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MD 2408: Study of Schottky Monitors for Q' Measurement at Injection

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Summary

The Schottky monitors installed at the LHC enable the detection of Schottky noise of the two circulating proton / ion beams. From Schottky noise, beam parameters like tune, chromaticity, and relative emittance, can be extracted in a non-destructive and purely parasitic method of measurement. The primary goal of this MD was to study the Schottky monitors capability to reliably and accurately determine the beam chromaticities at injection energy. Furthermore, the possibility to track the beam emittance has been investigated.

1 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 and they 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:

$$q = \frac{\mu_l + \mu_r}{2}, \tag{1}$$

where $\mu_{l/r}$ is the distance of the transverse coherent tune line from the coherent longitudinal line as displayed in Fig. 1a. 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]:

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

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

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:

$$\varepsilon \propto A_l \cdot \sigma_l + A_r \cdot \sigma_r, \tag{3}$$

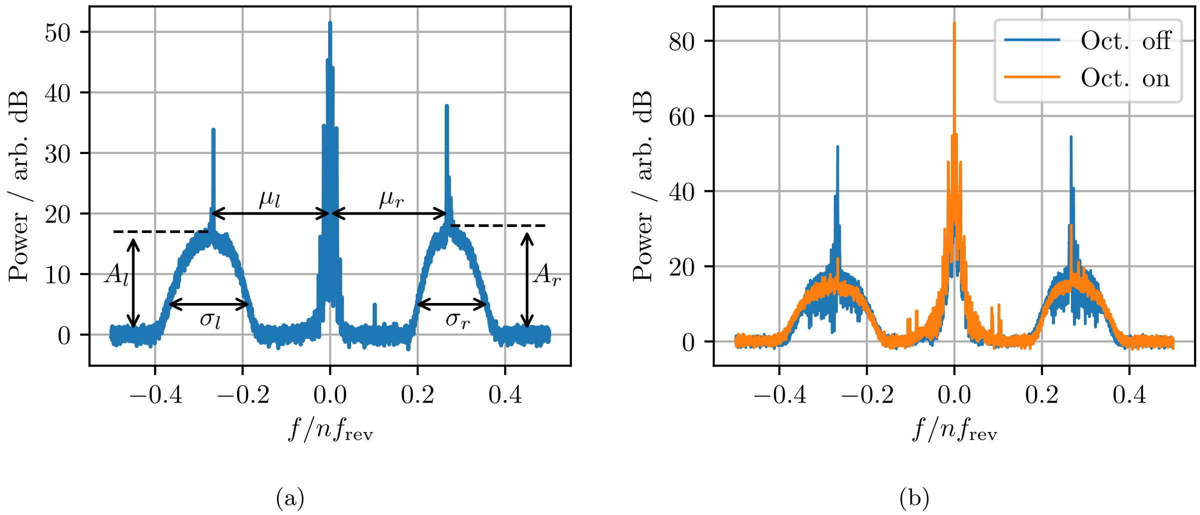

Figure 1: Typical Schottky spectrum (a) with longitudinal signal content in the center and the transverse signal components left and right. Spectrum taken at injection energy at LHC, Dec 1st 2017. Schottky spectra with and without excited octupoles for B1H (b).

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

For calibrating the analysis and determination of the chromaticities, multiple sextupole settings were investigated and the results from both fitting and threshold method [3] compared to chromaticity measurement by rf-modulation.

2 Machine Conditions and Settings

During most of the MD shift, the machine was kept at flat bottom in injection state ($E = 450\,\text{GeV}$). After probe bunch injection ($n_p = 5.0 \times 10^9$), the rf was modulated to measure the chromaticities. Afterwards, sextupoles were trimmed to set all chromaticities to $\xi_x = \xi_y = 15.0$. Nominals 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.

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 back and forth between 0.0 and -3.0.

Next, 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 emittance were tested by exciting B1H.

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

3 MD Results

3.1 Chromaticity

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

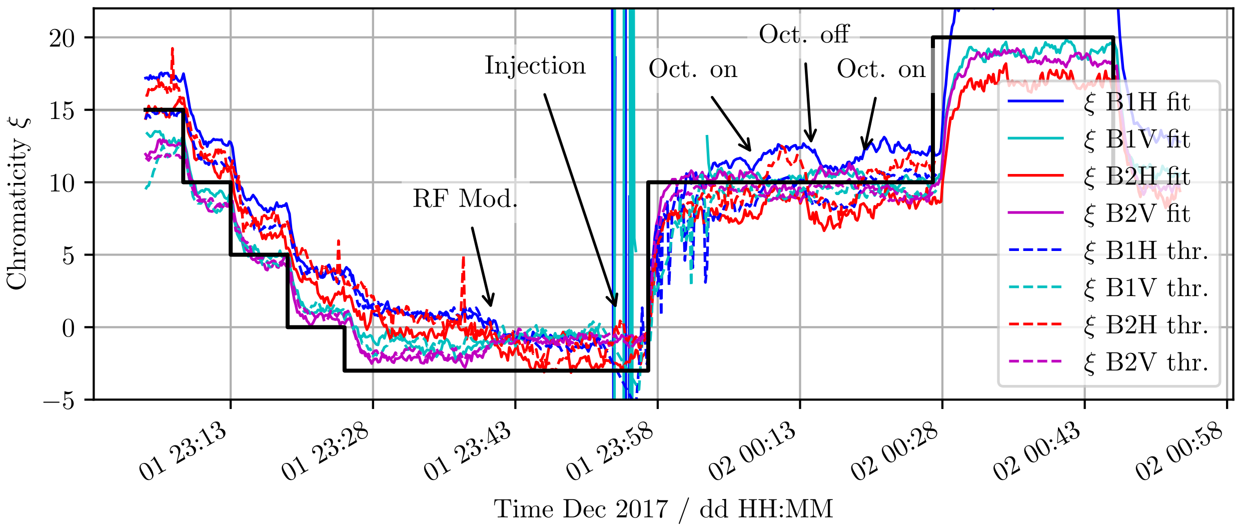

Figure 2: Chromaticity as a function of time during MD2408.

As shown in Fig. 2, the determined chromaticities, using either threshold or fitting method, follow the set up chromaticities (shown in black) qualitatively. There are differences between the monitors depending on beam and plane. Especially B2V appears to be well set up and predictions based on its spectra are able to follow the set up chromaticities even to negative (-3.0) values.

The horizontal planes for both beams will need further attention during start up in 2018 since there appears to be an systematical 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 missing.

The difference between fitting and threshold method appears to be negligible. Since the threshold method is the more stable method, it should be the preferred one during operation without human attendance.

3.2 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, 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. 1b. A possible explanation is the increase in frequency spread that coincides with increased Landau damping.

3.3 Emittance

The capabilities of the Schottky monitors to trace the emittance evolution have been studied by exciting B1H and during energy ramp.

At flat bottom, B1H was excited and the emittance was measured using wirescanner. The emittance of B1H was increased from 2.0 µm to 3.5 µm, corresponding to a relative increase of 75 %. B1V 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. 3a, the extracted emittance as calculated according to

$$\varepsilon \propto A_l \cdot \sigma_l + A_r \cdot \sigma_r, \tag{4}$$

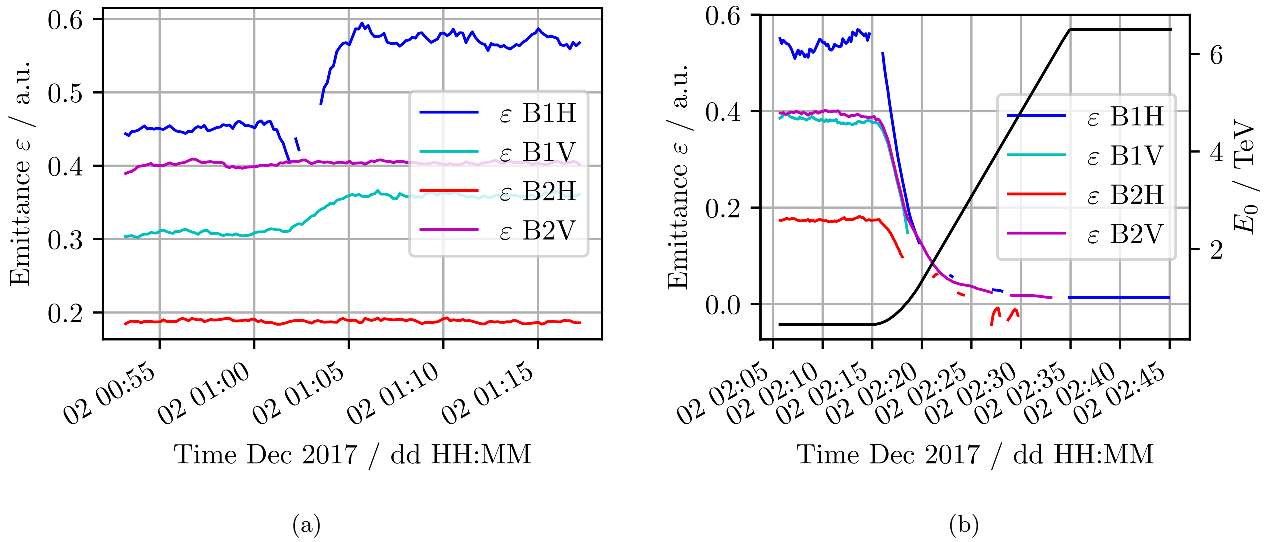

Figure 3: Emittance extracted from Schottky spectra while exciting B1H (a). Emittance extracted from Schottky spectra during energy ramp up (b).

from the height and width of the transverse Schottky humps, is presented during blow up. The change in emittance due to excitation is clearly visible in B1H and B1V. The ratios between the values for the extracted emittances before and after the excitation are 20 % for B1H and 13 % for B1V.

The difference between expected ratios and measured ratios by the Schottky needs further investigation.

During the energy ramp, it was possible to retrieve usable spectra only for B1H and B2V to follow the emittance evolution (Fig. 3b). From adiabatic damping, a emittance reduction to 7 % of the initial value at 450 GeV is expected. The extracted emittances from the Schottky spectra for B1H and B1V compare to that ratio as 4 % for B1V.

4 Conclusion

It was shown that the chromaticities extracted from the Schottky spectra follow the set chromaticities qualitatively and depending on beam and plane of the monitor also quantitatively. There is a difference between the four monitors in how well the extracted chromaticities agree with the set ones. Especially the Schottky monitor for B2V appeared to be very well adjusted, producing reliably good results. However, the systems will need attention during start up in 2018 so that all monitors yield satisfactory results. Currently the settings appear not to be perfect since the usability of the signal depends heavily on the monitor used.

The Schottky monitors capability to indicate changes in emittance showed to be promising. However, absolute values for the emittances or emittance ratios are not to be determined accurately in the current settings.

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