STUDY OF A WIDEBAND FEEDBACK KICKER FOR THE SPS

S. De Santis#, Z. Cay, A. Ratti, LBNL, Berkeley, CA 94707, USA
A. Gallo, F. Marcellini, LNF-INFN, Frascati, Italy

Abstract

The LHC luminosity upgrade currently being planned at CERN depends in large measure on a successful upgrade of its injectors chain. In particular the storing of higher currents in the SPS presents a significant challenge from the point of view of the beam stability. Electron cloud driven and transverse mode-coupled instabilities can disrupt the stored beam to the point of making injection in the LHC impossible. These types of instabilities are characterized by fast growth times and substantial spectral components at high frequency. Therefore a key aspect of any feedback system capable of effectively controlling the instability growth is the development of a suitable kicker with a high frequency response. In this paper we investigate the technologies available for such a kicker and identify a possible solution to be implemented on the SPS. We discuss the general requirements and the basic parameters of solutions based on stripline and damped RF cavity kickers.

INTRODUCTION

The US LARP program [1] is committed to the development, improvements and upgrades of the Large Hadron Collider (LHC). Among the many activities, one of the main candidates to removing a performance limitation of the injection chain is the design of a broad band feedback system to compensate the negative effects of electron cloud and Transverse Mode Coupling Instabilities (TMCI) in light of possible future upgrades of the SPS to operate with high charge (> 2×10^{11} protons per pulse) at low emittances (at or below 2.0 eVs) [2].

Since the instability occurs within the bunch, one of the key components of such a system is a broadband kicker capable of kicking in different ways the head and the tail of the bunch. Such a system is under study. The design of a wide-band feedback system for mitigating electron cloud effects on the SPS beam relies on the identification of the most suitable technology for the kicker elements. We have investigated possible solutions, trying to identify the limits of each technology for such a wide-band system, considering striplines, cavities and slow-wave structures and taking into account the relative advantages and disadvantages of each technique.

The work presented in this paper is focused on the study of a stripline based system as the main technology to deliver the necessary performance. The present model includes the use of 10cm or 5cm striplines as well as a combination stripline and low-Q deflecting RF cavities. With these, it is possible to reach bandwidths up to 1.5 GHz with total shunt impedances of at least 1 kΩ. These studies are a combination of analytical calculation with strong support from computer simulations, both 2D and 3D, that were performed to fully characterize the electromagnetic properties of our design.

Since both e-cloud driven instability and TMCI overwhelmingly affect the vertical stability in the SPS, we will refer exclusively to vertical kickers in this paper.

STRIPLINE KICKER

Analytical Calculations

Stripline kickers are a well-known device, commonly used in particle accelerators [3]. The analytical expression for the shunt impedance of a transverse stripline deflector is

$$R_s(\omega) = 2Z_c\left(g_\perp \frac{L}{h/2}\right)^2\left[\frac{\sin(\omega L/c)}{(\omega L/c)}\right]^2 \qquad (1)$$

where Z_c is the stripline characteristic impedance, $g_\perp$ its transverse coverage factor, L the stripline length and h the vertical separation between opposite striplines. From Eq .(1) we can see immediately that such a kicker has its maximum impedance at DC, proportional to its length squared and its first zero for $f=c/2L$. Moreover, everything else being equal, a stripline of length L yields the maximum shunt impedance at a frequency $f=c/4L$.

It is suggested in [4] that the e-cloud driven instability has a bandwidth around 700÷800 MHz. Therefore we choose L=10 cm which is the optimal length for a 750 MHz response. Furthermore we will design the kicker to achieve a 50 Ω characteristic impedance, for easier matching to the power supply/amplifier, a $g_\perp\approx1$ and h=40 mm, according to the stay-clear requirements in the SPS portion of beampipe available for kicker installation. With such parameter choice, the shunt impedance goes from 2.5 kΩ at DC to 1 kΩ at 750 MHz.

A likely value for the maximum required transverse momentum kick $\Delta p_\perp$ at the SPS 26 GeV injection energy, appears to be in the neighborhood of 3×10^{-5}eV·s/m [5]. The required deflecting voltage necessary is:

$$V_\perp = \frac{\Delta p_\perp}{e}\frac{c}{2}g_\perp\frac{h/2}{L}\frac{(\omega L/c)}{\sin(\omega L/c)} \qquad (2)$$

or from 1 kV at DC up to 1.6 kV at 750 MHz.

With these numbers we can estimate the power required for the SPS beam constituted of ~4ns long (±2 σ) proton bunches, spaced by τ_b= 25 ns, which sums up into a 20% duty factor. Keeping in mind that the transverse deflecting voltage can be distributed on the two opposite striplines,

#sdesantis@lbl.gov

we obtain the peak and average power requirement per stripline listed in Table 1, which do not appear to present any particular challenge.

Table 1: Required Power (per 10-cm long stripline)

L=10 cm	P_{peak} (W)	P_{avg} (W)
DC	50	10
750 MHz	320	65

A final theoretical consideration can be made regarding the time resolution of the stripline kicker. Since the input port is the downstream one, the kicker has to be "precharged", so that an incoming bunch will find the appropriate voltage at the upstream port. Even ignoring any stray capacitance, this will take a time $t_k = L/c$ just because of the finite propagation velocity of the electromagnetic signal. For analogous considerations it will take an equal time for the kicking waveform to cross the length of the kicker once the bunch has left. Finally, the kicking voltage level has to be maintained throughout the bunch passage adding another t_k to the total response time, which results in a minimum theoretical response time of $3L/c$.This means a 10-cm long stripline has a time resolution of 1 ns at best. This value is nonetheless acceptable for a 4 ns long bunch, as it allows exciting independent kicks to the head and the tail of the bunch.

Table 2: Required Power (per 5-cm long module)

Frequency	$V_\perp$	P_{peak}/strip.	P_{avg}/strip.
1.5 GHz	800 V	320 W	65 W

If we want to reach higher frequencies for TMCI damping, the spectrum of which seems to be reaching 1.5 GHz, a 10-cm stripline is ineffective and the optimal length is 5 cm instead (Table 2). From Eq. (1) we see that in order to reach the 1 kΩ impedance mark at 1.5 GHz four of such kickers are needed in series.

The shunt impedances of the two solutions are compared in Fig. 1. It can be noticed that, at the cost of a more complex system with four separate kickers, the 5 cm kicker not only extends the system bandwidth, but also outperforms the 10 cm kicker at lower frequencies.

3D Modeling

Computer modeling of the stripline kickers is underway using Microwave Studio [6]. We are utilizing virtual coaxial wire and two-wire measurements to calculate the structure beam coupling impedance, transfer impedance and transverse shunt impedance (Fig. 2). In addition simulations can show the transient behavior of the deflecting field. At present we have only designed a very simple model of kicker and feedthroughs; we plan to include more details and optimize the structure within the next few months.

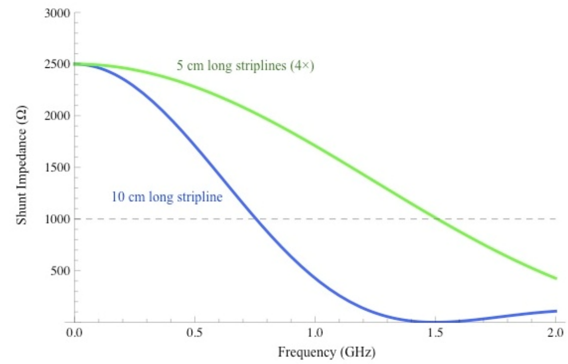

Figure 1: Shunt impedance for a single 10 cm long stripline kicker (blue) and for a set of four 5 cm long striplines (green).

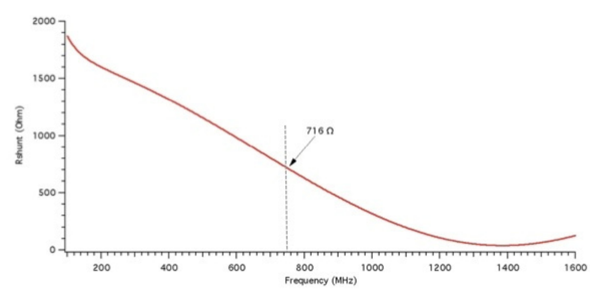

Figure 2: 10 cm stripline simulated shunt impedance (two-wire virtual measurement).

DAMPED CAVITY KICKER

Damped deflecting RF cavities could also be used to provide the necessary transverse kick. Using damped cavities compensates the more complex mechanical design with a much narrower total band occupation and the possibility of obtaining the desired shunt impedance at a given frequency independently of its value at other frequencies.

Such a kicker system consists of a number of low Q resonators operating in the TM110 deflecting mode. By centering each resonator on a harmonic of the bunch repetition frequency $f_b=1/\tau_b$, it is possible to replicate the effect of a continuous Gaussian feedback transfer function.

$$H(\omega) = H_0 e^{-\frac{\omega^2}{2\sigma_\omega^2}}. \quad (3)$$

This function corresponds to a kicking voltage waveform

$$v(t) = v_0 e^{-\frac{\sigma_\omega^2 t^2}{2}} \quad (4)$$

with a FWHM equal to $2.35/\sigma_\omega$; less than 0.4 ns for a 1 GHz bandwidth. Given that this time is much shorter than τ_b, we can rewrite the kicking voltage function as a series of identical waveforms, with a periodicity equal to the bunch duration and damped by a suitable factor t_d much shorter than the separation between bunches as:

ISBN 978-3-95450-115-1

$$v_d(t) = v_0 \sum_k e^{-\frac{\sigma_\omega^2 (t - k t_b)^2}{2}} e^{-\frac{t}{t_d}} \quad (5)$$

The Fourier trasform of this signal is a spectrum composed of Lorentzian harmonics with an envelope equal to the original transfer function shown in Fig. 3.

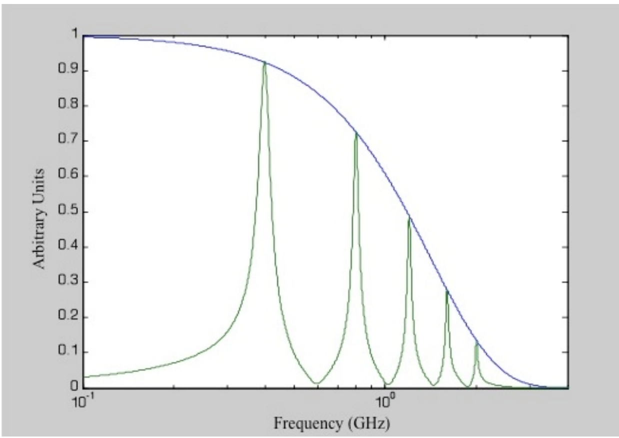

Figure 3: Beam-sampled feedback transfer function.

Such a transfer function can be approximated with a stripline for the lower frequencies, up to the first harmonic, and two damped cavities to cover the second and third harmonics, respectively at 800 and 1,200 MHz. as shown in Table 3.

Table 3: Fractional Bandwidth Kickers Main Parameters

	Stripline	Cavity #1	Cavity #2
Frequency (GHz)	DC – 0.4	0.8	1.2
Length (cm)	17	15	10
Filling time (ns)	0.6	10	10
Q_L	---	25	38
Shunt Impedance (kΩ)	1.5 (@ DC)	1.5	2.2

A simple geometry is being considered for the cavities (Fig. 4): a modified pillbox with beam ports of 100×36 mm^2, consistent with the SPS stay-clear. The pillbox is coupled to an input and a damping rectangular waveguides through large apertures.

HFSS [7] simulation results are summarized in Table 4.

Table 4: Deflecting Cavities Simulation Results

	Cavity #1	Cavity #2
Frequency	0.8 GHz	1.2 GHz
Q	23	38
H	≈100 cm	≈60 cm
WG standard	WR-1150	WR-650

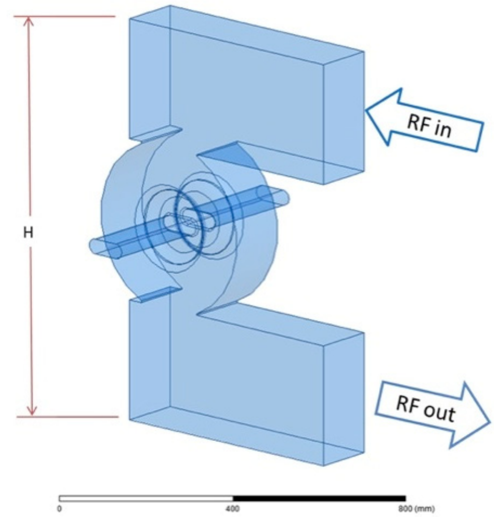

Figure 4: Model of the transverse feedback damped cavity.

CONCLUSIONS

In this paper we have presented the preliminary studies of two alternatives for the kicker of a feedback system designed to damp electron cloud driven instability and TMCI in the SPS, based on an initial assessment of those instabilities characteristics. Both solutions appear as viable ones. While system's requirements are being better defined, we plan to continue with more detailed studies of both systems until a final choice is made.

ACKNOWLEDGMENTS

Work supported by the US Department of Energy under Contract DE-AC02-05CH11231. The research leading to these results has received funding from the European Commission under the FP7 project HiLumi LHC, GA No. 284404, co-funded by the DoE, USA and KEK, Japan.

REFERENCES

[1] http://www.uslarp.org/
[2] J.M. Cesaratto, J. Fox et al., MOEPPB015, these proceedings.
[2] G. Lambertson, LBL-22085 (1986).
[4] M. Venturini, R. Secondo, and J.-L. Vay, WEPPP075, these proceedings.
[5] W. Höfle, private communication.
[6] http://www.cst.com
[7] http://www.ansys.com