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BEAM STABILITY IN THE MAX IV 3 GeV STORAGE RING

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Abstract

The MAX IV Laboratory, inaugurated in 2016, hosts a 3 GeV ultra-low emittance storage ring, a 1.5 GeV storage ring and a linear accelerator driven Short Pulse Facility to deliver synchrotron radiation to scientific users. A Stability Task Force has been assigned to ensure the delivery of stable beams since early on in the design phase of the laboratory and is continuing its work in an ongoing and multi-disciplinary effort. Measurements of the electron beam stability resulting from the passive stabilization approach taken for the two storage rings will be presented, as well as figures of beam stability with the Fast Orbit Feedback system in operation. Each ID beamline in the 3 GeV storage ring is equipped with a pair photon beam position monitors that are currently used to complement the electron beam position monitors. In the light of the city development around the MAX IV campus, maintaining the good mechanical stability of the laboratory has to be seen as an ongoing effort. A number of studies are being performed to identify possible risks and to decide where measures need to be taken.

INTRODUCTION

The MAX IV 3 GeV storage ring, is optimized for the production of high-brightness X-rays and features a 20-fold seven-bend achromat lattice reaching a bare lattice emittance of 328 pm rad [1, 2]. The emittance coupling is adjusted for a routine delivery beam with a vertical emittance of 8 pm rad. All user beamlines use insertion devices (IDs). The RMS electron beam sizes in the source points are 52.0 μm horizontally and 4.0 μm vertically when considering the horizontal emittance reduction by ID radiation damping.

In order to achieve our overall stability goal, a beam stability better than 10 percent of the RMS beam size, the tolerances on magnet stability of 20 nm to 30 nm RMS displacement had been defined during the project phase [3]. This is achievable also because the very good initial 'green field' ground vibration levels have not increased significantly by the presence of the laboratory.

This paper shows examples of the work of the MAX IV Stability Task Force covering mechanical stability topics and floor vibration, the orbit stability of the stored electron beam, the role of orbit feedback systems, as well as position and angle stability studies with the synchrotron radiation (SR) beam from IDs.

MECHANICAL STABILITY

Mechanical stability at MAX IV is in general achieved by passive systems [3]. While internal vibration sources are easily controlled by passive isolators, disturbances originating outside the borders of the facility must be dealt with differently: by careful design of the support structures, and by early involvement in planned projects near the laboratory. A few examples are mentioned below.

During the design phase of the facility, the main mechanical stability concern was heavy traffic on the nearby motorway (distance approx. 120 m). Here the special floor structure designed to mitigate traffic-related disturbances together with the implementation of a policy ensuring stiff foundations (by prescribing a goal for the lowest resonance frequencies for structures supporting accelerator and beamline components) turned out to be very successful. Even though vibration peaks due to heavy traffic are clearly observable in the floor of the laboratory (see the correlation between vibration peak count and heavy vehicle count in Fig. 1), as of today, only minor disturbances to beamline operations have been related to traffic. The vibration levels caused by motorway traffic are typically used as a reference to evaluate the impact of future projects in the vicinity of the laboratory.

MAX IV was one of the first buildings in Brunnshög, a quickly developing district of Lund where office buildings, research facilities and residential homes for 40 000 inhabitants will be built the coming decades. As the city is growing around the MAX IV Laboratory, the nature of addressing mechanical stability changes. The main focus has been shifted from ensuring proper design towards influencing potentially vibration-generating projects planned in close proximity to our operations. In practice, our concerns regarding mechanical stability are raised in early planning phase through discussions with policymakers and urban developers about the location and design of their projects. For instance, track vibration isolation of a new tramway line close to the laboratory was implemented thanks to the cooperation with the municipality, and as a result, no detectable influence has been observed on the accelerator since the tram has been in operation since the end of 2020.

Currently, we are involved in the decision on where to introduce speed bumps on nearby roads. To minimize the risk of disturbing ambient vibrations at the laboratory, tests were conducted in collaboration with the municipality to determine safe distances for different bump profiles, vehicle weights, and speeds, see Fig. 2.

ELECTRON BEAM STABILITY

The Slow Orbit Feedback (SOFB) system is designed to correct the electron orbit at repetition rates up to 10 Hz in order to handle slow drifts [4]. A total of 200 beam position monitors (rf-BPMs) are available in each plane as well as 200 horizontal and 180 vertical corrector magnets. The targeted orbit stability is achievable with the SOFB only during operation (see Fig. 3); a result of the excellent passive stability of the storage ring. Integrated up to 1 kHz

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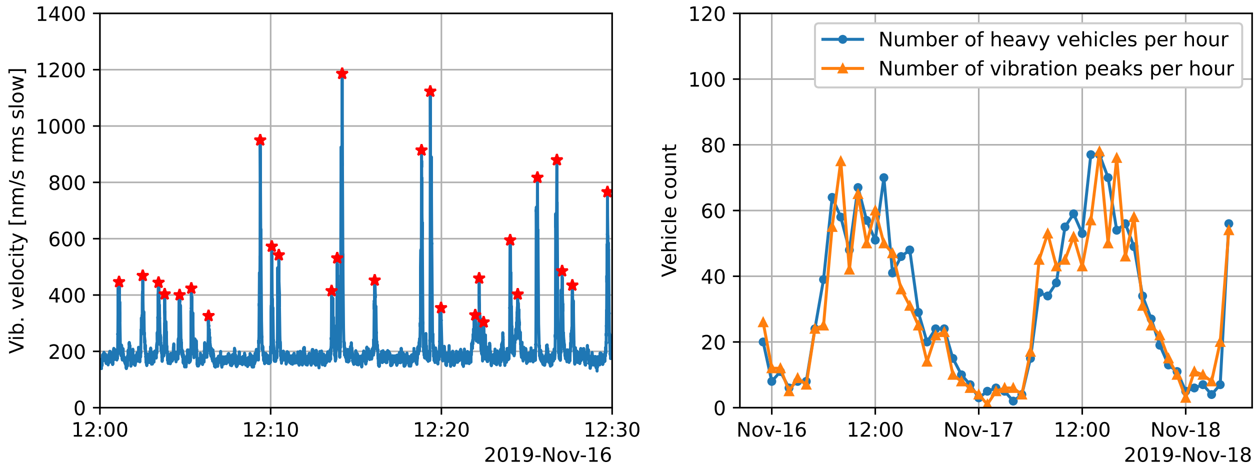

Figure 1: Left diagram: floor vibration time history (blue) and vibration peaks (red asterisks). Right diagram: comparison of the number of floor vibration peaks per time interval (blue) to the number of heavy vehicles on the nearby motorway (orange), measured by the Swedish road traffic authorities.

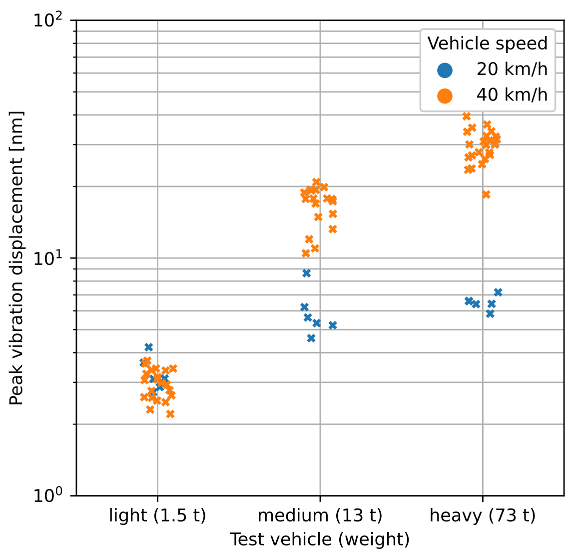

Figure 2: Results of an experimental study with vehicles driven over a speed bump. Floor vibration peak amplitudes for different test vehicle weights and speeds.

the horizontal RMS orbit displacement at beam position monitors closest to ID source points is 738 nm horizontally and 192 nm vertically.

Since the design of the slow correctors, iron core magnets and copper vacuum chambers, pose a physical restriction to the bandwidth of the SOFB system, an independent Fast Orbit Feedback (FOFB) [5] is installed using fast window-frame magnets at locations with stainless steel vacuum chambers. These fast correctors are of limited range and a periodical off-loading to the SOFB is required to avoid saturation, a principle that is also implemented at the Synchrotron Soleil [6].

The important role of the FOFB in the 3 GeV ring is the supression of orbit perturbations caused by transients induced by ID gap (or phase) movements, for which neither the SOFB nor the deployed ID orbit feed-forward system are fast enough. With the FOFB operating during user beam delivery ID gap and phase changes are transparent to the other user beamlines.

X-RAY BEAM POSITION MONITORING

Situated upstream of all beamline optics the frontend X-ray Beam Position Monitors (XBPMs) provide a valuable diagnostics tool for the SR delivered to each beamline and offer, due to the difference in their working principle, a complementary measurement to the rf-BPMs on the electron beam.

All of the ten insertion device beamlines at the MAX IV 3 GeV storage ring that are receiving SR today are equipped with a pair of XBPMs in their frontends [7]. Each XBPM head is equipped with four tungsten blades in a x-shape geometry. The blades interact with the outer region of the SR from the ID via the photoelectric effect and the resulting photocurrents are measured with electrometers [8]. Calibration of position is done on the control system level. The XBPM system is currently optimized for long term monitoring and archiving of position data.

XBPM measurements have confirmed the effectiveness of the SOFB and especially the FOFB in terms of stability of the delivered photon beams. The targeted observation of potential photon beam position drifts over time periods of hours to days, however, proved to be difficult because of the XBPM's intrinsic dependency on ID gap and phase as well as a dependency on stored beam current. Nevertheless, the combination of rf-BPM data, orbit corrector magnet currents

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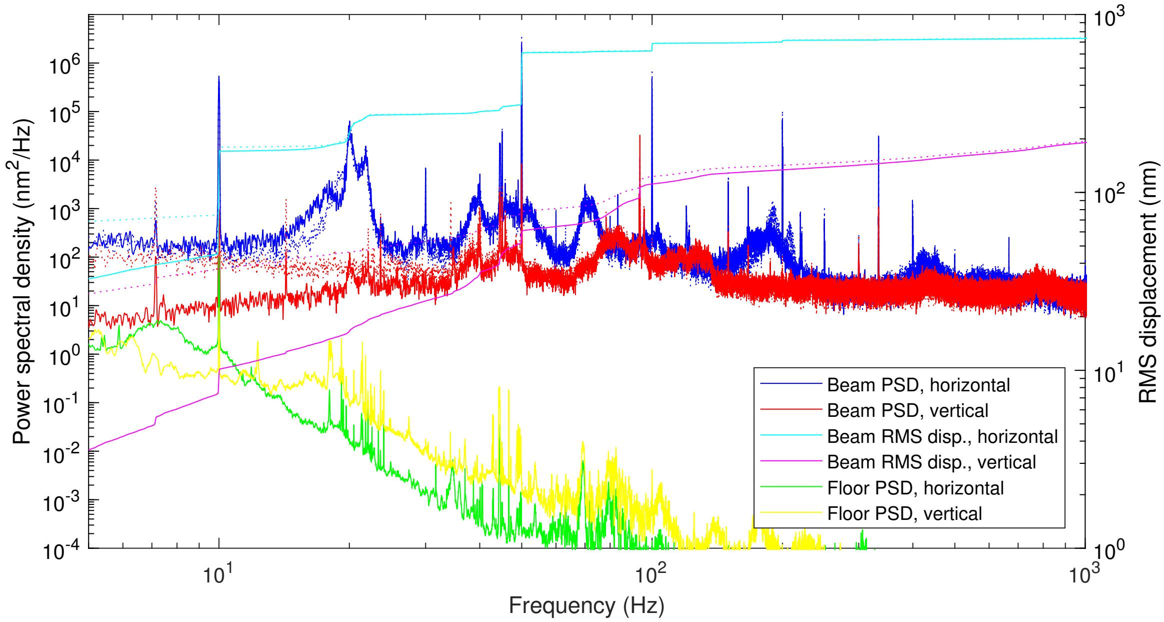

Figure 3: Electron beam motion (red and blue) and floor vibration (green and yellow) power spectral densities (on the left axis) as well as integrated RMS displacement of the electron beam in the horizontal and vertical plane (cyan and magenta, respectively, on the right axis) as a function of frequency. The electron beam data was measured with rf-BPMs flanking ID source points. The dotted lines show beam motion with only SOFB active while the solid lines show beam motion with active FOFB.

and XBPM data allow studies of the behaviour of both types of beam position diagnostics as well as an improvement of source stability.

CONCLUSIONS AND OUTLOOK

The MAX IV approach to beam stability is to a large extend based on the mechanical stability of the facility and its surroundings. The coming years in which a new city district will be developed in our neighborhood will require careful observation and possibly intervention in order to maintain our stability goals.

Slow and Fast Orbit Feedback systems are in daily user operation, stabilizing the orbit in the presence of slow drifts as well as fast perturbations for example from ID motion. Further improvement of the FOFB, for example the increase of its correction bandwidth require beam time and are planned for the near future. The installation and commissioning of a corresponding system in the MAX IV 1.5 GeV ring is ongoing.

XBPMs are currently in use for continuous monitoring. During the past months the option to change readout electronics to Libera Photon [9] has been investigated, a system that would allow for a much more efficient integration of the XBPMs into the existing rf-BPM system. In-house research is ongoing regarding alternative XBPM heads for the frontends of the 3 GeV ring [10].

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