ANALYSIS OF THE PERFORMANCE OF THE SPS EXPONENTIAL COUPLER STRIPLINES USING BEAM MEASUREMENTS AND SIMULATION DATA

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Abstract

The SPS exponential coupler stripline are used to study single bunch instabilities. An accurate description of the response of the pickup is required to obtain high resolution measurements of the bunch vertical motion along the longitudinal axis. In this study we present the results of the comparison between dedicated beam experiments and electromagnetic simulations of a geometrical model of the stripline.

INTRODUCTION

The SPS is presently considered the bunch intensity bottleneck in the LHC injector chain [1]. The limiting transverse instabilities are the instabilities caused by the electron cloud effect [3] and the TMCI[4]). For this reason a program for stading the feasibility of a single bunch feedback system has started in 2008 aiming at actively damping the transverse oscillation (see [5] in these proceedings).

In this paper we present the investigation on the exponentially tapered stripline structure, which has been used in the SPS to observe single bunch instabilities [8], to verify the analytical model and the actual transfer function in order to asses its usefulness for a feedback system.

The direct measurements of the pickup installed in the SPS dates back to 70s [2] and do not contain data for the phase response, which is important for correct reconstruction of time domain signals and thus for an active feedback system.

ANALYTICAL MODEL

The striplines in the pickup have an s-dependent (s being the coordinate in beam direction) width that translates in an s-dependent coupling constant. The distance of the stripline from the vacuum chamber diminishes as the width decreases such as to preserve a constant line impedance of 50 Ω. If the coupling, i.e. the electrode shape, is exponential, the resulting transfer function is almost flat in amplitude instead of having the typical notches of a constant width stripline pickup.

The absolute value of the transfer function in frequency domain is [2]

$$|F(\omega)| = \frac{K\omega l/c}{\sqrt{a^2+\frac{4\omega^2 l^2}{c^2}}}\sqrt{1+e^{-2a}-2e^{-a}\cos\left(2l\omega/c\right)} \tag{1}$$

and the phase is

$$\mathrm{Arg}\{F(\omega)\} = \arctan\left[\frac{2\frac{\omega l}{c}\sin\frac{2\omega l}{c}+a\left(e^a-\cos\frac{2\omega l}{c}\right)}{2\frac{\omega l}{c}\left(e^a-\cos\frac{2\omega l}{c}\right)-a\sin\frac{2\omega l}{c}}\right] \tag{2}$$

where $l = 0.4$ m is the kicker length, K a coupling constant and $a = \pm\log(0.03/0.002)$ describes the exponential tapering ([2]). We assumed ultrarelativistic beams, $v = c$.

Normally the pickup is installed with the beam passing the wide end of the strip first, we will call this forward installed. A backward installed coupler has the beam impacting the narrow end of the strip first. Note that the coupler is directional and signals are always extracted at the upstream ports.

Exponential couplers were built and installed in the SPS [2] and are readily available. The pickup has four electrodes at ± 45 degrees to the horizontal plane which allow to measure both bunch intensity, as well as horizontal and vertical displacement. In the SPS there are a total of four such pickups installed, two usually cabled for horizontal operation and two for vertical operation. The tests concentrated on the vertical observations, plane in which the electron cloud effect causes a high frequency instability.

The direct measurements of the pickup installed in the SPS dates back to 70s and [2] do not contain information on the phase. Therefore we looked at way to extract accurately the transfer function from the installed devices using a beam based method and simulations.

BEAM BASED MEASUREMENTS

Beam based measurements of the transfer function has been possible using a wall current monitor signal as reference, which features a relative flat response (-2dB in amplitude and few degrees in phase up to 1.8GHz [6]).

Two pickups have been measured labeled 319.01 and 321.01, they are oriented with the couplers at 45 degrees such that the vertical displacement signal is obtained from the difference of the sum of the two top and two bottom signals. The first sum is done directly in the tunnel with a resistive combiner while the difference (and the sum used for calibration) is performed by an hybrid (Macom H-9 2-2000 MHz) on the surface.

The distance from the tunnel to the surface is covered by a 7/8" air coaxial cable which not only introduces attenuation at high frequency but also phase distortion due to corrugation [7]. The model for the cable reads:

$$c_{\mathrm{tf}} = \exp\frac{1}{2}\left(-a_0\sqrt{2if}-a_1 f-2\pi i n_0 f^{n_1}\right), \tag{3}$$

Table 1: Fitting parameters for the cables for 319 and 321.

cable	$a_0 \cdot 10^5$	$a_1 \cdot 10^{10}$	$n_0 \cdot 10^{35}$	n_1
319	6.508	3.307	-6.235	3.672
321	8.207	3.346	-1.750	3.744

where the constant a_0, a_1, n_0, n_1 are constants fitted using dedicated measurements of joint cables in transmission (see Table 1) and the factor $\frac{1}{2}$ restores the correct parameters for a single cable.

The reference wallcurrent monitor signal is instead transported using an analog fiber optics link that has a flat response in the range of interest.

To measure the exponential coupler transfer function, the sum of top and bottom signal, labeled 'a' and 'b' respectively, has been measured with beam using the same acquisition device (oscilloscope TekTronix DPO7254 with a bandwidth of 2.5 GHz and trigger interpolation sampled at 10 GS/s) for 1000 consecutive turns. The reference signal of the wallcurrent monitor is labeled 'd' and acquired at the same time using the same scope.

Figure 1 shows the raw signal of 'a' and 'b' for the 319 and 321 couplers respectively installed in the forward and backward direction.

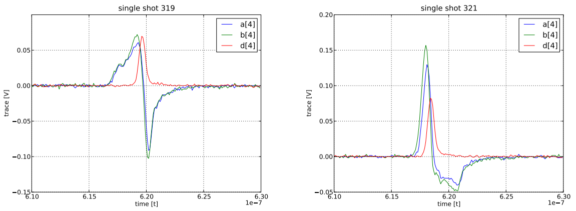

Figure 1: Measured transfer function of the pickups including cable.

The beam had a single short bunch with a total bunch length(4σ of a Gaussian fit) of 1.5 ns acquired in stable conditions at 450 GeV.

From a single bunch profile it is possible to obtain the transfer function by dividing in frequency domain (deconvolving in time domain) the profile of a bunch with the reference pulse.

In order to reduce the noise it is possible to average multiple acquisitions in several methods that we will call M_c, M_t, M_l.

$$M_t(a,d) = \text{fft}_j(\text{avg}_i a_{ij})/(\text{fft}_j(\text{avg}_i d_{ij}), \tag{4}$$

$$M_c(a,d) = \text{avg}_i\left(\text{fft}_j a_{ij}/\text{fft}_j d_{ij}\right), \tag{5}$$

$$\log M_l(a,d) = \text{avg}_i \log|\text{fft}_j a_{ij}| - \log|\text{fft}_j d_{ij}|, \tag{6}$$

where fft_j and avg_i are the DFT over a single bunch and avg_i is the average over the turns. a, d represent the acquired data in a table format where each row represents a single turn.

In noise free condition the three methods give the same result (the third method does not give information on the phase) for the transfer function, but they perform differently in the presence of noise. Method M_c is the most general and it does not assume any correlation between the reference signals, i.e. the bunch itself, but only on the transfer function. Method M_t assumes that all the bunch profiles are identical, therefore it first finds an average and finally performs a deconvolution. It is expected to give better estimates at higher frequency if the variation of the reference signals is due only to measurement errors. Method M_l is similar to M_c but it discards the information on phase (generally noisier).

Figure 2 shows the result of the three methods on the top couplers of pickup 319. They exactly match in the range where the bunch spectrum has high SNR. The same applies for the other three cases (not shown here).

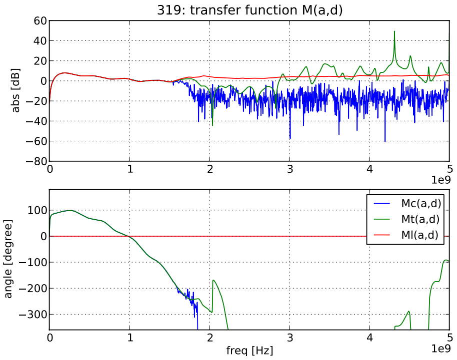

Figure 2: Measured transfer function of the pickup 319 including cable.

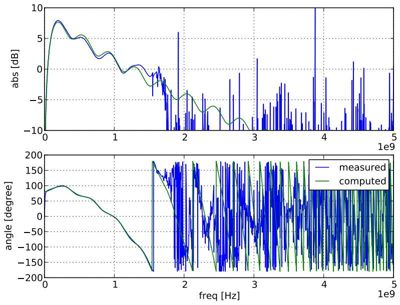

Figure 3: Comparison between the model and the measured transfer function of the pickup 319 including cable.

Figure 3 shows the comparison between the model and the measured transfer function of the pickup 319 and cable after a fitting procedure using measured data up to 1.5GHz. In the model we assume an addition factor $\exp(l_p f)$ that models frequency dependent losses of the pickup. The fit is performed for 319 and 321 top and bottom couplers. Table 2 shows the fitting parameters for the four cases:

The fit, obtained with a least square method using data up to 1.5GHz, is reliable in frequency up to 1.4GHz in amplitude and most notably up to 1.8GHz in phase. The non linear phase distortions differ from the ones obtained by

Table 2: Fitting parameters for the pickup 319 and 321.

name	a	$l_p \cdot 10^{10}$	$n_0 \cdot 10^{35}$	n_1
319 top	-2.230	-1.122	-18.933	3.657
319 bottom	-2.400	-0.710	-17.045	3.662
321 top	1.823	2.877	-1.998	3.769
321 bottom	1.806	3.552	-2.150	3.773

measuring the cable only, but they are needed to improve the fit for frequencies above 1.3GHz.

SIMULATIONS

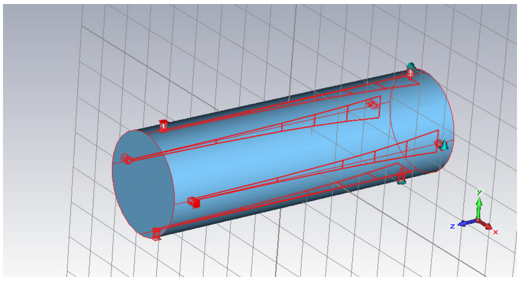

Figure 4: Exponential coupler stripline pickup as modelled in CST Particle studio.

A pickup structure has been modeled in CST Particle studio (see Figure 4). The shape of the coupler is coarsely approximated by parallelogram sections. The diameter of beam pipe is 133 mm compared to 105 mm of the measured pickup.

The coarse mesh does not allow an accurate and precise analysis of the frequency response. On the other hand it is sufficient to estimate the sensitivity and linearity of the pickup.

Figure 6 shows the displacement response for various displacements. Figure 5 shows the displacement response normalized with the displacement. The main features of the analytical and measured response are represented. To be noted that for a centered beam the response is not exactly zero due probably to model accuracy in the coupler shape and mesh precision of the time domain solver.

CONCLUSION

There is remarkably good agreement between beam measurements and the analytical model of the complete pickup transfer function both in amplitude and in phase, which is relevant for a feedback application.

The simulations, while reproducing the main features, suffers from the coarse modeling of the couplers and possibly by the precision error introduced by the mesh.

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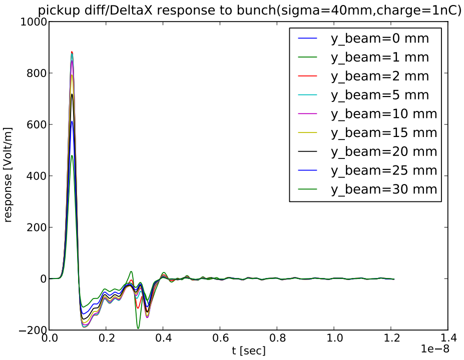

Figure 5: Pickup normalized displacement response in time domain

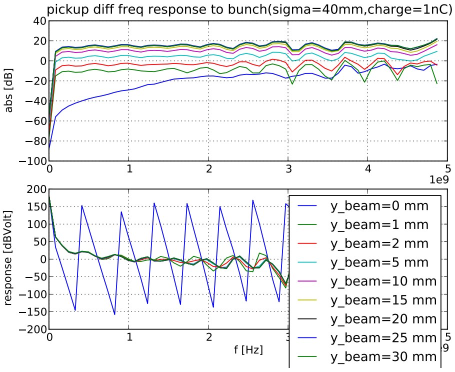

Figure 6: Pickup displacement response in frequency domain

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