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COMMISSIONING OF THE BUNCH-BY-BUNCH FEEDBACK SYSTEM IN THE MAX IV 1.5 GeV RING

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Abstract

The MAX IV 1.5 GeV ring is an electron storage ring for production of synchrotron light in the IR to soft X-ray spectral range. The ring will deliver light to its first users during 2018. Bunch-By-Bunch (BBB) feedback has been needed to suppress coupled-bunch mode instabilities (CBMIs), and the feedback has this far been provided in all three planes by a single stripline kicker. This is done by combining the horizontal and vertical baseband feedback signals with the longitudinal feedback signal that is upconverted to the 150 MHz - 250 MHz range. The combined signal is then fed to two stripline electrodes. The layout of the BBB feedback system in the MAX IV 1.5 GeV ring is presented in this paper. Results from instability studies are also discussed.

INTRODUCTION

The MAX IV facility in Lund, Sweden consists of two storage rings for production of synchrotron radiation, and a Short-Pulse-Facility (SPF) [1]. The two rings are designed for 3 GeV and 1.5 GeV, respectively, where the former has delivered light to external users since the spring of 2017. Both rings are operating with top-up injections delivered by a full-energy injector [2].

The 1.5 GeV ring has a 12-fold double-bend achromat lattice, and a circumference of 96 m [3]. The ring is optimized for production of light in the IR to soft X-ray spectral range, and has currently four installed insertion devices with beamline experimental stations. Commissioning of two beamlines has already started. The first external users for this ring are planned to arrive this year. A replica of the MAX IV 1.5 GeV ring has been built in the SOLARIS facility in Krakow, Poland [4].

The two MAX IV rings have been equipped with BBB feedback systems, where the signal processors are delivered by Dimtel [5]. In the 3 GeV ring, two stripline kickers are operating as horizontal and vertical actuators, while a waveguide overloaded cavity kicker is operating as the longitudinal actuator [6]. In the 1.5 GeV ring, a single stripline kicker is operating as an actuator for all three planes.

FEEDBACK SET-UP

A single stripline kicker with four electrodes, described in [7], is operating as an actuator in all three planes. Transverse (horizontal and vertical) feedback is applied when driving two of the electrodes in differential-mode that excites the odd mode, and longitudinal feedback is applied when driving the same two electrodes in common-mode that excites the even mode. The electric scalar potential over a stripline cross-section when exciting the odd and even mode is shown in Fig. 1.

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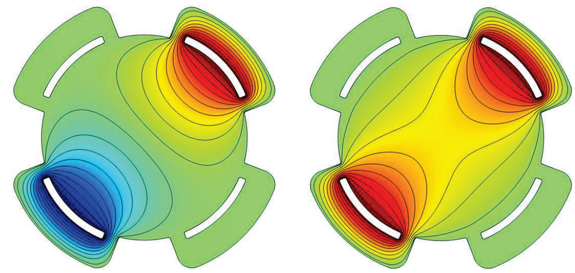

Figure 1: The electric scalar potenital over a stripline cross-section obtained numerically in COMSOL Multiphysics [8] for the odd (a) and even (b) TEM mode. The odd and even modes are excited when applying transverse and longitudinal feedback, respectively.

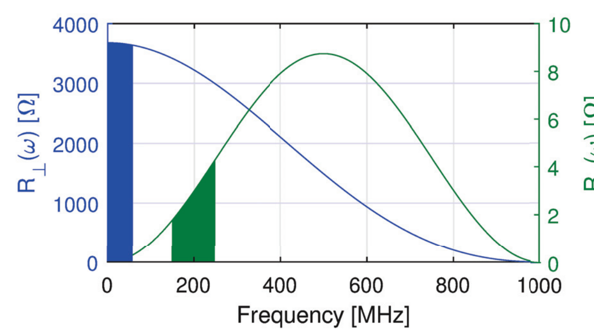

Figure 2: $R_\perp(\omega)$ and $R_{||}(\omega)$ obtained from (1) and (2), respectively. The blue and green areas show the frequency spans where the transverse and longitudinal feedback are applied, respectively.

The transverse and longitudinal shunt impedances, $R_\perp(\omega)$ and $R_{||}(\omega)$, of the stripline can be approximated as

$$R_\perp(\omega) = 2Z_{0,\perp}\left(\frac{g_\perp c_0}{a}\right)^2 \frac{\sin^2\left(\frac{\omega L}{c_0}\right)}{\omega^2} \tag{1}$$

$$R_{||}(\omega) = 2Z_{0,||}g_{||}^2 \sin^2\left(\frac{\omega L}{c_0}\right) \tag{2}$$

where $a = 14$ mm is the radius of the stripline chamber, and $L = 150$ mm is the length of the stripline electrodes.

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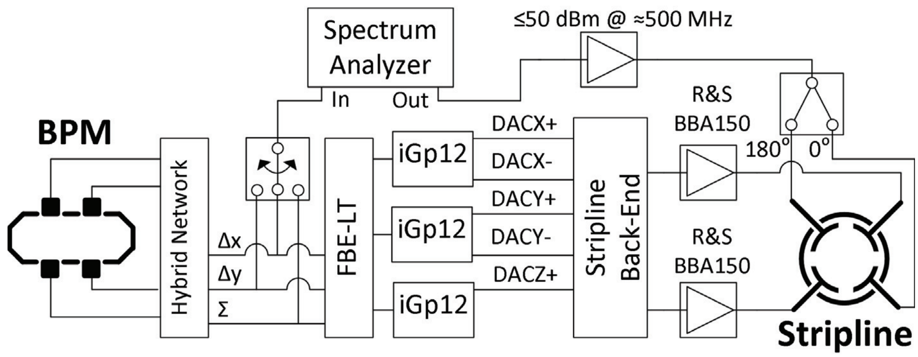

Figure 3: The set-up of the BBB feedback system.

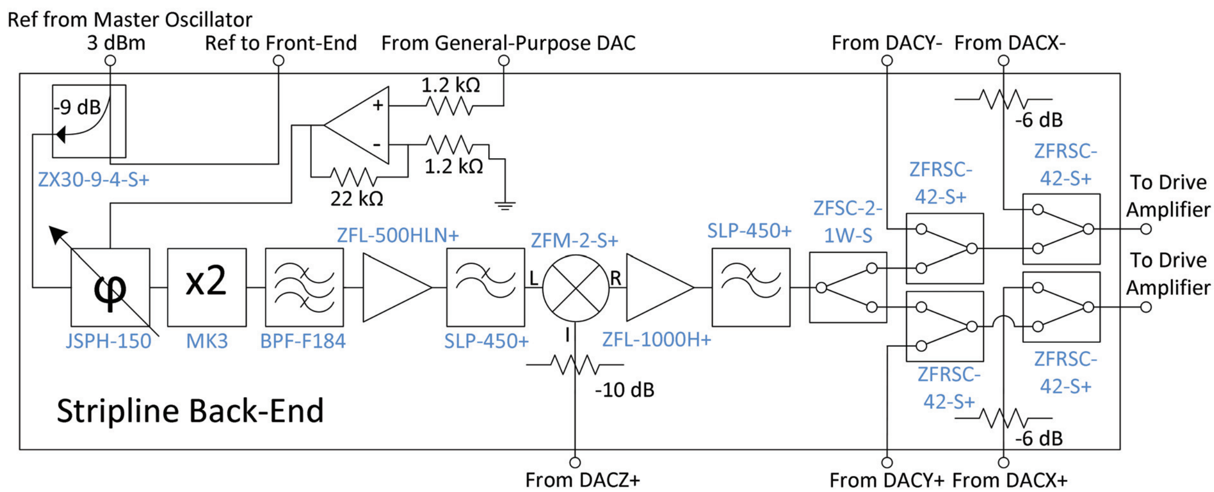

Figure 4: The circuit diagram of the stripline back-end. All part numbers (in blue) are from the Mini-Circuits' catalogue.

$g_\perp = 0.570$ and $g_{||} = 0.295$ are the transverse and longitudinal geometry factors obtained for the odd and even mode, respectively as defined in [9] when the stripline is excited as in Fig. 1. The geometry factors can be obtained analytically with high accuracy as shown in [7]. $Z_{0,\perp} = 49.3\ \Omega$ and $Z_{0,||} = 50.2\ \Omega$ are the characteristic impedances of the two electrodes when excited in differential- and in common-mode, respectively. $R_\perp(\omega)$ and $R_{||}(\omega)$ obtained analytically from (1) and (2) are shown in Fig. 2.

Figure 3 shows a simplified set-up of the BBB feedback system. The differential horizontal (Δx), differential vertical (Δy), and sum signal (Σ) of the beam motion are created from BPM signals in a hybrid network [7]. The BBB front-end (FBE-LT) and digital signal processors (iGp12) are delivered by Dimtel [5]. The front-end is operating at the 9:th RF harmonic ($9 f_{\mathrm{RF}} = 900$ MHz).

Since the main ring RF systems in MAX IV are operating at 100 MHz [10], the span of the BBB feedback baseband signals from the DACs is 0-50 MHz. In Fig. 3, DAC(X/Y/Z)(+/-) are the differential-mode baseband signals from the signal processors. The DAC signals are fed to an in-house constructed stripline front-end which is shown in Fig. 4. Here, the longitudinal feedback signal is upconverted to the 150 MHz - 250 MHz range and fed to the stripline electrodes in common-mode. The horizontal and vertical feedback signals are fed directly in baseband to the electrodes in differential mode. The frequency spans of the transverse and longitudinal feedback are illustrated in Fig. 2. As seen, it would be more efficient to upconvert the longitudinal feedback signal to a frequency span closer to 500 MHz where $R_{||}(\omega)$ has its maximum. However, this is above the 9 kHz - 250 MHz bandwidth of the two R&S BBA150 drive amplifiers [11].

The signals created in the hybrid network can also be monitored by a spectrum analyzer, and the beam can be excited diagonally by using its tracking generator. This is done by exciting the two stripline electrodes that are not used by the BBB feedback system in differential-mode as illustrated in Fig. 3.

INSTABILITIES IN THE 1.5 GeV RING

In the longitudinal plane, CBMIs are driven by Higher-Order Modes (HOMs) in the two main and in the two 3rd harmonic (Landau) cavities. It has been possible to suppress

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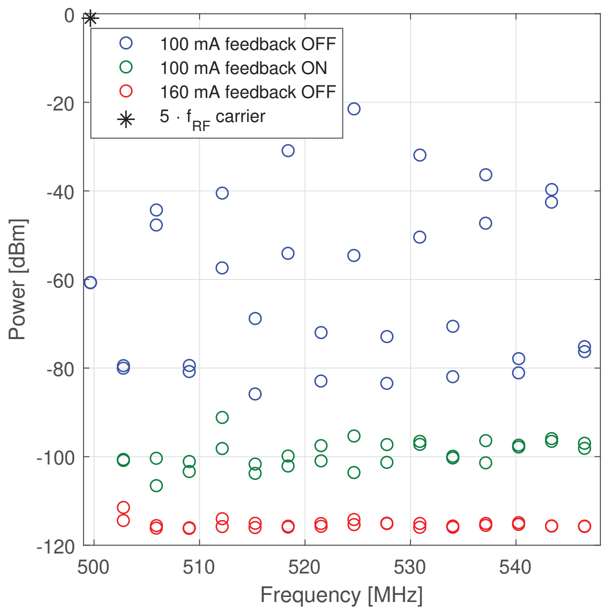

Figure 5: The magnitude of all the 32 coupled bunch modes obtained from the BPM sum signal. The measurement is done with a spectrum analyzer at different beam currents.

these CBMIs with longitudinal feedback presented above. This is, however, only possible after mapping the dangerous HOMs in the cavities and by tuning their resonance frequencies away from the frequencies of the nearby coupled-bunch modes. This was done by using grow-damp measurement with the BBB feedback system. With the cavity settings currently used, it is possible to turn off the longitudinal feedback at higher beam currents (typically above 150 mA) and still keep the beam stable. At these current levels, the CBMIs are completely suppressed due to the increased Landau damping and due to bunch lengthening, even without feedback. This is illustrated in Fig. 5 where the magnitudes of the 32 longitudinal coupled-bunch modes (the harmonic number is 32) are measured over the span $5f_{\mathrm{RF}} \leq f \leq 5.5f_{\mathrm{RF}}$ with the spectrum analyzer (see Fig. 3). Note that mode #0 around $5f_{\mathrm{RF}}$ for the stable beams at 100 mA and 160 mA (green and red curves) are not plotted since they are not visible around the noise floor of -90 dBm around the smeared out RF harmonic. It has been possible to keep the beam stable in the longitudinal plane up to a beam current of at least 240 mA.

At the nominal chromaticity of +2, transverse head-tail instabilities have been observed. With the feedback set-up presented in Fig. 3-4, it has not been possible to suppress them completely at higher currents. Here, the amplified longitudinal common-mode signal delivered to each stripline electrode has a maximum power of > 200 W, while the maximum power levels of the amplified transverse differential-signals are only a couple of Watts. This power unbalance between the planes is deliberate due to the much weaker longitudinal shunt impedance (see Fig. 2). The transverse voltage provided by the stripline can therefore be increased significantly just by increasing the input power to the drive amplifiers. As mentioned above, the bunch lengthening and Landau dampening provided by the 3:rd harmonic cavities seem to be sufficient to keep the beam longitudinally stable at higher currents, so it is unclear if longitudinal feedback is needed, except for diagnostic purposes, once beam delivery starts at higher currents. There are also plans to install more powerful striplines in the ring that are dedicated for transverse feedback. These striplines can simultaneously be used for Pulse Picking by Resonant Excitation (PPRE) which is one possible mode of operation for the ring [12].

CONCLUSIONS AND FUTURE WORK

Feedback in all three planes is applied via two stripline electrodes in the MAX IV 1.5 GeV ring. The instabilities in the longitudinal plane are driven by HOMs in the main and in the 3:rd harmonic cavities. It has been possible to keep the beam longitudinally stable at beam currents up to 240 mA. This is possible with a combination of relatively weak feedback, and with the bunch lengthening and Landau damping provided by the harmonic cavities. The instabilities in the transverse planes are driven by head-tail modes, and it has not yet been possible to suppress them entirely at higher currents with the feedback set-up presented here.

The work with stabilizing the beam in all three planes in the 1.5 GeV ring will continue. The maximum transverse feedback voltage will be improved by increasing the power delivered to the striplines. Improving the control over CBMIs in all three planes will become increasingly important when the first external users arrive later this year

REFERENCES

[1] P. F. Tavares *et al.*, "The MAX IV storage ring project", *Jour. of Synch. Rad.*, vol. 21, pp. 862–877, 2014.

[2] S. Thorin *et al.*, "The MAX IV LINAC", in *Proc. 27th Linear Acc. Conf. (LINAC'14)*, Geneva, Switzerland, Sep. 2014, paper TUIOA03, pp. 400–403.

[3] MAX IV Detailed Design Report, https://www.maxiv.lu.se/accelerators-beamlines/accelerators/accelerator-documentation/max-iv-ddr/

[4] SOLARIS, http://www.synchrotron.uj.edu.pl/

[5] Dimtel, http://www.dimtel.com/

[6] D. Olsson *et al.*, "The Bunch-by-Bunch Feedback System in the MAX IV 3 GeV Ring", in *Technical Report LUTEDX/(TEAT-7253)/1-48/(2017)*, 2017.

[7] D. Olsson *et al.*, "Design of Striplines for the MAX IV and SOLARIS Storage Rings", in *Technical Report LUTEDX/(TEAT-7254)/1-60/(2017)*, 2017.

[8] COMSOL Multiphysics, http://www.comsol.com/

[9] D. A. Goldberg and G. R. Lambertson, "Dynamic Devices A Primer on Pickups and Kickers", in *AIP Conf. Proc. Series - Phys. of Part. Acc.*, 1992.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPAL028

[10] Å. Andersson *et al.*, "The 100 MHz RF system for the MAX IV storage rings", in *Proc. 2:nd Int. Part. Acc. Conf. (IPAC'11)*, San Sebastian, Spain, Sep. 2011, paper MOPC05, pp. 193–195.

[11] Rohde & Schwarz, http://www.rohde-schwarz.com.

[12] C. Stråhlman and T. Olsson *et al.*, "Preparing the MAX IV Storage Rings for Timing-based Experiments", in *Proc. 12th Int. Conf. on Synch. Rad. Inst. (SRI2015)*, New York, USA, July 2015, paper 020043.