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PROCESSING OF THE SCHOTTKY SIGNALS AT RHIC*

A. Sukhanov†, K. A. Brown, W. C. Dawson, J. P. Jamilkowski, A. Marusic, J. Morris,
Brookhaven National Laboratory, Upton, USA

Abstract

Schottky monitors are used to determine important beam parameters in a non-destructive way. In this paper we present improved processing of the transverse and longitudinal Schottky signals from a hi-Q resonant 2.07 GHz cavity with the main focus on providing the real-time measurement of beam tune, chromaticity and emittance during injection and ramp, when the beam conditions are changing rapidly. The analysis and control is done in Python using recently developed interfaces to Accelerator Device Objects [1].

INTRODUCTION

Instrumentation

The high Q cavity [2] is mounted on a dual axis moving frame. It has four probes to detect signals from the different modes in the cavity. Peak frequency of the vertical probe is 2.067 GHz, horizontal probe: 2.071 GHz, longitudinal probe: 2.742 GHz. The signal processing diagram is shown on Fig. 1.

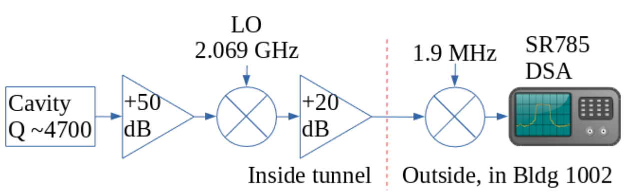

Figure 1: Signal processing diagram.

The signal from the cavity is amplified, filtered, down converted on a mixer with local oscillator (LO) and measured by a digital spectrum analyser (DSA).

Schottky Spectrum

The frequency domain signal of the bunched beam near the cavity resonant frequency is demonstrated on Fig. 2.

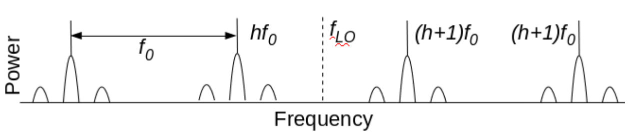

Figure 2: Schottky power spectrum.

The frequency of the local oscillator f_{LO} is positioned in the middle of the neighbouring harmonics of the revolution frequency f_0, to eliminate images from the highest harmonics. The high harmonic number h = 26525.5 helps to reduce power of the parasitic coherent peak. The signal registered by DSA is a superposition of differences between f_{LO} and several nearest harmonics.

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† sukhanov@bnl.gov

Extraction of Beam Parameters from Signal

Figure 3 shows a typical transverse Schottky signal from proton beam at the RHIC. It consist of very narrow coherent peak on the top of the underlying revolution peak and two side band peaks due to particles betatron motions.

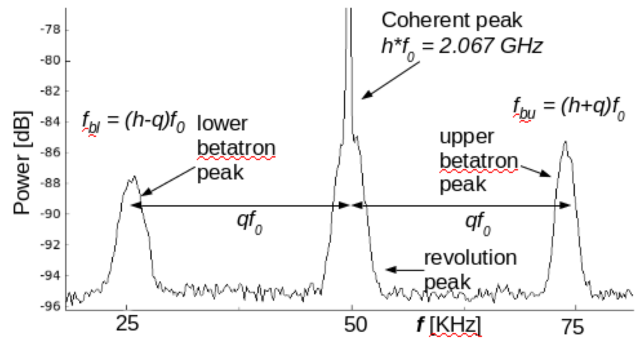

Figure 3: Schottky signal from the spectrum analyser.

The fractional part q of the tune is recovered from the positions of betatron peaks [3]:

$$q = \frac{f_{bu} - f_{bl}}{2 * f_0} \quad (1)$$

The chromaticity ξ is determined from the width asymmetry of the betatron peaks [3].

$$\xi = \eta \left(\frac{\Delta f_{bl} - \Delta f_{bu}}{\Delta f_{bl} + \Delta f_{bu}} h - q \right) \quad (2)$$

Here the η is a phase-slip factor of the accelerator.

The beam emittance is proportional to the rms beam size σ, which is determined from the power of the betatron peaks [3,4]:

$$P_{bu} = P_{bl} = \frac{1}{2} f_0^{\,2} Q^2 N \sigma^2 \quad (3)$$

Where the N is the number of particles in the beam and the Q is the particle charge.

SIGNAL PROCESSING

Signals are changing rapidly during the ramp, the RF frequency is changing for ~8 harmonics in 30 seconds.

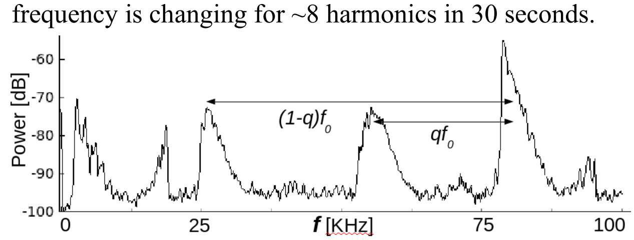

Figure 4: Schottky signal during the ramp.

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To stabilize the peak positions, the frequency f_{LO} of the local oscillator need to be adjusted synchronously with the changing RF frequency. The required precision of the f_{LO} adjustment is 10^{-8} (200 Hz over 2 GHz), which makes this task very challenging.

Another approach is to analyse the complex multi-peak signal as it shown on Fig. 4. Two facts makes this task possible:

- The peak positions can be very well predicted, based on known RF frequency.
- The shape of the peak is irrelevant for extraction of the beam parameters according to equations (1)-(3). The required peak characteristics: position, width and power can be calculated without curve fitting.

Processing Algorithm

Steps of the algorithm:

- Convert spectrum data to linear scale. The data from the spectrum analyser comes in logarithmic scale. The main benefit of using the linearly scaled data is that the analysis is not sensitive to the base line fluctuations.
- Filter the noise using Gaussian FIR filter of the N-th order. The order of the filter is selected to be equal to the width of the expected coherent peak but not less than 4 points. The filter is normalized to conserve the signal energy.
- Peaks recognition, based on known RF frequency, described below.
- Find the coherent peak using Gaussian fit in the near vicinity of the found peak.
- Recover the revolution peak:
  Make the hole in the revolution peak by excluding the coherent peak points.
  Fit the chipped peak with a Gaussian.
  Fill the hole in the peak with the fitted points.
- Find parameters of all peaks:
  - Find the left and right edges of the peak at the crossing points of the filtered data at a half-amplitude level.
  - The peak width is the difference between the edges.
  - The peak position is the arithmetic average of edge positions.
  - The peak area is the sum of the peak points above the noise floor (pink line above the noise floor on Fig. 6).
- Calculate the beam parameters according to equations (1) – (3).

Peaks Recognition

The example of the signal spectrum at the end of the injection is shown on Fig. 5. The peaks are searched in the narrow Regions Of Interest (ROI), calculated using known RF frequency. The width of the ROI are calculated according to tune limits, which are provided externally, based on beam energy and beam species.

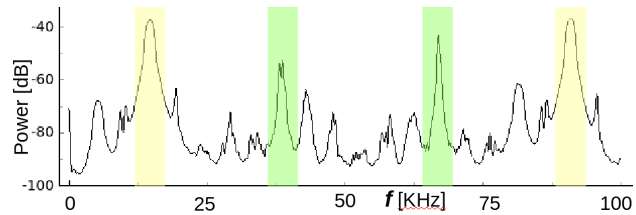

Figure 5: Regions of interest for the coherent (yellow) and betatron (green) peaks at injection energy.

Steps of the algorithm:

- Calculate ROI (Regions Of Interest) of the coherent and betatron peaks. Two coherent peaks may be present in the spectrum.
- Find N=10 of highest local peaks, sort them according to amplitude.
- Identify the coherent peak as a highest narrow peak in the coherent ROI.
- Iterate over the rest of the peaks and check if they are in the ROI for betatron peaks .

Adjustable Parameters

The algorithm requires small number of external parameters, which depend on beam energies and beam species. The parameters are:

1,2): Limits for expected tunes, which defines the ROI for betatron peaks.
3) Filter width, default 4.
4,5,6): Guess widths of the coherent, revolution and betatron peaks.

RESULTS AND DISCUSSION

The described algorithm have been implemented into a Python-based ADO Manager [1] and it was used for online monitoring during the routine RHIC operations. The following figures shows the results of the monitoring of one of the RHIC stores.

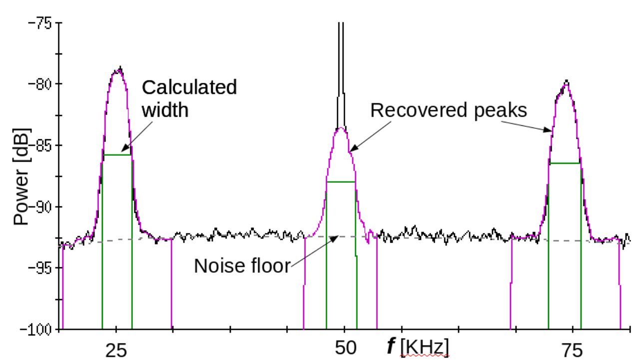

Figure 6: Results of the peak processing for proton beam at top energy. Black solid line represents the raw signal. The identified peaks shown as a solid pink line. The solid horizontal green lines represent the calculated widths.

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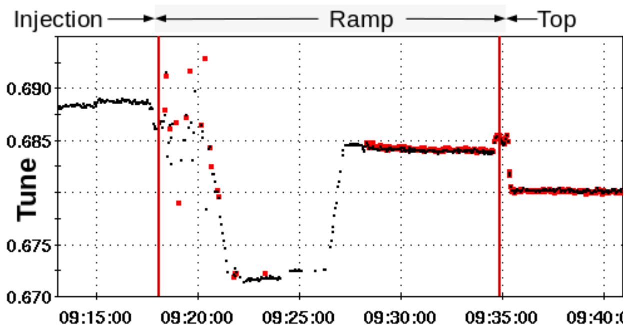

Figure 7: The tune measurement display.

Figures 7,8 and 9 represent operational displays of the beam tune, chromaticity and emittance during 500 GeV proton-proton run in 2007.

The black dots on Fig. 7 represent results of the described algorithm, the red dots are results of the previous analysis, based on the curve fitting using gaussian peak shapes. Both methods shows consistent results at top energy and at the end part of the ramp. The described algorithm works well during injection and during the most part of the ramp while the curve-fitting analysis fails to converge. The precision of the tune measurements top beam energy is ~0.1%.

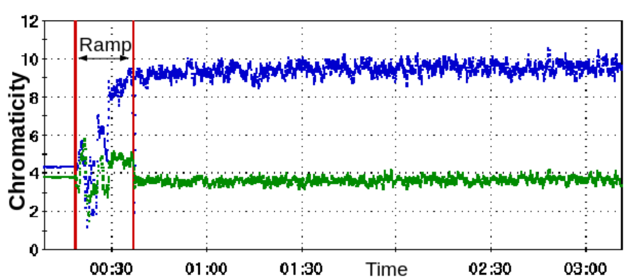

Figure 8: Chromaticity display.

The blue and green points on Fig. 8 represent chromaticity measurements from horizontal and vertical Schottky probes respectively. The precision at injection energy is 2%, at top energy it is 10% due to the low signal amplitude.

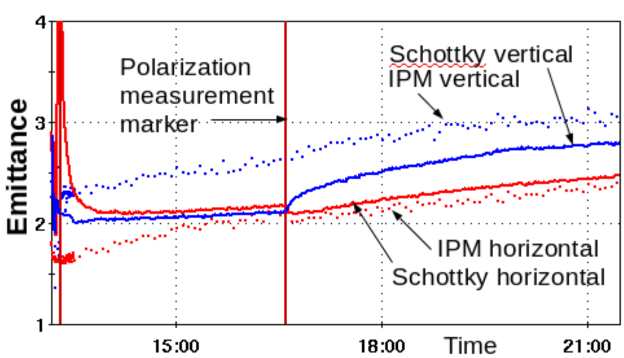

Figure 9: Emittance display.

Figure 9 shows vertical (blue solid line) and horizontal (red solid line) transverse emittance of one of the RHIC rings at top energy. Also shown is the emittance, measured by the Ionization Profile Monitors (IPM). The precision of the emittance measurement is 2%. The red vertical marker indicates an event when the beam have been disturbed due to polarization measurements.

CONCLUSION

The fast, robust algorithm for extracting beam parameters from the Schottky signals in dynamic beam conditions is presented. It provides the same precision as a conventional algorithm, based on a non-linear least-square fitting, but does not suffer from convergence problems.

The precision of the tune measurement is 0.1% at injection and top energies and 0.4% during ramp .

The chromaticity is measured with precision 2% at injection and 10% at top energy.

The power of betatron peaks, which is proportional to emittance, is measured with 1% precision.

The implementation using Python made it possible to quickly develop new, more efficient algorithms and even gain in processing performance over C++ code (the processing time of a 800-point spectrum is ~20 ms).

This analysis is used to provide beam parameters during routine RHIC operations with proton and heavy ion beams.

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