BEAM STABILIZATION AT BESSY: SET-UP, PERFORMANCE, PLANS*

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Abstract

At 3rd generation light sources user experiments require ultimate beam stability while at the same time operational activities cause significant perturbations. High precision continuous orbit drift control combined with compensation schemes for the residual effects of insertion device gap changes are mandatory. Beam stabilization procedures have to fulfil a number of boundary conditions: 'good' minimization of orbit deviations, reproducibility, minimal induced noise, constant beam energy, robustness against systematic changes or spurious hardware failures etc. Due to precision and reliability of diagnostic (electron and photon BPM systems), corrector and software components the identification, characterisation and tailored suppression of perturbation sources has become the most promising approach. In addition detectors along the whole beamline up to the experiment location allow to distinguish accelerator dominated effects from beamline specifics. Since perturbations tied to beamlines and beam orbit are of similar order monochromator set-ups get increasingly involved into the process tuning efforts. In this paper characteristic solutions as well as available options are presented.

INTRODUCTION

BESSY operates a high brilliance VUV to soft X-ray synchrotron light source. Today helical and planar permanent magnet undulator structures with gaps of the vacuum chamber down to 11mm occupy 9 out of 16 straight sections. Strong superconducting wavelength shifters (WLS) with fields up to 7 T are installed in 4 sections. Typical user service mode consists of 3 full energy injections per day where 350 buckets accumulate 250 mA at 1.7 GeV. For data taking 8 h of decaying beam is available. Quality of experimental conditions at most of the 40 stations depend directly on the stability of electron beam intensity, position and pointing accuracy, emittance and energy[1]. Fill-to-fill reproducibility, orbit drift control as well as fluctuation suppression are essential performance requirements for the facility. At the same time ongoing installation of devices with significant effect on the beam as well as increasing variety of user activities introduce numerous new perturbation sources.

'STATIC' PROVISIONS

In view of the demanding beam stability requirements of a 3rd generation light source the well established measures of precautions have been respected in all device specifications: installation of vibration damping pads to decouple eigenmode optimized girders from thick concrete slabs, careful alignment of all components, stabilization of power-supplies at beam guiding magnets to a few ppm, temperature control of cooling water, air in tunnel and experimental hall to fractions of a degree. Critical components like RF cavity cooling, magnet sorting and shimming of undulators etc. have been handled with due diligence. Nevertheless operational experience, ongoing characterisation and understanding of the facility as well as increasing users experimental sensitivity enforced a couple of rectifications:

Four bunch lengthening passive NC 3rd harmonic cavities had been installed to reduce the Touschek losses. These cavities as well as the main accelerating cavities had to be equipped with HOM dampers to suppress the coupled bunch modes and the associated energy fluctuations[2]. At the main RF amplifier phase control had to be improved too to reduce the RF phase noise.

Resolution of the basic I/O equipment of all dipole correctors with thermally stabilized 16 bit DACs turned out to be inappropriate for continuous orbit drift control. All boards have been replaced by units with 24 bit coarse/fine DAC modules[3]. The less tightly specified corrector power supplies had to be additionally damped to reach the same stability level with respect to fast output modulations as the main power supplies. This measure reduced the 50 Hz and harmonic components of e.g. horizontal orbit movements to half of the previous RMS values.

Seven squew quadrupoles have been installed at places of large coupling contributions[4] and tuned to de-coupling values to provide the small vertical emittance desired for high brilliance and optimal monochromator resolution.

DIAGNOSTIC MEANS

Diagnostic means available for stability monitoring at BESSY cover accelerator and beamline characteristics in a complementary way: on the electron side there are precise current and beam loss monitors for the beam intensity, strip lines for the beam energy spectrum, button BPMs with single turn, fast and slow high precision capabilities for positions, spin depolarization and compton backscattering energy calibration set-ups. On the photon side[5] are beam position monitors for undulator (XBPM) and dipole (SPM, TPM) users, pin-hole array cameras, streak camera and bunch purity detector. For analysis of beamline performance and conditions of the beam delivered at the experiment there are avalanche diodes, position sensitive detectors, microfocus viewer and spot-monitors as well as the FTIR (infra-red beamline) signals.

*Funded by the Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie (BMBF) and the Land Berlin

Most of the data are available via EPICS and CA gateways at literally any networked client computer. They are background logged to a long term archive allowing for trend and correlation analysis.

RECALIBRATION PROCEDURES

Basic storage ring parameters are regularly checked by measuring and analyzing orbit response matrices. Model descriptions used by the correction algorithms are constantly adjusted and refined[6]. After major modifications, significant shutdown activities, replacement or repair of BPM electronics BPM offsets are re-calibrated using all quadrupoles for beam based alignment (BBA) procedures. The BBA results are mostly in good agreement and consistent. Significant deviations typically occur in close correspondence to segments of major hardware activities.

Insertion device induced resonances and their effect on beam lifetime are characterized by two dimensional tune scans: lifetime and beam loss monitor data allow to acquire gap parameterized resonance diagrams with quasi spectroscopic precision[7] and to develop measures to effectively avoid lossy resonances[8]. High precision depolarisation measurements of beam energy help to ensure proper correction of thermal or ground plate induced circumference changes and balance RF frequency variation with non-zero average kick of horizontal dipole correctors[9].

ID FEED-FORWARD SCHEMES

According to basic operational philosophy at BESSY the storage ring is characterized and tuned in all accelerator physics aspects with open gaps (bare lattice). Insertion devices have to be as ‘transparent’ as possible over the whole ID tuning range to minimize perturbations during wave length scans. In the elliptically polarizing two-beam undulator case compensations in all 3 dimensions of gap, shift and modulator setting are required.

Insertion device induced modifications are handled by the device control procedures as much as possible. Kicks due to residual magnetic imperfections are compensated with built-in dipole correctors. On gap changes the interpolated values of experimentally determined currents are applied at a 10Hz rate. Set-point tables are routinely checked and refined: Gap (and shift) are systematically varied and the best possible orbit improvements are found by the orbit correction program in restricted mode (only relative current changes of the associated internal dipole steerers are considered). Combining the applied offsets with the existing compensation currents gives the updated feed-forward tables. For the natural focusing of the insertion devices no internal compensation magnets are available. Gap (and shift) dependent tune, beta beat and phase jump control is accomplished by applying appropriate current corrections to the main ring quadrupoles[10, 11].

FEEDBACK SYSTEMS

Longitudinal and transverse bunch-by-bunch feedback systems are in routine operation since December 1999[12]. The longitudinal SLAC design digital system was installed to counteract HOM induced instabilities and improve photon intensities by reducing electron energy spread. After the installation of HOM dampers at all cavities importance of this system has become less crucial. The analog transverse system suppresses instabilities caused by the resistive wall effect and is necessary to confine the beam sizes. Effective operation of the transverse system is an essential prerequisite for user service beam intensities.

Global orbit correction is mandatory to suppress thermal effects of the decaying beam, residual insertion device perturbations etc. Since the problems of I/O resolution and energy preserving RF path length correction have been solved the orbit correction system at BESSY runs robust and reliably with nearly unmodified base parameters: 109 BPMs, 48+1 horizontal and 64 vertical correctors are usable. 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 RMS stability of typically 1 μm/week and 0.2 μm fill to fill is fully satisfying. Localized sources are locally corrected and do not spread out to other sectors. BPM or power supply failures rarely have serious consequences on experimental conditions. Shortcoming of the orbit correction system with increasing importance is the long BPM averaging time of 200ms and the low correction frequency of 0.2Hz.

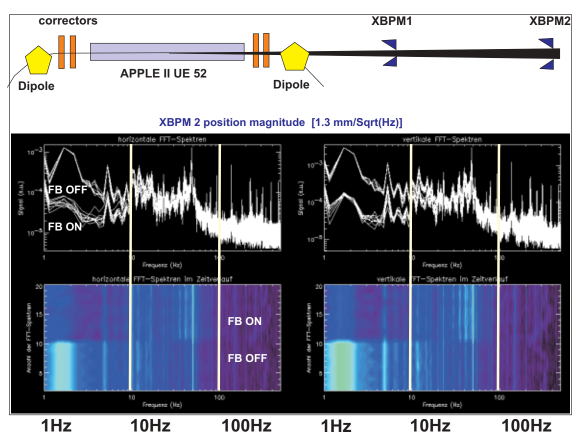

Figure 1: Prototype: fast local orbit feedback[14].

A fast XBPM based local feedback prototype has been developed and shown to be able to address the frequency range up to 50 Hz[14]. The detrimental 1.6 Hz jitter caused by the WLS cryo-system (see) could be damped between 25 and 35 dB (fig. 1). XBPM findings are consistent with fast BPM data. The new BPM system is under development to evaluate the feasibility of a fast global orbit feedback.

At BESSY the close linkage of electron and photon

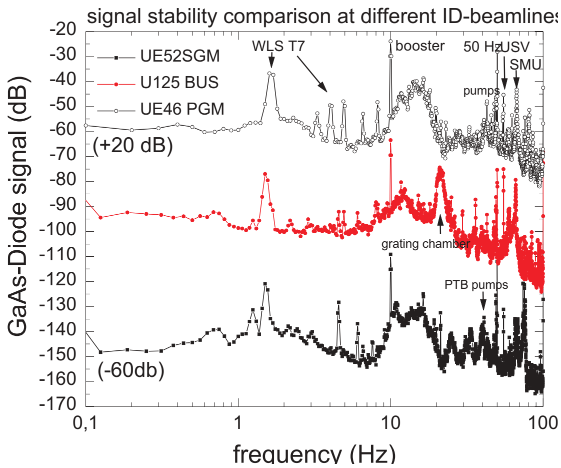

Figure 2: Signal Stability at different experiments.

beam diagnostics (see) allows to discriminate perturbations due to beamline characteristics from those caused by the electron beam (fig. 2). In a first prototype set-up a lateral position sensitive diode together with a PID feedback loop applied to the split mirror unit feeding the plane grating monochromator (fig. 3) reduced residual horizontal thermal drifts from 0.6 μrad/mA to less than 0.1 μrad (0.2% spot size). Vertically a 10μm micro-focus at 30m distance from the source is stabilized to 10% of its spot size.

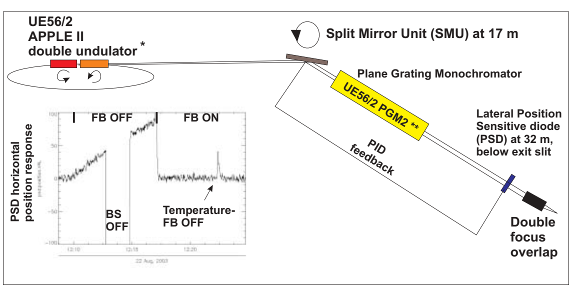

Figure 3: Prototype: horizontal mirror feedback[13].

At the double helical undulator UE56 the two beam mode and a chopper allow to take spectra for both polarisation directions during a single scan. Homogeneous overlap of both beams with differences below 3% at exactly the same energy for microscopy application is maintained by a piezo driven mirror oscillator.

REMAINING PERTURBATION SOURCES

Numerous unexpected perturbations have been identified and appropriate countermeasures have been tried: the impact of an experiment using magnetization reversal[3] has been reduced by moving the experiment to a different location and by improving the shielding of the current leads. Influence of magnetic brakes used for fixing ID gaps could be reduced at some devices by a modified geometry. Magnetic chicanes of double undulator set-ups are only tuned at injection time when perturbations do not matter.

The cryo-system of the superconducting WLS cause serious orbit changes that are hard to compensate: A strong mechanical 1.7 Hz step perturbation (fig. 2) caused by the He cryostat needs either major modifications of the recondensor or a very fast feedforward or feedback compensation. Compared to that the slow drifts due to pressure changes of the He gas flow during refill activities are less problematic since uncorrectable orbit residuals result in localized bumps at the relatively insensitive WLS locations.

SUMMARY

Variety and reliability of the diagnostic inventory at BESSY allow 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.

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