ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-MOPMF058

STATUS OF THE LHC SCHOTTKY MONITORS

T. Tydecks*, D. Alves, T. Levens, M. Wendt, J. Wenninger, CERN, Geneva, Switzerland

Abstract

The Large Hadron Collider (LHC) features four transverse Schottky monitors detecting Schottky noise from the beam. Beam properties like tune, chromaticity, and bunch by bunch relative emittance, can be extracted from the Schottky noise. As a non-destructive and purely parasitic method of measurement, the Schottky system is of great interest for real-time determination of beam chromaticities especially. Results from a dedicated machine development (MD) shift concerning its capability to accurately measure the beam chromaticities are presented.

INTRODUCTION

Statistical current fluctuations caused by individual particles in a bunch produce noise-like signals in pick-ups [1, 2]. This Schottky noise contains useful information about machine and beam properties such as coherent / incoherent tune, chromaticity, and beam emittance.

A typical Schottky spectrum is displayed in Fig. 1. The longitudinal signal content appears as a central line in the spectrum. The longitudinal signal content contains the coherent signal as the central peak as well as the incoherent longitudinal signal content responsible for a broadening of the peak at its base. Likewise, the transverse signals, i. e. the sidebands left and right of the central longitudinal signal, contain coherent and incoherent signals. The central peak on top of each transverse sideband at location $\mu_r / - \mu_l$ in Fig. 1 belongs to the coherent content whereas the sideband itself contains the incoherent signal. For a more detailed and comprehensive description the interested reader is referred to [3].

From Schottky spectra, tune, chromaticity and emittance can be extracted as listed in the following [1, 3]. The non-integer part of the betatron tune may be easily determined from the position of the transverse coherent tune lines:

$$q = \frac{\mu_l + \mu_r}{2}, \quad (1)$$

where $\mu_{l/r}$ is the distance of the transverse coherent tune line from the coherent longitudinal line as displayed in Fig. 1. The non-integer part of the incoherent betatron tune may be determined by fitting the incoherent transverse sideband with an appropriate function and recording its center.

Chromaticity may be extracted from the difference in width of the incoherent transverse signal content $\sigma_{l/r}$ as [1, 3]:

$$\xi = \eta \left(n \frac{\sigma_l - \sigma_r}{\sigma_l + \sigma_r} + q \right). \quad (2)$$

Here, η is the slip factor, n is the harmonic of the revolution frequency (for the LHC Schottky system, $f = 4.81$ GHz, $n = 427725$).

* tobias.tydecks@cern.ch

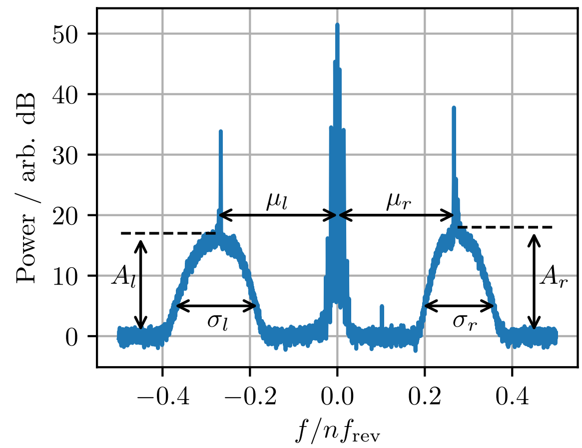

Figure 1: Typical Schottky spectrum with longitudinal signal content in the center and the transverse signal components left and right. Spectrum taken at injection energy at LHC, Dec 1st 2017.

Emittance is related to the total power of the transverse Schottky sidebands [1], and therefore can be extracted by determining the area underneath the transverse sidebands divided by the beam current. For simplicity we focus on the evolution of the relative emittance and concentrate on how the area underneath the transverse sidebands evolves, assuming the beam current to be constant in time:

$$\varepsilon \propto A_l \cdot \sigma_l + A_r \cdot \sigma_r, \quad (3)$$

with $A_{l/r}$ being the height of the transverse Schottky sideband as depicted in Fig. 1.

In the past years, different fitting methods have been tested to determine the width of the transverse Schottky sidebands [3, 4]. As a preliminary result, a so called "threshold" method (described in [3]) has been put into daily operation. This method does not pre-assume a particular shape of the Schottky sideband and searches for exclusively two crossings of spectral power at different levels of power. The width of the sideband is determined from the average distance between these crossings. The advantage of this method is that it is insensitive to the exact sideband shapes.

For comparison, a fourth order Gaussian fit was used in the analysis as

$$y(x) = A \cdot \exp\left(-\frac{(x-\mu)^4}{2\sigma^4} \right). \quad (4)$$

In December 2017 a dedicated MD shift was held to calibrate the analysis and determination of the chromaticities for the LHC. Multiple sextupole settings were investigated

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-MOPMF058

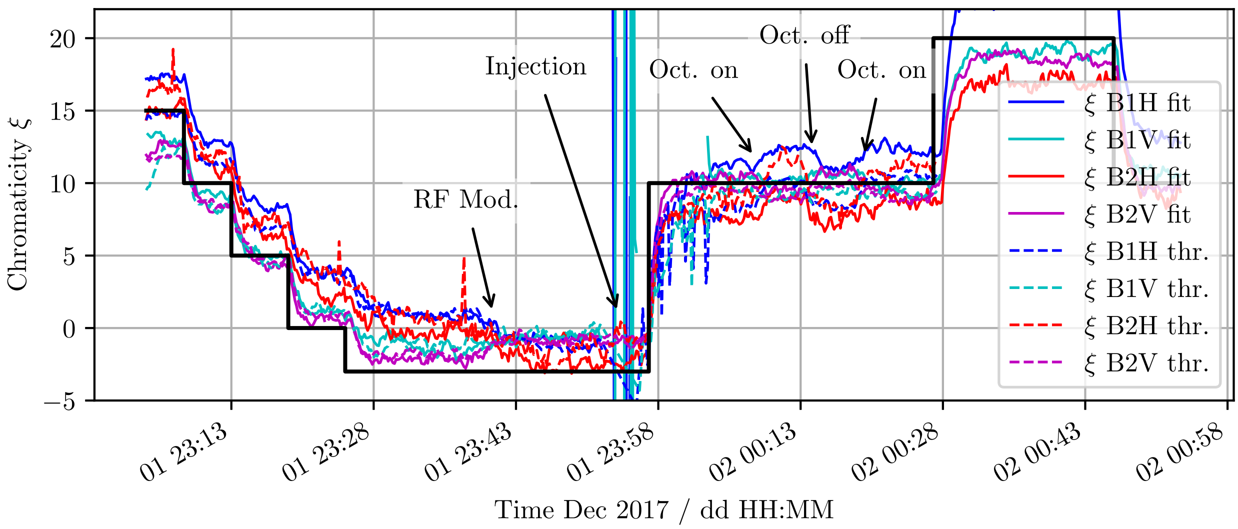

Figure 2: Chromaticity as a function of time during MD2408.

at injection energy. The results from both fitting and threshold method, were compared to reference measurements of chromaticity by RF-modulation.

MACHINE CONDITIONS AND SETTINGS

During most of the MD shift, the machine was kept at injection energy, corresponding to a beam energy of 450 GeV. Following the injection of a probe bunch ($n_p = 5.0 \times 10^9$), the RF frequency was modulated to measure the chromaticities. Afterwards, sextupoles were trimmed to set all chromaticities to $\xi_x = \xi_y = 15.0$. Nominal bunches ($n_p = 1.1 \times 10^{11}$) were injected, and chromaticities were trimmed in steps of 5 units per plane from 15.0 to 0.0. Subsequently, negative chromaticity of −3.0 was tested.

The chromaticity was then changed to $\xi_x = \xi_y = 10.0$. With this setting, the effect of excited octupoles on the Schottky spectra was investigated by trimming the octupoles multiple times between 0.0 and −3.0.

Next, the chromaticity was set to 20.0 units and back to 10.0 units. With the latter setting, the capabilities of the Schottky monitors to trace the evolution of beam emittance were tested by exciting the horizontal plane of beam 1 (i. e. B1H for **Beam 1 H**orizontal plane).

After trimming the chromaticities back to 15.0, an energy ramp was performed while tracking the evolution of the emittance.

MD RESULTS

Chromaticity

In the course of the MD, chromaticities were trimmed between 20.0 and −3.0 units. In Fig. 2, the evolution of the chromaticity during the MD, as extracted from the Schottky spectra, is displayed together with the chromaticity defined by the set values of the sextupoles, verified by intermediate measurement through RF-modulation.

Comparing the chromaticity values, determined by threshold and fitting method to the set up chromaticity values, shows a qualitative good agreement. In particular, the monitor for the vertical plane of beam 2 appears to be well set and capable of following the set up chromaticities even to negative values.

The horizontal planes for both beams will need further attention during start up in 2018 since there appears to be a systematic offset. On the other hand, the vertical plane of both beams appear to follow the set up values qualitatively better, however a scaling factor seems to be missing.

The difference between fitting and threshold method appears to be negligible. Since the threshold method is the

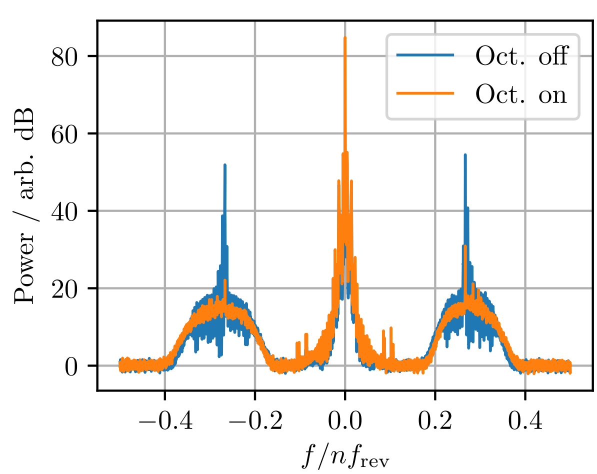

Figure 3: Schottky spectra with and without excited octupoles for B1H.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-MOPMF058

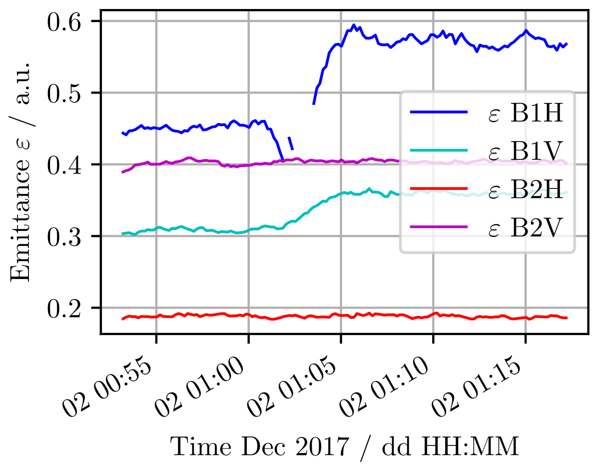

Figure 4: Emittance extracted from Schottky spectra while exciting B1H.

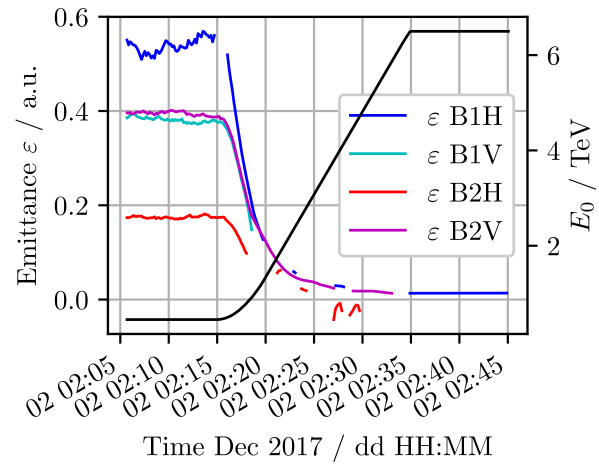

Figure 5: Emittance extracted from Schottky spectra during energy ramp up.

more robust method, it should be the preferred one during operation without human attendance.

Effect of Octupoles on Coherent Lines

During the MD, it was possible to study the effect of excited octupoles on the Schottky spectra. With excited octupoles, the tune spread is increased leading f. i. to increased Landau damping. What could be observed is that the transverse coherent content of the signal is significantly reduced by exciting octupoles as can be seen in Fig. 3. A possible explanation is the increase in incoherent tune spread that coincides with increased Landau damping.

Emittance

The capabilities of the Schottky monitors to trace the emittance evolution have been studied by exciting beam 1 in the horizontal plane at injection energy and by tracking the emittance evolution during energy ramp.

After exciting beam 1 in the horizontal plane at injection energy, the emittance was measured using wire-scanner. The horizontal emittance of beam 1 was increased from 2.0 µm to 3.5 µm, corresponding to a relative increase of 75 %. The vertical plane of beam 1 was affected as well: the vertical emittance of beam 1 increased from 1.75 µm to 2.0 µm, corresponding to a relative increase of 14 %.

In Fig. 4, the extracted emittances are presented during blow up. The change in emittance due to excitation is clearly visible in the horiztonal and vertical plane of beam 1. The ratios between the values for the extracted emittances before and after the excitation are 20 % for the horizontal plane and 13 % for the vertical plane of beam 1.

The difference between expected ratios and measured ratios by the Schottky monitors needs further investigation. During the energy ramp, it was possible to retrieve usable spectra only for the horizontal plane of beam 1 and the vertical plane of beam 2 to follow the emittance evolution (Fig. 5). From adiabatic damping, an emittance reduction to 7 % of the initial value at 450 GeV is expected. The extracted emittances from the Schottky spectra for the horizontal plane of beam 1 and the vertical plane of beam 2 compare to that ratio as 2.5 % and 4 %, respectively.

CONCLUSION

The Schottky monitors at LHC have been tested regarding their reliability in accurately and non-destructively determining the beam chromaticities at injection energy. There are differences between the different monitors observed: while the monitors for the horizontal plane of beam 1 and the vertical plane of beam 2 appear to work well, the vertical plane of beam 1 and the horizontal plane of beam 2 need further fine tuning during start up 2018. The capabilities to track the emittance evolution deserves further investigation as well as possibilities to extract transverse Schottky sidebands from noisy spectra using pattern recognition techniques.

ACKNOWLEDGEMENT

The authors would like to thank the management of CERN and the LHC MD committee for supporting this work.

REFERENCES

[1] S. van der Meer, Diagnostics with Schottky noise, CERN/PS/88-60 (AR), in: Proc. of 3rd US-CERN School on Particle Accelerators, Anacapri, Italy, 1988.

[2] D. Boussard, Schottky noise and beam transfer function diagnostics, in: Proc. of CERN Accelerator School: Accelerator Physics, Berlin, Germany, 1989.

[3] M. Betz et al, Bunched-beam Schottky monitoring in the LHC, Nuclear Inst. and Methods in Physics Research, A874, 113-126, 2017.

[4] O. Chanon et al, Schottky signal analysis: tune and chromaticity, internship report, CERN, Geneva, Switzerland, 2016.