance, have furthermore evolved to achieve 3.7 nm•rad.

In the vertical plane, the emittance would ideally be zero. However, the inevitable magnetic imperfections in the storage ring give rise to the coupling mainly via the transfer of the horizontal betatron oscillation to the vertical. The generated coupling should therefore be corrected as much as possible. Since the relevant parameter for the beamlines is the actual vertical photon beam size, at the ESRF we derive the vertical emittance (and therefore the coupling) from the direct measurement of the photon beam size, using two x-ray pinhole cameras [1].

The principal source of the coupling is a skew quadrupole field, arising from a transversely tilted quadrupole magnet, or from a vertical orbit offset in a sextupole magnet. Efforts have been made to reduce the uncorrected coupling of around 10% ever since the commissioning stage. 16 skew quadrupole correctors introduced in the ring are tuned to compensate the two major resonances excited by the error sources; the difference ($Q_x - Q_z = 22$) and the sum resonances ($Q_x + Q_z = 51$), where Q_x and Q_z are the horizontal and the vertical tunes, respectively. The resulting coupling is reduced to less than 1%, which has been provided in the daily user service mode since 1995 [2].

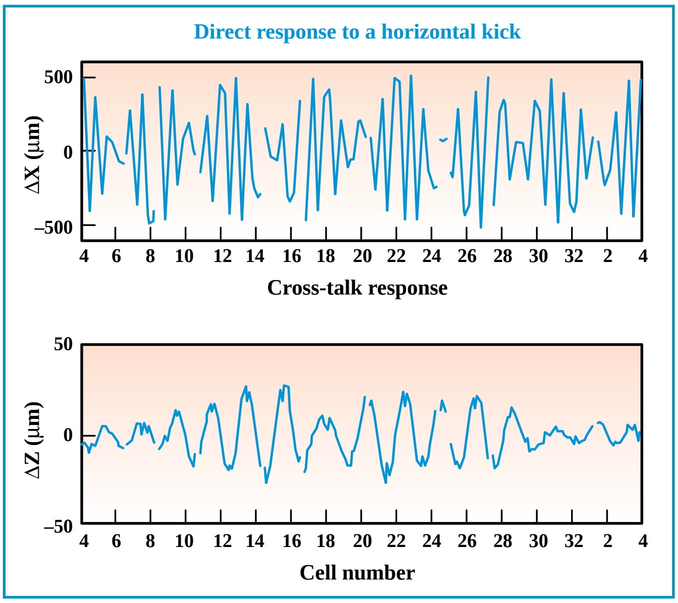

Fig. 1: An example of measured orbit responses.

RESPONSE MATRIX MODELLING

In developing a new correction scheme to proceed further, we have focused on orbit cross-talks, which are the orbit response in the plane perpendicular to the plane in which the orbit is shifted by a steerer magnet (Figure 1). While the direct response in the excited plane constitutes the diagonal response matrix, orbit cross-talks fill the off-diagonal part. Orbit cross-talks are generated by skew fields in a similar way as the coupling. The idea of using orbit cross-talks came from the fact that the aforementioned correction works well by starting from corrector values that give a reduced orbit cross-talk, as well as from the success of an accurate calibration of the quadrupoles with the diagonal response matrix. Thus the quadrupole strengths could be determined to 10^{-4} accuracy by analyzing measured matrices that consist of 224 BPM readings against each of the 96 steerer excitations (224 x 96 matrix in one transverse plane) [3].

Encouraged by this success, attempts were made to solve the equations for the unknown skew errors [4]. It must be noted that amplitudes of orbit cross-talks can only be a few tens of micrometers to stay in the linear optics regime. The present approach is therefore only applicable thanks to the excellent relative reading accuracy of the ESRF BPMs to a few micrometers, as well as to the precise knowledge of the quadrupole and the steerer calibration, obtained from the diagonal matrix analysis as stated above.

Despite finding that orbit cross-talks do not provide enough spatial resolution to identify a single quadrupole rotation, due primarily to the large scale of the ESRF machine, skew errors integrated over a certain longitudinal distance can be determined reliably. Several

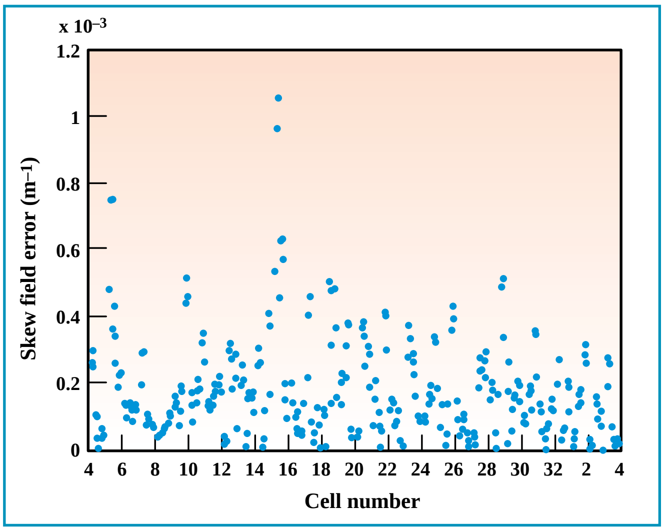

Fig. 2: Obtained skew error distribution in the ESRF machine.

localized peaks are seen in the resulting error distribution (Figure 2). It was verified with the Alignment Group that the corresponding tilt angles are too large to be girder rotation errors. Challenging attempts shall be made by the Alignment Group to identify the skew field errors in the vicinity of the peaks and possibly to remove them. The measured tune separation around the difference resonance as well as the vertical dispersion are well reproduced with the obtained skew errors in the simulation [4]. The use of orbit cross-talks for the coupling analysis was also studied by the SOLEIL project team in collaboration, confirming the obtained result independently [5].

With non-uniformity revealed in the error distribution, a search was made for the most effective skew corrector positions. It was found that with a more symmetrical arrangement, the coupling can be reduced to less than 0.1% in the simulation, which led to 16 additional correctors being installed. As expected, actual application of the model solution led to a lower coupling than the standard correction. The remaining discrepancy with the predicted value is mostly attributed to inaccuracies in the analysis.

EMPIRICAL CORRECTION USING THE TWO X-RAY PINHOLE IMAGES

The best solution found in the simulation is expected to exist in the vicinity of the applied point. A difficulty was encountered here, however, that as a consequence of the reduced coupling, the orbit cross-talk is now too small to iterate the procedure. As the only remaining yet promising alternative, use of the x-ray pinhole measurement was considered. The pinholes are capable of measuring the vertical emittance to less than 5 pm•rad [1]. The simulation finds that, starting from the model solution with proper weighting on the vertical dispersion, minimization of the vertical beam size measured at two locations in the ring (ID8 and D9) leads to the minimal coupling. It was in this way that the record value of 9 pm.rad, i.e. a coupling of less than 0.25%, was actually achieved as measured on both pinholes (Figure 3).

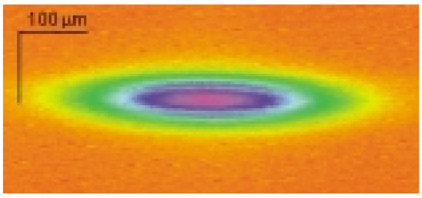

Fig. 3: The x-ray pinhole image (ID8 source point) at the smallest coupling (< 0.25%).

SOME ASPECTS OF THE ELECTRON BEAM AT THE SMALLEST COUPLING

It became clear, through the empirical corrections, that small vertical beam oscillations significantly disturb the beam size measurement as the coupling is reduced. The capability of varying the integration time between 20 to 1 ms in the pinhole measurement allowed the effect to be quantified. To fully benefit from small couplings, the vertical oscillations must be removed. The global orbit feedback plays an important role in suppressing the oscillations around 7 Hz, which also aims to tackle the peak existing around 50 Hz in the near future. Notable progress is being made in parallel to reduce the vibration level of the girders with damping materials. Lifetime reduction for smaller couplings is found to be roughly up to 10 hours under the standard multibunch operation at 200 mA, in agreement with expectation. Although the sensitivity to insertion device gap variations increases for smaller couplings, it has been confirmed that an update of the empirical correction can well compensate their effects. An automatic correction procedure is foreseen.

CONCLUSION

The scheme developed to use the orbit cross-talk for the coupling analysis and the x-ray pinholes to reach the final minimum, along with the installation of new correctors, has successfully reduced the coupling of the ESRF machine by nearly a factor of three to less than 0.25%. With additional efforts either to damp the vertical oscillation or to eliminate the source, some further reduction could be attained. The first test beam delivery with the small coupling is scheduled for a limited number of shifts in October 1999. ■

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