ORBIT STABILITY AT BESSY*

J. Feikes, K. Holldack, P. Kuske, R. Müller†, BESSY, Berlin, Germany

Abstract

Traditionally, intrinsic component stability as well as perturbation source identification and suppression (like set-up modifications or feed-forward compensations) have been the preferred methods used to guarantee beam orbit stability for user operation at BESSY. The second focus of activity is the reliability of slow drift control and the high degree of beam position reproducibility maintained under frequently changed operation conditions.

Along these lines, an overview of the measures taken, the available diagnostic means as well as the achievements and shortcomings of the existing slow orbit feedback is given. Diagnostic capabilities of a fast BPM read-out and data distribution system give insight into the demands on a fast orbit feedback that could provide better operational flexibility and improved performance.

INTRODUCTION

BESSY operates a high brilliance VUV to soft X-ray synchrotron light source. Today 6 helical and 6 planar permanent magnet undulator structures with gaps of the vacuum chamber down to 11mm occupy 10 out of 16 straight sections. Strong superconducting (SC) wavelength shifters (WLS) and a 17 pole wiggler (MPW) with fields up to 7 T are installed in 4 sections. Replacement of the WLS by superconducting dipoles (superbends) is considered. Prototype magnet hardware is tested.

The typical user service mode consists of 3 full energy injections per day, where 350 buckets accumulate 250 mA at 1.7 GeV (multi-bunch, MB). One of the 50 buckets in the ion clearing gap is filled with up to 5 mA [1]. For data taking 8 h of decaying beam is available at 28 insertion device and 20 bending magnet beamlines. Specific operation modes are offered during dedicated beamtime periods: single bunch (SB) for time resolved experiments, optics with low momentum compaction factor (low-α mode) for sub-ps pulses and coherent synchrotron radiation [2], low current (pA) and (very rarely) low energy (0.9 GeV) for metrology purposes. Parasitically, in one sector a 1 mrad beam separation bump serving the femtoslicing experiments is introduced or removed on demand during the beam delivery interruption at injection time.

The quality of experimental conditions at most of the 48 stations depend directly on the stability of electron beam intensity, position and pointing accuracy, emittance and energy [3]. Fill-to-fill reproducibility, orbit drift control as well as fluctuation suppression are essential performance requirements for the facility. In this respect the ‘bare’ storage ring BESSY II delivered an intrinsically very stable beam allowing for experiments with record-breaking resolution. Ongoing installation of strong devices with significant effect on the beam as well as increasing variety of user activities introduce numerous new perturbation sources to standard user mode operation. Maintenance of the high level of beam quality has become a difficult task.

ESTABLISHED ACHIEVEMENTS

‘Static’ Provisions

At BESSY the well known measures of precautions essential for the beam stability requirements of a 3rd generation light source have been respected in all device specifications [4]. Nevertheless operational experience and ongoing understanding of the facility enforced a couple of rectifications:

Resolution of the basic I/O equipment of all dipole correctors have been replaced by units with 24 bit coarse/fine DAC modules [5] to allow for a smooth slow orbit correction. Fast output modulations of all corrector power supplies had to be additionally damped to the stability level of the main power supplies. Measurement and control of orbit parameters depend also on general beam quality conditions: 15 skew quadrupoles have been installed for coupling and vertical emittance control. The four bunch lengthening passive NC 3rd harmonic cavities and the main accelerating cavities had to be equipped with HOM dampers to suppress the coupled bunch modes and the associated energy fluctuations. An analog bunch-by-bunch feedback system maintains transversal beam dimensions and spot sizes.

The most recent and significant improvements have been the modifications of the cold heads of the SC devices: before these changes mechanical vibrations generated by some He-recondensors have been transferred to the magnet structures causing vertical beam motions at frequencies around 1.6 Hz (WLS) and 16 Hz (MPW) with maximum amplitudes as large as 5 μm. Today with all local cryostats refurbished their contributions to the beam motion are no more essential (fig. 1). Now the achievable resolution is again limited by seismic noise, power supply ripple etc.

Diagnostics, (Re-)calibrations

Diagnostic means for stability monitoring at BESSY cover accelerator and beamline characteristics in a complementary way: on the electron side there are precise current

---

[*] Funded by the Bundesministerium für Bildung und Forschung and the Land Berlin

[†] Roland.Mueller@bessy.de

and beam loss monitors for the beam intensity, striplines for the excitation and detection of the beam, button BPMs with single turn, fast and slow high precision capabilities for positions, spin depolarization and compton backscattering energy calibration set-ups. Data of the longitudinal SLAC design digital feedback system give insight into issues connected with instabilities and bunch-by-bunch beam dynamics.

On the photon side [6] are beam position monitors for undulator (XBPM) and dipole (SPM, TPM) users, pinhole array cameras, streak camera and bunch purity detectors. The conditions of the beam delivered at the experiment are analyzed with avalanche diodes, position sensitive detectors, microfocus viewers and spot-monitors. A complementary class of signals originate from the IR (infrared) and a new dedicated THz diagnostic beamline.

The basic storage ring parameters are regularly checked by orbit response matrices, beam based alignment (BBA) procedures, tune scans and β-function measurements. The high precision beam energy measurements help to ensure proper RF frequency variation required by thermal or ground plate induced circumference changes.

Two substantial upgrades of the electron BPM system extended the usability of this already precise and versatile instrument: After the electronics has been modified the system is now coping with large SB intensities and delivers intensity independant position information from 20mA/bunch (SB) down to the threshold values of 0.001 mA/bunch (MB). After this change vertical SB beam stability measured at a dipole photon BPM has been improved by a factor of 15.

In preparation of a fast orbit feedback (FOFB) system the output of the 1 kHz low pass filtered analog button signal is centrally digitized with 10 kHz sample rate. Data are available and used for FFT analysis (fig. 1) of the 0.5 to 200 Hz frequency range of beam motion and for FB studies. In a FOFB pilot setup a strong 1.6 Hz component could be damped by a factor of 20.

Insertion Device Compensations

The insertion devices have to be as ‘transparent’ as possible over the whole ID tuning range to minimize perturbations during wavelength scans. In a few cases, residual magnetic imperfections had to be reduced by reshimming. Gap and shift dependent kicks are compensated with built-in dipole correctors. Corrections interpolated from 2-dimensional tables are applied at a 10 Hz rate. Required set points are routinely checked and refined. Gap (and shift) dependent tune, beta beat and phase jump control is accomplished by appropriate current offsets applied to the ring main quadrupoles [7].

At ‘slow’ scanning operation remaining perturbations are easily compensated by the orbit correction. But modern polarisation switching units with fast shift drives, operation of magnetic brakes and modulator changes for phase shift tuning still cause undesirable transients.

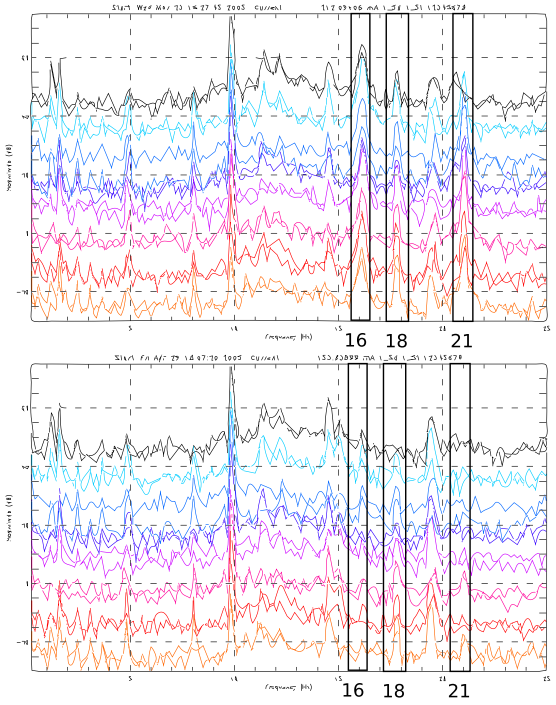

Figure 1: Example of vertical beam spectra (1-25 Hz) gained with FFT analysis of the data from all 16 BPMs located downstream in the straights. Shown are the final improvements of a last refinement at an otherwise ‘harmless’ cold head. See the 16 Hz, 18 Hz and 21 Hz components before (top) and after (bottom) the modification.

ORBIT CORRECTION

Setup, Performance

Global orbit correction is mandatory to suppress thermal effects of the decaying beam, residual insertion device perturbations etc. The orbit correction system at BESSY has been running robust and reliably with nearly unmodified base parameters over the past 5 years: 109 BPMs, 64 vertical, 48 horizontal correctors and the RF frequency are used. In the vertical plane a SVD cut off parameter is chosen where about half the number of eigenvectors is used for correction. In the horizontal plane full matrix inversion is necessary due to the small number of correctors. The long term behaviour of the orbit correction with a typical RMS stability of 1 μm/week and 0.2 μm fill to fill is fully satisfying. Localized sources are locally corrected and do not spread out. BPM or power supply failures happen rarely and have no serious consequences on experimental conditions. Shortcoming of the orbit correction system with increasing importance is the low correction frequency of 0.2 Hz despite an averaging time of only 0.2 s.

Most of the orbit control tasks are solved with model based procedures. Only under ‘pathological’ conditions (low α-modes, optics distorted by the MPW at 7T) the orbit correction switches to measured sensitivity matrices.

Problem Areas

The cryo-system of the superconducting WLS and MPW cause serious orbit changes not fully compensated by the present correction scheme: The slow pressure changes of the He gas flow during refill activities or spurious pressure regulation problems translate into orbit residuals - mostly a localized vertical bump at the relatively orbit insensitive MPW experiments (∼100 μm displacement). It is generally not noticed as a problem but the leakage of a few μm into the adjacent sectors perturb experimenters with specifically sensitive setups.

Separation of the fs pulses from the sliced beam requires a 1 mrad bump with position reproducibility of 10 μm (0.5%) and a drift ‘free’ optimal overlap with the laser beam - a challenging task in view of the hysteresis, magnetic cross-talk, heat load, bump non-closure and ‘floating’ BPM problems.

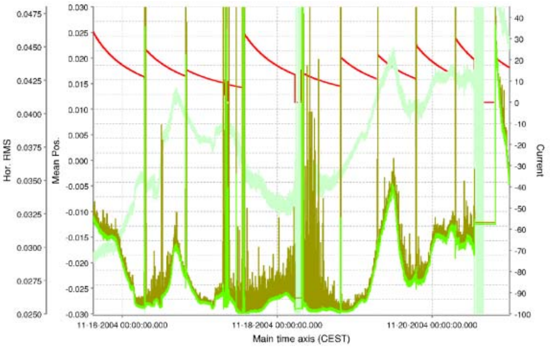

Figure 2: Horizontal beam stability during a low-α week. The light curve shows the mean position, the noisy dark curve shows the band of corrective action/step.

Low α-modes have 10–200x increased horizontal sensitivities and require specific treatment: the minimal digitally controllable change of the RF frequency (1 Hz) is unusable for the orbit correction. As a result, the mean beam position varies ± 20μm/week. Even the correction activity itself ranges from 0.1μm to 15μm RMS improvement/step (fig. 2) and closely follows the outside temperature. The latter is probably an aliasing effect of fast orbit jumps and the slow corrective actions: dependent on α (or the synchrotron tune $f_{syn} \sim \alpha^2$) large and fast horizontal orbit jumps have been observed that may be due to tiny energy fluctuations: 0.1 mm changes at 20Hz (f_{syn}=1.3 kHz) and 3mm jumps at 44 Hz (f_{syn}=0.3kHz) have been documented. Below f_{syn}=1 kHz measurements of the sensitivity matrix become meaningless. Orbit correction at 0.2Hz is justified only by the ability to keep the beam within its useful bounds but the introduction of additional noise can only be avoided by a FOFB system.

Plans, Strategies

Presently BESSY is preparing for topping up operation. This mode will eliminate orbit problems connected with thermal non-equilibrium and beam intensity dependent effects. Unspecific suppression of ‘fast’ and transient beam motions will require a global FOFB system. Local and global fast feedback prototypes have been tested and shown to be able to address the frequency range up to 50 Hz and to enhance experimental capabilities.

Some photon beam motions are due to setup or location of a specific beamline and not caused by the beam. Time sharing beam usage introduces additional sensible beam guiding components and varying heat loads. Thus active control of beamline components will be of increasing importance. First installations are very promising: a lateral position sensitive diode together with a PID feedback loop applied to the split mirror unit feeding the monochromator reduced residual horizontal thermal drifts by a factor of 6 down to 0.2% of the spot size. Vertically a 10μm microfocus at 30m distance from the source is stabilized to 10% of its spot size. Homogeneous overlap of two beams with differences below 3% at exactly the same energy for microscopy application at the double helical undulator UE56 is maintained by a piezo driven mirror oscillator.

SUMMARY

The variety and reliability of the diagnostic inventory at BESSY allows to disentangle the mixture of vibrational perturbations, heat load effects and electron beam stability issues. Accordingly, the most effective beam stabilization strategy is a combined effort of perturbation source suppression or local compensation, accelerator refinements and beamline improvements.

On the other hand, there are always new noise sources introduced. Identification and commissioning of eliminating countermeasures need quality beam time. A FOFB would allow for more operational headroom and enhance the stability properties of an already well defined electron orbit.

REFERENCES

[1] S. Khan, *Storage Fill Patterns for Femtoslicing Applications* and *Femtoslicing in Storage Rings*, this conference

[2] G. Wüstefeld, J. Feikes, K. Holldack, P. Kuske, *Compressed Electron Bunches for THZ-Generation, Operating BESSY II in a Dedicated Low Alpha Mode*, 2004 EPAC, Lucerne

[3] R.O.Hettel, *Beam Stability Issues at Light Sources*, 25th ICFA Advanced Beam Dynamics Workshop SSILS, SSRC Shanghai, 2002

[4] J. Feikes, K. Holldack, P. Kuske, R. Müller *Beam Stabilization at BESSY: Set-Up, Performance, Plans*, 2003 ICALEPCS, Gyeongju, Korea

[5] R. Müller et. al., *Orbit Drift Correction Using Correctors with Ultra-High DAC Resolution*, 2001 PAC, Chicago

[6] K. Holldack, J. Feikes, W.B. Peatman, *Review of Emittance and Stability Monitoring using Synchrotron Radiation Monitors*, 2001 DIPAC, ESRF, Grenoble

[7] T. Birke, J. Feikes, B. Franksen, R. Lange, I. Müller, G. Pfeiffer, J. Rahn, *A Tune Feed Forward System for the BESSY II Storage Ring*, 2003 ICALEPCS, Gyeongju, Korea