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MOTORIZED GIRDER REALIGNMENT TEST IN THE PETRA III STORAGE RING

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Abstract

The system in place for remote alignment of the girders, which carry the storage ring elements of the PETRA III light source, was never used to perform re-alignments after the initial installation of the storage ring in 2009. Since the planned upgrade, PETRA IV, can benefit from the fine control of the girder position to achieve the design beam performance, a movement test of one of the PETRA III girders was performed in December 2022. The ability to safely and precisely remote control the equipment was demonstrated and the accuracy of the optics model that describes the effect of the girder movement on the orbit could be evaluated. The findings of this experiment are summarized in this paper.

MOTIVATION

The next generation light source PETRA IV [1, 2] should be built within and extend the existing infrastructure of PETRA III [3,4], where a significant part of the old tunnel, that is made of individual tunnel segments, will remain. Owing to the lower emittance, PETRA IV will have a factor of two to ten lower alignment and aperture tolerances with respect to PETRA III. Investigations at PETRA III related to long-term orbit stability and its correlation to environment parameters, including the tunnel temperature and the mechanical movement of different tunnel segments with respect to each other, revealed that the expected ground motion could potentially impact the machine performance of PETRA IV [5, 6].

Similar to other light sources, the storage ring elements in the lattice of PETRA IV will be placed on girders that mechanically connect and carry a group of elements, such that those can be assembled, transported and aligned as a unit. Slow orbit drifts introduced by ground motion and temperature effects are compensated by the orbit corrector system. However in order to prevent operating the low-strength corrector magnets at their current limit, the girders will feature a remote-controlled alignment system. Based on the corrector strength patterns and a response matrix, alignment corrections will be applied to individual girders and so provide an alignment stability within the required tolerances.

In PETRA III, the Max von Laue experimental hall is equipped with girders that have a remote controllable alignment system (see Fig. 1). However, here the girders are not moved during beam operation, the system has only been used during the initial installation of the storage ring elements in the tunnel in 2009. Thanks to the tolerances, potential movements or drifts are well compensated by the orbit correction system.

It is of crucial importance for the PETRA IV performance prospects to understand the limits of the girder-response-matrix model and the accuracy with which this procedure can be performed. Therefore, after a successful dry run in October 2022 [7], a movement test was performed on a PETRA III girder in the Max von Laue hall in December 2022.

EXPERIMENT SETUP

The PETRA III girder alignment system is not built to perform automatic remote-controlled girder displacements from the accelerator control room. Movements can only be initiated when locally connecting to the motor controls

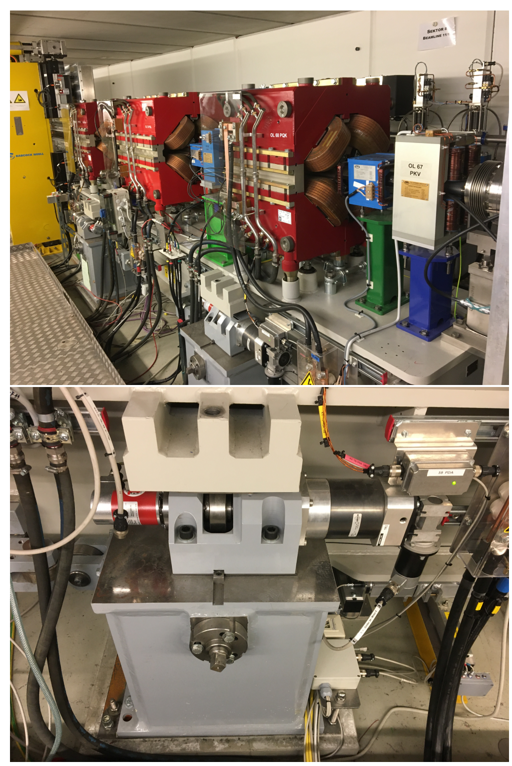

Figure 1: Top: View of a girder installed in the PETRA III tunnel downstream of an undulator (yellow element on the left), carrying three quadrupole magnets. Bottom: Zoom to a motor and encoder installed on the cam mover-based alignment system connecting the supporting feet to the girder table.

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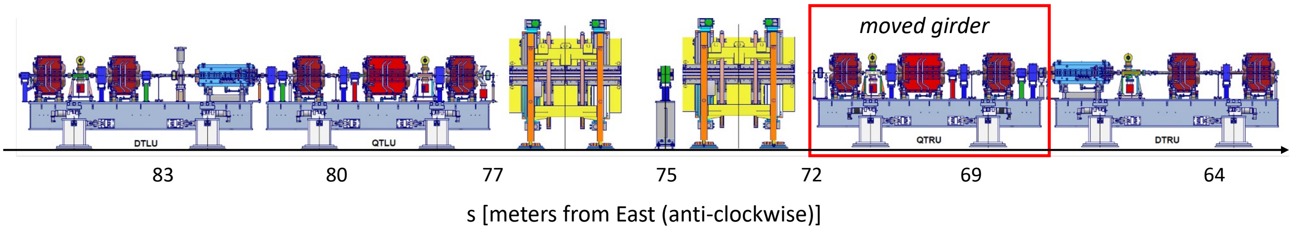

Figure 2: Graphical view on the accelerator elements in the proximity of the moved girder (marked with red rectangle). Location numbering is given from the East symmetry point of the PETRA III ring counting anti-clockwise (towards the left, viewed radially outward from the centre of the ring).

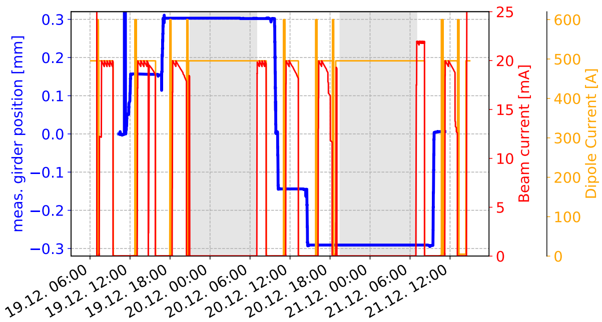

Figure 3: Time evolution over the three-day experiment. The left axis (blue) shows the measured horizontal girder position, the right axes display the beam (red) and dipole magnet (orange) currents, showing the time periods during beam operation and tunnel access for girder movement. Gray shaded areas indicate night time, with magnet current on, but no circulating beam.

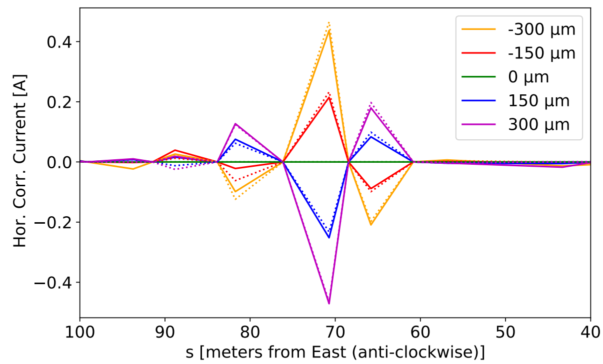

Figure 4: Measured (solid) and simulated (dotted) horizontal corrector currents for the five girder positions as a function of the corrector location counted from the East symmetry point in anti-clockwise direction. Corrector magnets are displayed as small dark blue elements in Fig. 2. Values are given relative to the original girder position.

in the tunnel. This implies that girders cannot be moved while beam is circulating. A time-consuming experiment procedure with alternating periods of tunnel access for girder movement and beam operation to observe the beam orbit response was necessary. The time evolution of the experiment is shown in Fig 3. Throughout three days the girder was shifted in the horizontal plane to five positions $[-300, -150, 0, +150, +300]$ μm. The most extreme positions were kept over night without circulating beam, but the magnet current set to operational values. This kept the tunnel temperature relatively constant and so guaranteed compatible experimental conditions through all steps of the experiment.

Figure 2 shows a graphical view of a Double Bend Achromat (DBA) cell that structures the lattice in the Max von Laue hall with two canted undulators in the centre (yellow elements) [8]. Location numbering is given for the cell hosting the moved girder (marked with the red rectangle), counting anti-clockwise from the East symmetry point of the PETRA III ring. This girder was chosen for the experiment, because it is the only one in its cell that features bellows to both ends. Nevertheless, those bellows only compensate longitudinal movement of the vacuum chamber, but are transversely rigid [7]. To mitigate the risk of damaging the vacuum system, the maximum movement range was limited and drifts of the vacuum chamber were carefully monitored along with the overall girder position. So-called *High Frequency Movement Monitors* (HF-MOMO) [9] constantly observe the position of the vacuum chamber at the location of the Beam Position Monitors (BPM). Additionally, at the end of each beam time, Beam Based Alignment (BBA) measurements were performed to identify any shift of the vacuum chamber and the BPMs attached to it.

At each step, stable beam conditions at 20 mA beam current and operating orbit feedback were set up. The beamlines P04, P07 and P14, all located in the Max von Laue hall, evaluated their photon beam positions. P14 receives the photon beam from the undulator just upstream of the moved girder.

OBSERVATIONS

Re-injection of the beam with the initial corrector settings (taken at the zero position) after each girder movement was always immediately possible without threading. The corrector currents necessary to compensate the girder offset are shown in Fig. 4.

The girder displacement was performed with the precision of a few micrometers. However, due to the rigid vacuum joints, up to about 40% of the girder movement was observed

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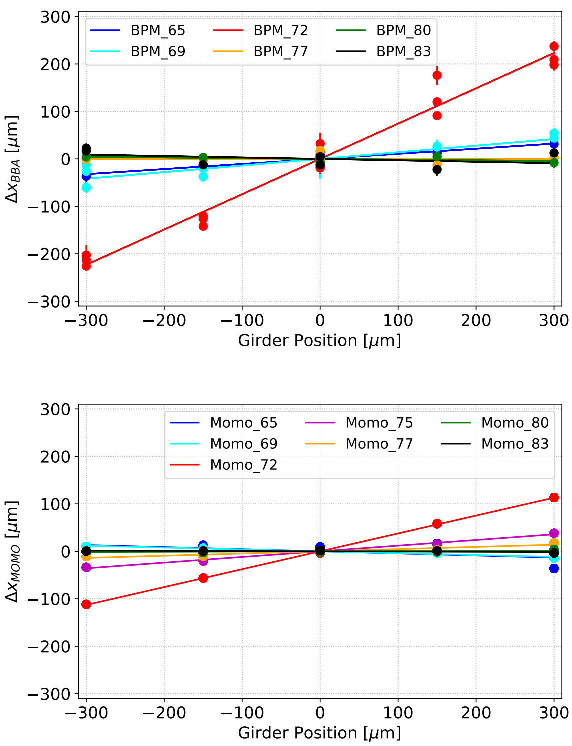

Figure 5: Horizontal beam-based alignment (BBA) data (top) and beampipe position measured with the HF-Movement Monitors (HF-MOMO) (bottom) as a function of the girder position. Lines show the measurement at different locations in the proximity of the moved girder, numbers in the legend labels indicate locations according to Fig. 2.

as shift of the undulator vacuum chamber. The largest shift of the chamber occurred at 72 m (red line in Fig. 5), just upstream the bellow between the undulator and girder. This indicates that the bellow partially decoupled the transverse movement of the girder and the adjacent vacuum chamber. The BBA for the BPM at 72 m was performed with the first quadrupole on the moved girder (centred at 71 m), while the BPM itself is installed upstream the bellow. Therefore, the BBA result shows (within the measurement accuracy) the offset of girder minus the observed shift of the vacuum chamber, see Fig. 5 (top). A small coupling to the vertical plane was present, most probably because of small unevenness of the ground underneath the girder.

Taking these observations into account, the corrector currents, which compensate the introduced girder misalignment, are in good agreement with the expectation, as demonstrated in Fig. 4.

The photon beam position of beamline P14 drifted locally with the girder movement. This is directly related to the drift of the undulator chamber, since the BPMs responsible to stabilise the photon beam position are attached to the chamber and the orbit feedback accordingly pushes the electron beam position in the undulator to follow the BPM displacement.

CONCLUSION

The first motorized girder displacement since its installation has successfully been performed in the PETRA III storage ring. The effects on the circulating beam orbit and technical limitations have been studied. During the three-day experiment five girder positions could be evaluated. Because of time and technical constraints the movement was limited to ±300 µm in the horizontal plane.

The circumstances in PETRA III are not optimal for this kind of experiment, nevertheless the ability to safely and precisely remote control the equipment was demonstrated. The optics model that describes the effect of the girder movement on the orbit reproduces well the observed changes in corrector currents when the effect of the drifted vacuum chamber is considered.

The knowledge compiled in the preparation and execution of this experiment concerning technical requirements and the automation of the alignment provides valuable input for the design of the PETRA IV system.

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