I.FAST Workshop 2025 on Stability of Storage Ring Based Light Sources

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KIT North Campus

Book of Abstracts

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Qualification of Series Magnets in the SLS Upgrade at the Paul Scherrer Institute: Challenges, Results, and Lessons Learned

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To enhance the performance of the Swiss Light Source (SLS) at the Paul Scherrer Institute (PSI), a comprehensive upgrade known as SLS 2.0 is currently underway (2021–2026). This ambitious project involves the renewal of the storage ring, achieving 40 times lower emittance in user operation mode, thereby significantly increasing the source brightness, and enabling groundbreaking research capabilities. The SLS 2.0 upgrade imposes stringent requirements on field quality and magnetic alignment across a total of 1,285 magnets, which are being magnetically qualified at PSI. For the first time in a light source facility, the storage ring will utilize a unique combination of three magnet types: 1) NdFeB-based permanent magnets, offering high field quality with minimal power consumption. 2) Combined-function electromagnets, optimizing compactness and efficiency. 3) two 5-T Nb-Ti superconducting longitudinal gradient dipoles, to be installed during the second phase of the machine upgrade. This talk will provide an overview of the magnetic measurement challenges encountered during the project, the measurement strategy and results related to permanent and electromagnets, as well as the lessons learned from executing a large-scale magnetic test campaign achieving a 10-3 relative accuracy level under tight time constraints.

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BESSY III orbit correction scheme layout and performance

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Currently in its Conceptual Design Phase (CDR), the 4th generation light source BESSY III aims to become a world-leading soft X-ray source, enabling numerous applications in metrology, life sciences, energy and catalysis materials, and many more. Its performance relies on ultra-low transverse emittances, achieved through the use of strong focusing magnetic elements that are sensitive to magnetic and alignment errors.

If left uncorrected, these errors give rise to a distortion of the closed orbit, beta beating, linear coupling, and a stronger impact of resonances thus impairing the storage ring performance.

In this work, we address how to devise an initial BESSY III orbit correction scheme. Two criteria

were considered to find the optimal locations of Beam Position Monitor (BPM) and dipolar Corrector Magnet (CM). Different orbit correction scheme candidates are presented and their advantages and disadvantages are discussed. All calculations were performed in parallel with the Matlab toolkit Simulated Commissioning (SC) and its Python counterpart (pySC).

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Orbit Stability at BESSY II: Progress of FOFB Upgrade and Current Stability

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Development of Control Systems for the Stabilization of Synchrotron X-Ray beams

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This work investigates the study, design, and implementation of a control system for stabilizing focused X-ray beams in synchrotron beamlines. Due to the challenges and high costs associated with direct and continuous access to these facilities, a custom Lab-replica was instead employed.
This replica utilizes an analog oscilloscope to represent the X-ray beam, two electromagnets to simulate disturbances, and two electrical deflection plates to replicate the actuation system. A custom detection system was integrated to identify a first-order experimental model, establishing a correlation between the light spot position on the oscilloscope screen and the input voltage signals of the replica's actuators. Based on this model, a PID control loop was designed and validated, first through simulations and later through experimental campaigns.

As a proof of concept, a typical disturbance encountered in X-ray Absorption Spectroscopy (XAS) was simulated by inducing drift in the Lab-replica setup using an electromagnet. The PID controller, tested at control frequencies up to 1 kHz, successfully tracked the reference signal, maintaining an error below 0.2% of the total drift and achieving a rise time of less than 15 ms. These results demonstrate the controller's effectiveness in mitigating beam drift within the Lab-replica, highlighting its potential for optimizing real XAS measurements.

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Design and commissioning of the asymmetric beam optics in the SSRF storage ring

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Lattice upgrade, consisting of replacing the conventional bending magnets with super-bend locally, constructing two double-mini-y optics (DMB) and installing a superconducting wiggler (SCW), was implemented in the Beamline-Project of Shanghai Synchrotron Radiation Facility (SSRF). The symmetry of the SSRF storage ring was completely destroyed, forcing the global optics to be modified. The lattice of the new SSRF storage ring, matching the new elements perfectly, was designed. Sufficient dynamic aperture and energy acceptance were obtained by elaborate lattice design and nonlinear optimization. Study on beam dynamics, including the closed orbit correction, the linear optics correction, the coupling correction, the chromaticity correction and the nonlinear dynamic optimization, achieved good results for the new lattice. The critical step in the study is the restoration of the linear beam optics, which greatly restored the machine performance. The resulting beam parameters, as well as the operation status, are also presented.

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Application of deep learning method for insertion device orbit and coupling feedforward at the SSRF

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The Shanghai Synchrotron Radiation Facility (SSRF), a third-generation synchrotron radiation source, demands exceptional beam stability for high-precision user experiments. However, manufacturing and installation inaccuracies in insertion devices (IDs) can lead to beam orbit and coupling distortions. To address this, we developed a data-driven predictive model leveraging deep learning to forecast the effects of ID gap variations. The model facilitates real-time feedback control by adjusting corrector and skew quadrupole currents, effectively mitigating ID-induced perturbations on beam orbit and coupling. Implementation at SSRF demonstrates a substantial reduction in these perturbations, resulting in enhanced experimental stability and reliability.

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Bunch-by-bunch feedback system used as a diagnostic device for multi-bunch instabilities in the DAΦNE collider

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DAΦNE is an electron-positron collider operating at INFN-LNF. Bunch-by-bunch feedback systems installed in each of the two rings allow to store high-intensity and stable beams, by counteracting strong coupled-bunch instabilities due to e-cloud and RF higher-order modes. These feedback systems can be also used as a diagnostic tool which is able to measure beam parameters which are important for the evaluation of the instabilities. In this talk, we first describe the acquisition system used to record the beam data obtained with the feedback systems. Then we report transverse-tune shift and grow-damp measurements performed in 2024 with positron beams, by using the feedback as a diagnostic device. These measurements contributed to the characterization of the e-cloud beam instability, which currently is one of the main limitations for the DAΦNE performances. Finally, we describe the first beam measurements and feedback-system setup designed to automatically record turn-by-turn bunch position displacements when an unexpected loss in beam current occurs due to any faults in the collider. This tool can be useful in identifying the causes of these events.

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Statistical and interferometric beam diagnostics in IOTA at Fermilab

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At the Fermilab Integrable Optics Test Accelerator (IOTA), we are carrying out a research program on the statistical and quantum-optical properties of undulator radiation from electron bunches down to single electrons [1]. As a result of this program, novel beam diagnostic techniques have been developed. From the intensity fluctuations of undulator radiation, it is possible to infer very small beam sizes, which would otherwise be very challenging to observe [2]. In addition, we applied interferometric methods to observe vibrations of the apparatus at the nanometer scale [3]. A review of these methods is given, with an outlook on possible developments.

[1] https://doi.org/10.18429/JACoW-IPAC2024-MOPG06
[2] https://doi.org/10.1103/PhysRevLett.126.134802
[3] https://rpubs.com/gist/clara-vibration-studies https://doi.org/10.5281/zenodo.14897587

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HEPS Fast Orbit Feedback System

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Beam-based girder alignment in PETRA-IV: conceptual simulations

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DESY is advancing plans to upgrade PETRA III into a 4th generation light source. Magnetic lattice components are assembled and pre-aligned on extended girders before being installed in the tunnel.

However, the considerable length of these girders and the inherent misalignment of the magnets introduce challenges for the PETRA IV lattice, particularly in storing the beam within the ring. Previous commissioning simulations indicated that the orbit correction system demands relatively high corrector strengths. In response, a simulation study was carried out to explore the feasibility of beam-based girder alignment correction as a means to reduce these corrector strength requirements during operation.

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Orbit stability and reproducibility at SOLARIS storage ring

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Ensuring the stability of the electron beam at the SOLARIS synchrotron has been a key objective throughout its development. Several structural measures, including the installation of a vibro-elastomer mat and concrete block magnet girders, have effectively maintained the stability of the experimental hall within acceptable limits below 1.6um rms for low frequency range(below 10Hz) and below 0.3um rms in the frequency range between 10 and 50Hz. Thermal stability, particularly in the cooling water system, has been progressively enhanced, culminating in a major upgrade in 2022 that achieved a stability level of ±0.1℃.The orbit correction system has undergone significant improvements, with the Slow Orbit Feedback (SOFB) system being redesigned and accelerated by over an order of magnitude. Additionally, the successful development and implementation of the Fast Orbit Feedback (FOFB) system have further refined beam stability. To optimize performance, an offloading procedure was introduced, mitigating conflicts between the SOFB and FOFB systems.These advancements have enabled submicron precision in electron beam stability and reproducibility. While beam position reproducibility remains at a high level, the drifts of several micrometres over 12 h persist in the X-ray Beam Position Monitor (XBPM) readouts. Continuous efforts are being made to further enhance long-term orbit stability for the most demanding experimental applications.

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Effects of the ALBA slab movement on ALBA-II

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The spanish 3rd generation synchrotron light source ALBA of 268.8 m and 3 GeV, is planning to renovate the Storage Ring to a 4th generation synchrotron, called ALBA-II, to be installed in the same location. The current ALBA storage ring has been used to validate the ALBA model behavior subject to ground motion and the ALBA-II ground movement studies have been based on 6-months and 1-year cycles from 2022 and 2023 alignment data. The ground movement seems non-cumulative in the most recent years, large amplitude and low spatial frequency. The lattice could be corrected in case of either: a 6-months or 1-year of continuous motion modelled as low spatial frequency and high amplitude components that increase the orbit correction budget by less than 50 µrad and would be continuously used; or weeks/months of continuous motion modelled as girder to girder variations of 10 µrad rms cut at 2 sigma, equivant to jumps of 40 um, contributing to another 50 urad to the corrector budget. Girder movers could help to reduce the corrector budget by removing the girder-to-girder jumps. In case of non-continuous correction we expect once every 5 years at most 1 mm loss in horizontal D.A. This is the case of a long stop, for example in winter or summer, and could reduce efficiency or stop off-axis injection. As a way to mitigate this issue we will keep the possibility to come back to on-axis injection, allowing to inject, diagnose, correct and recover fully the D.A. Alternatives to increase the D.A. from design so that we can tolerate 1 mm hor. DA. loss are also foreseen.

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Development of permanent magnet dipoles for ESRF-EBS

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The ESRF-EBS (Extremely Brilliant Source) is an upgrade done at ESRF (European Synchrotron Radiation Facility) in the period 2015-2022. It aims to decrease the horizontal emittance and to improve the brilliance and coherence of the X-ray beams to best serve the new science opportunities. Permanent magnet longitudinal dipoles (DLs) have been developed for the ESRF-EBS upgrade. The use of permanent magnets has mainly two advantages: in the one hand, it allows a more compact distribution of magnets, since there is no need of coils and water cooling; in the other hand, it allows to reduce the running costs and the carbon footprint of the facility thanks to the removal of the power supplies associated to conventional electromagnets. In this presentation I will report about the magnetic and mechanical design of these dipoles, prototype and series magnets production including thermal compensation, magnetic measurement and tuning. I will report also about the commissioning of this now machine and the problems related to the cross-talk between magnets. Finally, I will give a feedback about the DLs after 5 years operation.

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Observing sudden beam loss events using bunch-by-bunch BPMs at SuperKEKB

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SuperKEKB is an electron-positron collider aiming for high luminosity. However, its stable operation is challenged by Sudden Beam Loss (SBL), where beam instability occurs within tens of microseconds, leading to significant beam loss and triggering a beam abort. To better understand and mitigate SBL, we developed a new Bunch Oscillation Recorder (BOR) using AMD/Xilinx RFSoC. The BOR records bunch-by-bunch beam position and charge before a beam abort. In the 2024 operation, two BORs were deployed in the main ring, enabling detailed observation of SBL. Analysis of the BOR data revealed that during SBL, not only do bunch positions oscillate, but their sizes also increase. Furthermore, SBL is strongly correlated with "pressure burst", where the local vacuum pressure in the beam chamber rises abnormally at specific locations. Our results suggest that at these locations, the beam may receive kicks, triggering instability. Inspections of these locations revealed dust and vacuum seal contamination in the chamber, suggesting that interactions between the beam and these foreign materials could be a potential cause of SBL.

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Vibration analysis and stability control for High Energy Photon Source in China

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The High Energy Photon Source (HEPS) is the first high-energy diffraction-limited storage ring (DLSR) light source built in China with designed natural emittance of 35 picometer radian. Beam stability is a critical issue for such an ultralow-emittance facility. To study ground vibration effects more closely aligned with reality, a novel beam dynamics analytical model is developed. In this model, different frequency influence together with wave speed caused phase difference and vibration decay are considered. The vibration controlling requirement are deduced using this model. The vibration specifications on storage ring floor is set to be 25nm for displacement RMS integral within frequency range of 1 to 100Hz.To control such rigorous restrictions, stable design concepts for the critical component such as slab, magnet and BPM girder are adopted to ensure the vibration not magnifing during propagation. The actual vibration control effect will be presented.

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Beam position measurements: from pickups to stable beams at cSTART

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The KIT project, cSTART (Compact storage ring for accelerator research and technology), aims to demonstrate the injection and storage of sub-ps bunches and the use of LPAs (Laser plasma accelerator) as injector.
The long damping time of the low energy beam (50 to 90 MeV) compared to the storage time grants opportunities to study non-equilibrium beam dynamics. Ultrashort non-equilibrium beams in electron storage rings are expected to strongly evolve, especially in the first few turns after injection. This requires fast and sensitive turn-by-turn beam diagnostics with a high dynamic range. In this talk, we present the cSTART project and elaborate on the beam position diagnostics system including the pickup electrodes and turn-by-turn readout electronics. Furthermore, we present preliminary results of characterization tests on the BPM readout prototype unit using signal generators. We also show preliminary results on misalignment studies and orbit corrections with varying resolution of the turn-by-turn beam position measurements.

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Status of the design and simulations for the FOFB of PETRA IV

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PETRA III is one of the most important facilities at DESY. The PETRA IV project aims to replace PETRA III with an ultra-low emittance ring (20 pm), add a new experimental hall in two additional octants and replace DESY II with a new low emittance booster. In this way, the emittance will be reduced from 1300 pm to 20 pm. A brief overview of the activities on the way to a stable beam orbit will be given. The following points will be introduced during the presentation: The stability task force, the system modelling and hardware design, the perturbation and noise models used and the SISO simulation as a first step towards a full ring simulation.
Finally, we will conclude the presentation.