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MAX IV OPERATIONS - DIAGNOSTIC TOOLS AND LESSONS LEARNED

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Abstract

New beam diagnostic and monitoring tools developed by the MAX IV Operations Group are presented. In particular, new beam position monitoring (BPM) and accelerator tunes visualization tools and other simple but useful applications are presented. We also briefly share our experience with the development of audible alarms, which help operators monitor various parameters of the machine, and explain how the implementation of all these tools have improved accelerator operations at MAX IV.

INTRODUCTION

The MAX IV laboratory [1, 2] is a synchrotron radiation laboratory in Lund, Sweden. MAX IV is the first Multi-Bend Achromat (MBA) Synchrotron Radiation Light Source in the world and provides scientists with the most brilliant X-rays for research. The laboratory was inaugurated in June 2016 and consists of two storage rings operated at 1.5 and 3 GeV providing spontaneous radiation of high brilliance over a broad spectral range. The 1.5 GeV ring has a circumference of 96 m and employs a double-bend achromat lattice to produce an emittance of 6 nm rad. The 3 GeV storage ring on the other hand is aimed towards ultralow emittance to generate high brilliance hard X-rays. The design of the 3 GeV storage ring includes many novel technologies such as MBA lattice and a compact, fully-integrated magnet design. This results in a circumference of 528 m and an emittance as low as 0.2 nm rad [3].

A linear accelerator (linac) works as a full-energy injector for the storage rings as well as to a Short Pulse Facility (SPF). The prime sources for synchrotron radiation at the rings are optimized insertion devices (IDs), providing intense X-ray light for each of the MAX IV beamlines.

MAX IV ACCELERATOR OPERATIONS

The Operations Group is responsible for delivering stable high-quality beams to the beamlines (users). Figure 1 shows the facility status in May 2019, when eleven beamlines had closed undulator gaps and open shutters, indicating that they were actively taking synchrotron light produced at the accelerators, all at the same time. As one can also see from the plot, the linac performed excellently as injector providing beam current top-up every 30 minutes, as well as high bunch charge (100 pC) to the SPF.

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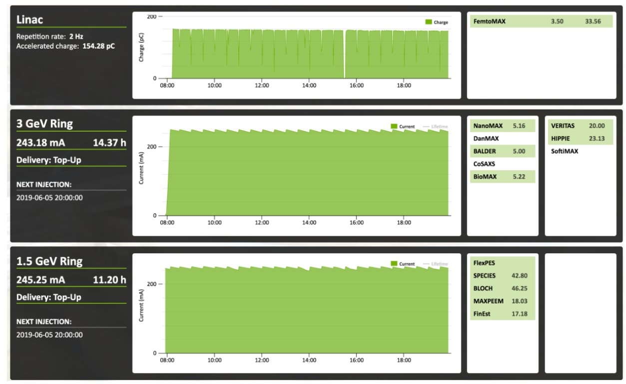

Figure 1: MAX IV status page in May 29, 2019.

BEAM POSITION MONITOR TIME EVOLUTION

BPM trends is a tool developed by the operations group that shows the storage rings beam positions over time (a real-time "sliding plot" during operations) as measured by all the rings' BPMs. The vertical scale on the right (in µm) controls whether there is any deviation within the lower and upper limits set by the scale. Figure 2 shows a typical example of stable delivery, where all BPM readings show the beam is kept within the required limits (within 0 µm ± 0.3 µm , in this example) and are therefore shown in green. When the deviation is above the upper limit (0.3 µm) the points are shown in red. An illustration of this fact is demonstrated in Fig. 3, where one can observe that small changes to one of the beamline's gap in the 3 GeV storage ring can cause visible disturbances to the beam. In Fig. 4 it is noticeable that during injections a large vertical line can be observed in the 1.5 GeV ring BPM trends, due to the significant disturbances caused by the dipole kicker that it is used in the smaller ring. A similar line is not observed in Fig. 2 as the 3 GeV ring makes use of a multipole injection kicker (MIK), which accomplishes top-up injections without visibly disturbing the beam orbit.

ACCELERATOR TUNES VISUALIZATION

The accelerator tunes visualization makes use of similar concept as the BPM trends, but it monitors the synchrotron and betatron frequencies variations measured by MAX IV's Bunch by Bunch (BBB) system [4]. Figure 5 shows (starting approximately at -40 min) a manual increase of the Master Oscillation (MO) RF of the 3 GeV storage ring in steps of 5 Hz in order to reach a vertical tune tune of 0.265. At -5 minutes one of the beamlines closes its undulator gap, causing the tune to shift, which is clearly visible at right end of the plot.

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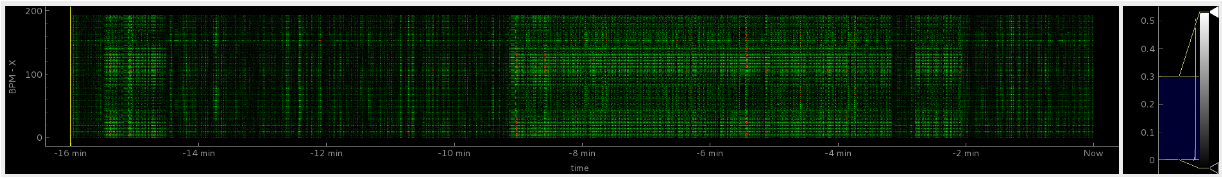

Figure 2: BPM trends in the horizontal plane for the 3 GeV storage ring during stable-beam delivery.

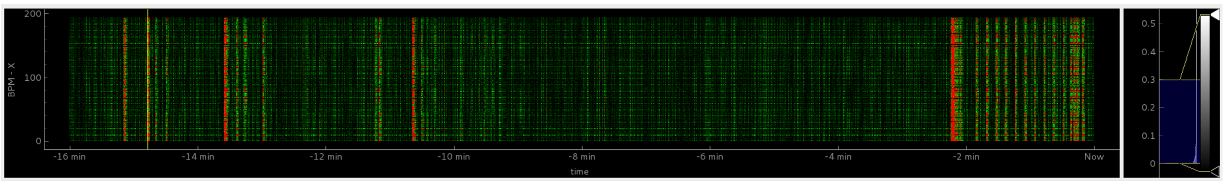

Figure 3: BPM trends in the horizontal plane for the 3 GeV storage ring. The vertical lines at before -10 min and around and beyond -2 min are due undulator gap movements from a beamline.

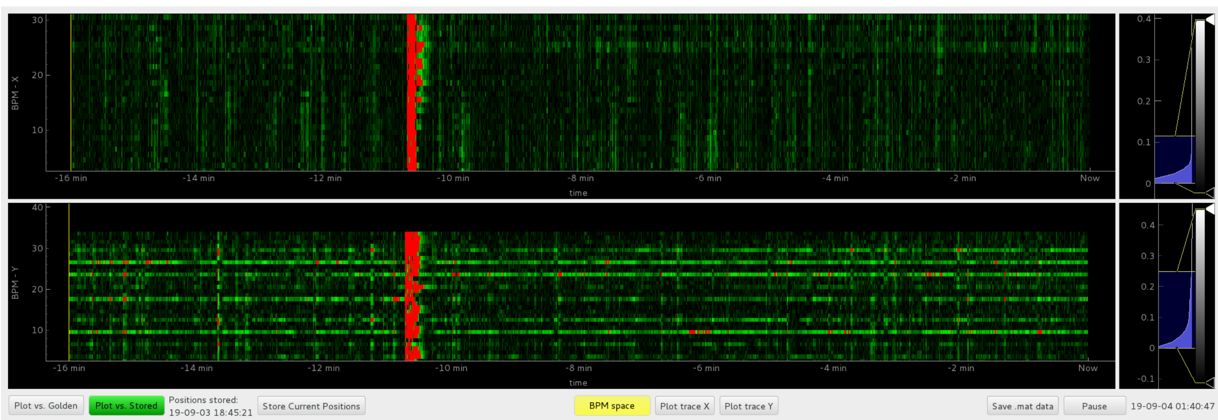

Figure 4: BPM trends in the horizontal (top) and vertical (bottom) planes for the 1.5 GeV storage ring. The thick vertical lines seen in both planes are due to dipole kicker top-up injections.

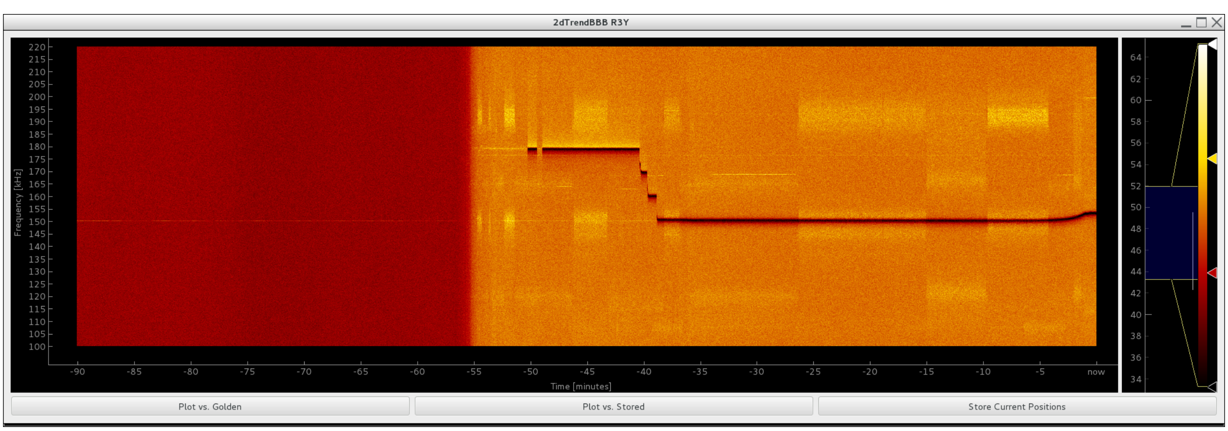

Figure 5: Accelerator tunes visualization in the 3 GeV storage ring. At -40 min the ring RF is increased in 5 Hz steps causing the vertical oscillation frequency to decrease, thus increasing the vertical tune away from an instability region.

Figure 6 shows the longitudinal and transverse frequencies for the 1.5 GeV storage ring. In the longitudinal plane (synchrotron frequency) one can see the effects of the top-up injections done by the linear accelerator every 30 minutes. In the vertical plane (middle plot) one can see the signal is strongest around 350 Hz, but lines for higher and lower frequencies, albeit weaker, can be seen for higher and lower frequencies, which is consistent with the lower signal amplitudes measured by the BBB system in those regions. A similar, but less pronounced effect can be observed in the horizontal plane (bottom plot).

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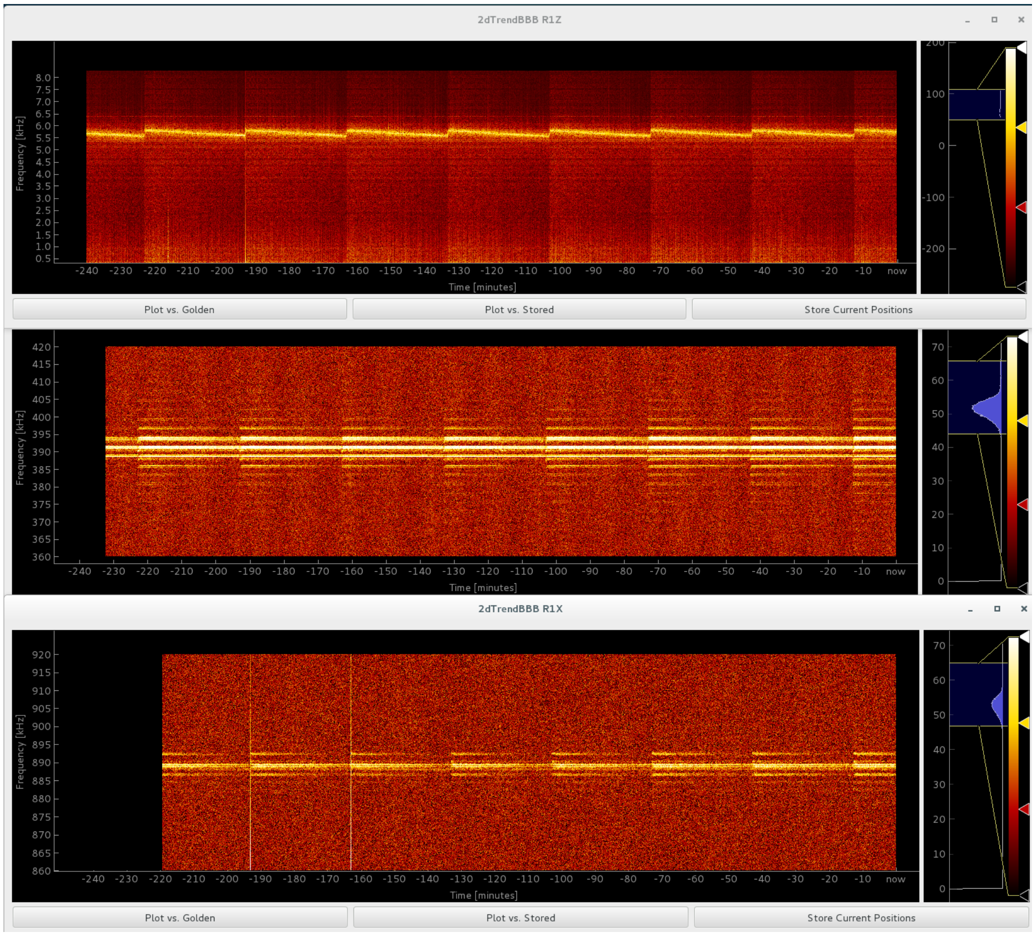

Figure 6: Accelerator tunes visualization in the 1.5 GeV storage ring. Top: synchrotron frequency; middle: vertical oscillations' frequency; bottom: horizontal oscillations' frequency.

SYSTEM MONITOR RF

SMoRF (System Monitor for RF cavities) is a software that monitors the RF cavities of the two storage rings at MAX IV Laboratory, as shown in Fig. 7. It shows their forward power, reflected power, and the ratio between the reflected power and forward power. It is useful for detecting e.g. if an amplifier is failing. If the amplifier status is green, all amplifiers are on and working for that cavity whilst orange means that an amplifier is off or failing. Hovering with the mouse above the cavity status reveals which amplifier(s) is/are in fault or off.

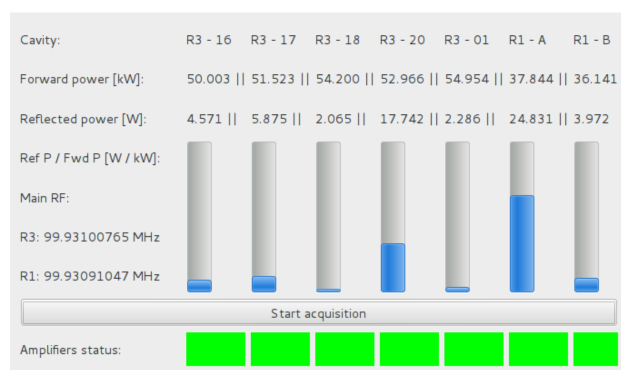

Figure 7: The System Monitor for RF (SMoRF).

ALARMS

The audible alarms tool monitors key parameters of the storage rings and of the linear accelerator, and were chosen by their impact on availability and beam quality. These include e.g. current lifetime, beam emittance, water systems, modulators interlock status, total charged delivered to the Short Pulse Facility (SPF), and fields in the harmonic (Landau) cavities. This application, shown in Fig. 8, allows easy addition of new parameters when required and all existing parameters have editable limits. The alarms aim to improve operators' reaction time, reducing beam losses and improving the overall quality of delivered beam.

SOFT MO RF SWEEPER

The soft Master Oscillator RF (soft MO RF) sweeper is a tool for changing the MO RF in combination with an orbit feedback system. With this tool, the RF can be changed without affecting beamlines that are sensitive to beam instabilities. The simple GUI of this tool shows the current MO

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Figure 8: The Accelerator Operations audible alarms GUI.

RF of the storage ring and enables users to set the desired change of the MO RF. After activating the sweep, the MO RF is moved in steps of 0.05 Hz until the defined change has been accomplished. Between each step, at least 1 second has to elapse and at least 5 iterations of beam trajectory corrections has to be carried out by the orbit feedback system.

Since small adjustments at 0.05 Hz to the MO RF and the minor adjustments to the beam orbit carried out by the orbit feedback system (to keep up with the changes in MO RF) does not affect the beam as seen by the beamlines, this tool has proven itself that it can be used to adjust the MO RF during delivery. In Fig. 9, the difference between when applying a change of 5 Hz directly and by using the soft MO RF sweeper is clearly visible.

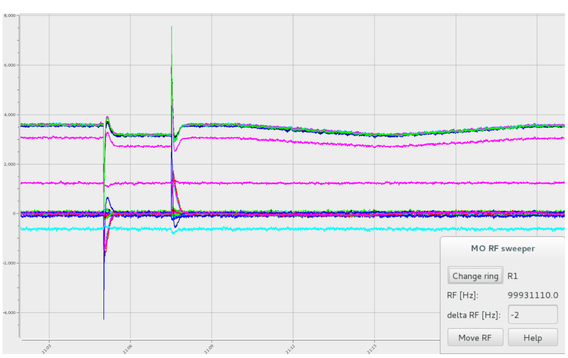

Figure 9: The soft Master Oscillator RF in use. At 21.05 the MO RF is increased by 5 Hz directly (without the sweeper) and it is again decreased by 5 Hz directly at 21:07. A clear disturbance in the beam is measured by the BPMs. At 21:10 the same 5Hz increase is applied to the MO RF, followed by a 5 Hz decrease at 21:21 - disturbances to the beam orbit are then barely seen. The tool's GUI can be seen in the bottom-right corner.

AVAILABILITY AND DOWNTIME MONITORING

In order to improve the gathering of statistics concerning downtime duration and facilitate reliability studies, a "downtime web-application" built by the Operations Group was deployed at the start of 2019. As shown in Fig. 10, the application reports Mean Time Before Failure (MTBF), Mean Time To Failure (MTTF), and Mean Time to Repair (MTTR), on timescales controlled by the user. It allows easy offline analysis of downtime duration by system (beamlines, beam instability, controls, diagnostics, human error, high level software, injector, insertion devices, infrastructure, laser (photo-cathode gun), magnets, machine protection system, network, orbit interlock, programmable logic controller, personnel safety system, radio frequency, vacuum, water, WatchDog (software)).

A beam availability of 98.6% was achieved for the 1.5 GeV storage ring (with 60h of MTBF) and of 98.0% for the 3 GeV ring (with 40h of MTBF) during the first half of 2019, compared to a beam availability of 96.7% for the 1.5 GeV storage ring (with 59.6h of MTBF) and of 96.2% for the 3 GeV ring (with 34.5h of MTBF) during 2018.

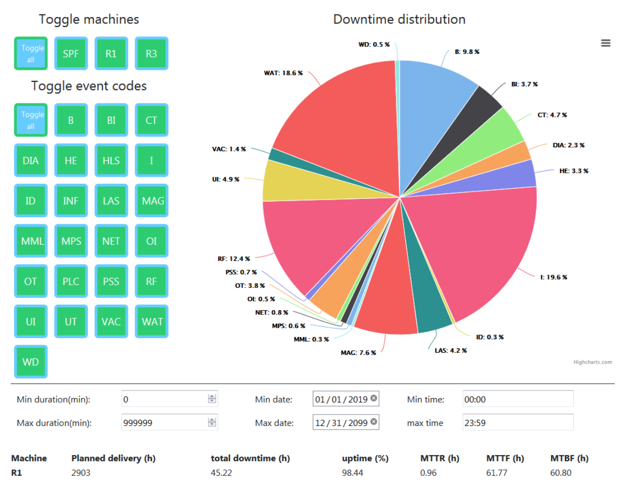

Figure 10: The downtime web-application.

CONCLUSION

Several applications developed by the MAX IV accelerator operations group were presented[5]. Most of the tools are for monitoring purposes, but the group has also developed software that directly improved the beam stability seen by the beamlines, as it is the case with the soft MO sweeper. The development of these tools improved accelerator operations and new ideas are in constant development. A beam availability of 98.6% was achieved for the 1.5 GeV storage ring (with 60h of MTBF) and of 98.0% for the 3 GeV ring (with 40h of MTBF) during the first half of 2019.

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