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RESULTS FROM THE SPS 1.7 GHz TRAVELLING WAVE SCHOTTKY MONITOR

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CERN, Geneva, Switzerland

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A 1.7 GHz waveguide Schottky detector system was recently built and installed in the SPS accelerator following the design of the detectors of the Fermilab Tevatron and Recycler accelerators. The waveguide detector is designed to measure the transverse and longitudinal Schottky signals of the accelerator at a frequency high enough to avoid coherent effects. This paper describes the first tests carried out with the Schottky detector using LHC type beams. The principal goal of these tests was to check whether such a detector can be used for transverse Schottky diagnostics in LHC.

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INTRODUCTION

Using a suitable detector, one can detect fluctuations in the instantaneous number and position of particles in a circular accelerator. The frequency spectrum of these signals consists of a set of lines at integer multiples of the particle revolution frequency, and a second set which is shifted in frequency from the first one due to the particles' betatron motion. If the beam is bunched, the synchrotron motion splits each line into a set of satellite lines. One can use Schottky signals to obtain a variety of information on a particle beam without perturbing it [1].

Slow wave slotted waveguide pickups were installed in Tevatron and Recycler accelerators at Fermilab and they are used as a means of non-destructive measurement of betatron tunes, chromaticity, momentum spread (*dp/p*), transverse emittances and the synchrotron frequency.

First data obtained from the detector installed in the CERN SPS clearly show Schottky betatron lines and even a faint signal with pilot beam without gating.

SCHOTTKY PICKUPS

A travelling wave Schottky pickup consists of a rectangular beam pipe with two waveguides on either side (Figure 1). The wall between waveguide and beam pipe is made of slotted thin aluminium foil for coupling signal into the waveguide. This kind of detector is bi-directional and is used in FNAL to provide both proton and antiproton signals [2].

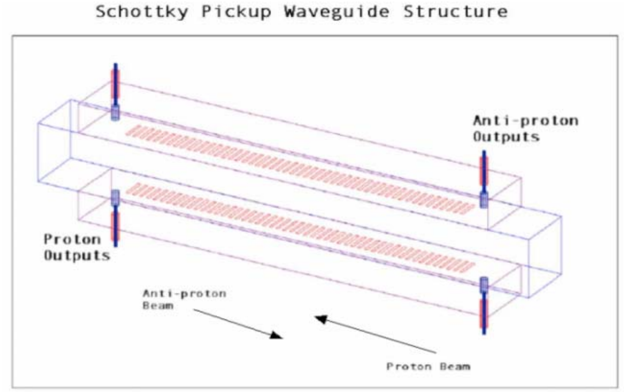

Figure 1: Schottky Pickup design

The designed operating frequency is approximately 1.745 GHz for the DELTA mode and 1.813 GHz for the SUM mode. The Schottky PU at CERN has been used as a vertical detector and tuned for an operating frequency of 1.8 GHz which is a multiple of 40 MHz LHC and 200 MHz fixed target beams harmonics.

EXPERIMENTAL SET-UP

Measurements were taken using both Delta and Sum signals coming out from the arms of the pickup. The Sum signal is an indicator of the longitudinal sensitivity of the detector whilst the Delta signal was used to get the transverse Schottky spectrum.

In the tunnel, Sum and Delta signals were obtained from the pickup by means of a 180° hybrid. Each of the plates was connected to a set of mechanical attenuators in such a way that attenuation for each channel could be varied in steps of different attenuations between 0 and 7.5dB (Figure 2). The objective of the attenuators was to minimize the longitudinal signal (common-mode lines) in the transverse spectrum by trying to electrically center the beam in the pickup. The control of the attenuators was done from the surface. The Delta signal was fed into a narrowband filter installed in tunnel and centered at 1.803GHz. Taking into account the attenuation of the cables carrying signals to surface (~12dB), the Sum signal provided $100V_{peak\text{-}peak}$ and the Delta signal $10V_{peak\text{-}peak}$.

The signal processing was done using a conventional FFT analyzer (SR785 Dynamic Signal Analyzer). The frequency range of the device goes from 195.3mHz to 102kHz and, since signals are expected to appear at frequencies around 1.8GHz, the whole spectrum needed to be shifted to that interval. To do that, a further filtering and two down mixing stages were employed.

Filtering and first down mixing was carried out on a Hewlett Packard spectrum analyzer (SPA). The signal coming from the tunnel was applied to the RF input of the SPA for filtering with the Central Frequency set to 1.8GHz. The SPA has an internal local oscillator placed at 21.4 MHz below the Center Frequency so that the whole spectrum is moved to 21.4 MHz. The IF output of the SPA becomes now the RF input for the next mixing stage where the LO frequency is supplied by a signal generator. Frequencies around 21.45-21.46 MHz were chosen so that the base band signal was at 50-60 kHz in the FFT analyzer (Figure 2).

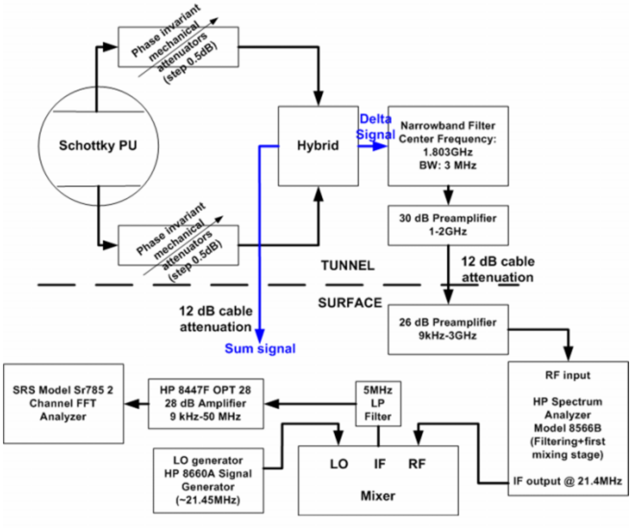

Figure 2: Data acquisition with FFT analyzer

EXPERIMENTAL RESULTS

Data were acquired during several separate SPS runs, all of them with bunched beam, 26GeV coast energy and 40MHz LHC beam pattern (72 bunches spaced by 25ns).

Table 1: Typical SPS beam parameters during data acquisition.

	UNITS	SPS
Coast beam Energy	GeV	26
Momentum	GeV/c	26
Revolution Frequency	kHz	43.347
Betatron Tune, QH		26.13
Betatron Tune, QV		26.19
Intensity per bunch		$1.3*10^{+11}$
Number of bunches		72
Number of batches		Up to 2
Bunch Spacing	ns	25
Bunch Length	ns	4
Normalized r.m.s Vertical Emittance (ε^*v)	μm	~3.5-3.6
$\Delta p/p$ (r.m.s.)		1×10^{-3}
Beam r.m.s radius (a_{rms})	mm	1.8
(Main) RF Frequency	MHz	200
SPS γ_{tr}		23.4
SPS circumference (C)	m	6911.560387

A spectrum obtained with the FFT analyzer is shown in Figure 3 and illustrates most of the important features of the data.

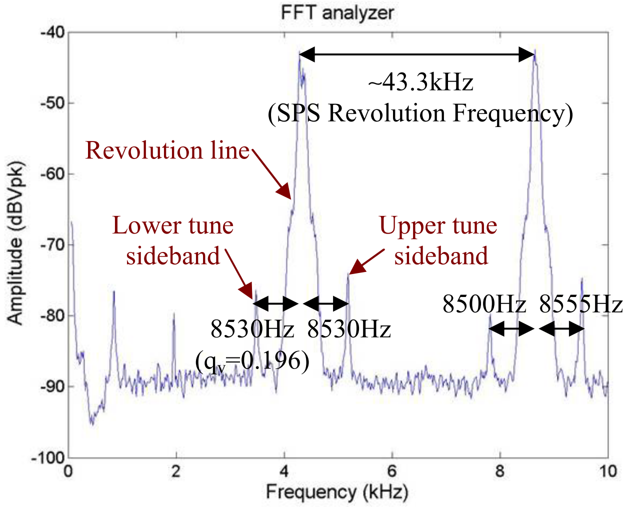

Figure 3: Spectrum of Delta signal from Schottky detector

The large peaks are revolution lines. They repeat at integer multiples of the SPS revolution frequency (43.347kHz at 26GeV) and are due to the residual longitudinal signal. Each peak is a compound peak: a narrow one due to the residual coherent signal at 1.8GHz and a broad peak that is the longitudinal Schottky signal. The two peaks appearing on the right and left of the revolution lines are the betatron signals or the 'upper and lower sidebands'.

According to theory, the distance of the tune lines to the revolution line is equal to the fractional part of the betatron tune multiplied by the revolution frequency ($q_v \cdot f_{rev}$) and the line width is

$$\Delta f_{u,l} = \frac{\Delta p}{p} \cdot f_{rev} \cdot \left[(n \pm q) \cdot \eta \pm Q \cdot \xi \right] \qquad (1)$$

where n is the harmonic number, q is the fractional part of tune, η is the 'slip factor' and ξ is the machine chromaticity.

The fact that the particles have different energies leads to a change in the revolution frequency and a change in focusing strength when particles pass through the quadrupoles. This creates a change in the tune (q) that is related to a change in momentum by the chromaticity. All this together has an effect on the width of the tune lines. Depending on the sign of the chromaticity and the slip factor, either the upper or lower sideband will be wider but since the total power in the two sidebands, independently of the value of the harmonic number, has to be the same, the amplitude of the broader line will be smaller than that of the narrower one.

The longitudinal sensitivity of the detector can be measured using the Sum signal coming out from hybrid. The obtained result in the SPS (Figure 4) shows the bunched structure of the beam (72 bunches spaced by 25ns) with lines spaced by 40MHz. The best response of the pickup is around 1.7625GHz whilst maximum response for Schottky detector in FNAL is around 1.8GHz; this shift in frequency is due to the convolution of longitudinal bunched beam frequency spectrum and pickup frequency response.

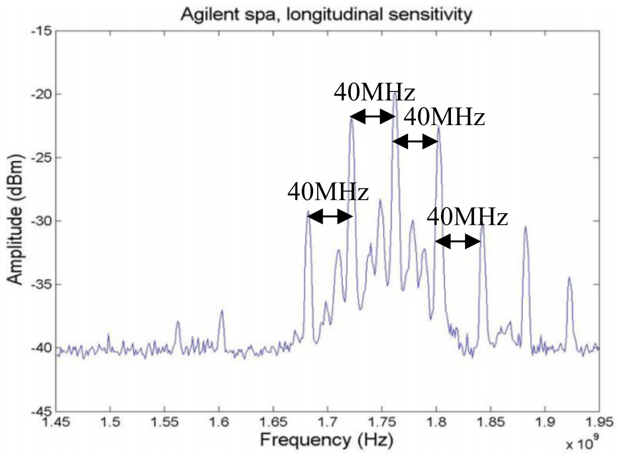

Figure 4: Longitudinal sensitivity of the Schottky detector

SIGNAL TO NOISE RATIO

The level of signal being received in the SPA is consistent with calculations. These calculations are based on the beam power ratio given by

$$g = \frac{P_{beam} - P_{noise}}{P_{noise}} \tag{2}$$

The power ratio can be extracted from the formula of the difference mode impedance for a slow wave pickup [4]:

$$Z_\Delta = (g-1) \cdot \frac{N_f \cdot S_{therm}}{2 \cdot e \cdot I_{dc} \cdot \left(\frac{\sigma}{d}\right)^2} \tag{3}$$

where Z_Δ is the difference mode impedance, S_{therm} the power spectral density of white thermal noise at 300K, e is the charge unit, I_{dc} is the longitudinal DC total current, σ is the beam radius, d is the beam pipe half section and N_f is the noise figure of preamplifier. All these values are known.

Once g has been calculated, and considering thermal noise only ($P_{noise} = 4 \cdot 10^{-21}$W/Hz), the beam power can be extracted from (2). The signal to noise ratio (S/N) is given as follows

$$S/N = 10 \cdot \log\left(\frac{P_{beam}}{P_{noise}}\right) = 10 \cdot \log\left(\frac{1.58 \cdot 10^{-19} W/Hz}{4 \cdot 10^{-21} W/Hz}\right) = 16dB \tag{4}$$

Result is in agreement with the one observed in the SPA in Figure 5.

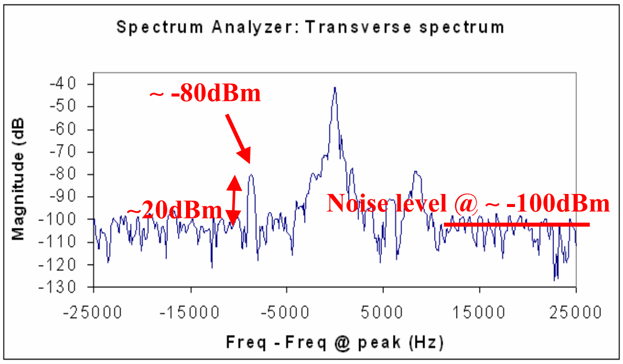

Figure 5: Observed signal to noise ratio

CONCLUSIONS

An extensive signal analysis for static and dynamic beam conditions has been done on different beams from the 1.7-1.8GHz pickup installed in the SPS. Observed signals agree with those predicted by Schottky theory. Vertical tune sidebands could clearly be seen with expected signal level according to calculations. Some signal was even visible with a pilot beam without gating. A passive detector capable of bunch by bunch measurement of tune, chromaticity, momentum spread and emittance would be very interesting for early LHC operation. Such a development is currently underway as part of the US-LARP collaboration.

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