DESIGN OF THE CAVITY BPM SYSTEM FOR FERMI@ELETTRA

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Abstract

The cavity Beam Position Monitor (BPM) is a fundamental beam diagnostic instrument for a seeded FEL, like FERMI@elettra. It allows the measurement of the electron beam trajectory non-destructively, on a shot-by shot basis and with sub-micron resolution. The high resolution the cavity BPM is providing relies on the excitation of the dipole mode that is originated when the bunch passes off axis in the cavity. In this paper we present the prototype of the cavity BPM developed for the FERMI@elettra facility. Furthermore, the design of the prototype electronics for the acquisition and the processing of the signals from the BPM cavities is presented. The adopted scheme consists of a down converter from the C-band to an intermediate frequency followed by an IQ demodulator to generate the base-band signal which is proportional to the transverse beam position. The performed simulation session is presented as well which we run before building the hardware for bench tests.

INTRODUCTION

The FERMI@Elettra FEL project requires an accurate measurement of the transverse beam position throughout all the machine. In order to provide the required single shot resolution for the position measurement cavity BPMs have been adopted. They are a resonant pill-box cavity where the information on beam position is encoded in the amplitude and phase variations of the dipole mode (TM_{110}) with beam transverse position [1, 2]. A scaling from X-band to C-band of cavity BPM was performed in [3]. Here we present the prototype of the cavity BPM developed and the design of the electronics for the acquisition and the processing of the signals from the BPM and reference cavities. Since wakefields budget is an important issue for FEL machine, longitudinal and transverse wake potentials have been calculated using the GdfidL code [4]. The comparisons between analytical and numerical results are presented here.

CAVITY BPM PROTOTYPE

Figure 1 shows a 3-D view of the cavity BPM as mechanically designed [5]. The prototype is actually fitted with two cavities: one for the position measurement and a second one for the generation of the reference signal for the demodulator. The signal from waveguide is coupled out by means of a coaxial feedthroughs antenna. In the cold test a optimization of the antenna coupling is foreseen. Table 1 shows RF parameters of the BPM and reference cavity prototype. Since the electronics require an overlapping between the BPM and reference resonant frequencies, the requirement on the cavity frequencies becomes stringent. Besides it is important to maintain the cavity simmetry to minimize the monopole mode leakage and $x - y$ coupling. Thus, the required machining tolerance was fixed to $\pm 10 \mu m$ for cavities, waveguides and their relative positioning.

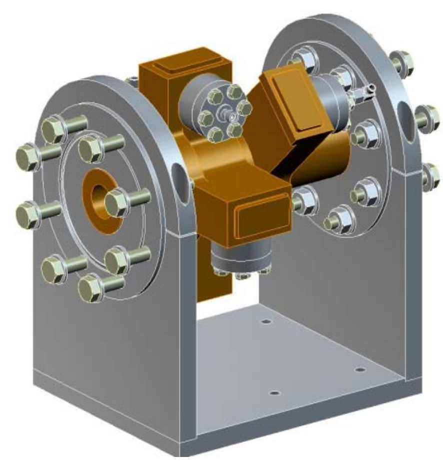

Figure 1: A 3-D view of the cavity BPM prototype.

Table 1: RF parameters for BPM and reference cavities. Charge $1nC$, *offset $1\mu m$ and **on axis, voltage normalized to $R = 50\Omega$ and $T = 0s$.

cavity BPM	ref. cavity
Mode TM_{110}	Mode TM_{010}
$f_{110} = 6479MHz$	$f_{010} = 6475MHz$
$Q_0 = 8400$	$Q_0 = 7250$
$Q_{ext} = 10500$	$Q_{ext} = 36800$
$k_{110} = 8.3V/nC/mm^2$	$k_{010} = 1410V/nC$
$\partial f/\partial r = -2.3MHz/10\mu m$	$\partial f/\partial r = -3.7MHz/10\mu m$
$V^*_{ext} = 1.27mV$	$V^{**}_{ext} = 8.85V$

CAVITY BPM ELECTRONICS

In general a cavity BPM provides two independent signals, one for each x and y axis. As known from the theory when the beam passes off axis through a resonant cavity dipole mode is excited and its outputs can be modeled by a

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damped sinusoidal signal:

$$m_x(t) = V_{110,x} e^{-\alpha_{110} t} sin(\omega_{110} t + \varphi_{110,x}) \quad (1)$$

$$m_y(t) = V_{110,y} e^{-\alpha_{110} t} sin(\omega_{110} t + \varphi_{110,y}) \quad (2)$$

where $\alpha_{110} = \pi f_{110}/Q$ is the attenuation constant, f_{110} and Q are the 6.5 GHz resonant frequency and loaded quality factor of the cavity, respectively. $\varphi_{110,x}$ and $\varphi_{110,y}$ are the phases of the signal, which may assume only $-\frac{\pi}{2}$ or $\frac{\pi}{2}$ values, depending on the beam position with respect to the axis considered. V_{110} is the amplitude of the signal which is linearly dependent on the transverse position of the beam. Figure 2 shows the simulated output from the BPM when we assume a duration of the RF signal of approximately $2.5\mu s$ and a load $Q = 10000$ for the cavity. Furthermore

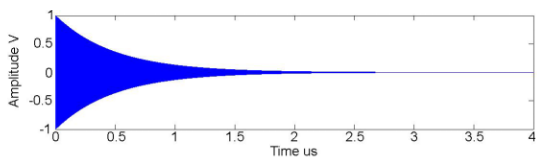

Figure 2: Simulated signal from cavity [6].

a reference resonant cavity, at the same frequency of the dipole mode, is adopted to desensitize the system from the timing jitter of the beam. In this cavity the beam excites the monopole mode TM_{010} and the output signal can be written by:

$$r(t) = V_{010} e^{-\alpha_{010} t} \sin(\omega_{010} t + \varphi_{010}) \quad (3)$$

where $\alpha_{010} = \pi f_{010}/Q$ is the attenuation constant, f_{010} and Q are the resonant frequency and loaded quality factor of the cavity, respectively. φ_{010} is the phase and V_{010} is the amplitude of the signal which is in a first approximation independent on the transverse position of the beam.
In order to get a deeper understanding of the electronics, a bench test characterization, shown in figure 3, is currently in progress. In this block diagram the receiver is a single-stage three-channel heterodyne receiver. The RF signals from the two cavities are attenuated and filtered by means of low band pass or pass band filters. Then the signals are down-converted from the C-band frequency of 6.5 GHz to the intermediate frequency (IF) in the range from 30 to 40 MHz by means of mixers. As an example figure 4 shows a typical output from the receiver. The local oscillators (LO) are all synchronized and phase locked with the global timing of the LINAC [7]. Furthermore the LO, used to down-convert signals from the measurement cavity, is locked for working at 6.46-6.47 GHz, while the LO of the reference chain is tunable in the range of 6.46-6.54 GHz. By doing so any possible mismatch between the frequency of the reference cavity and the frequency of the measurement cavity due to mechanical tolerances is compensated. The outputs from the receivers after filtering are given by:

$$m_{IF,x} = A_x e^{-\alpha_{110} t} \sin(\omega_{110,IF} t + \varphi_{110,x}) \quad (4)$$

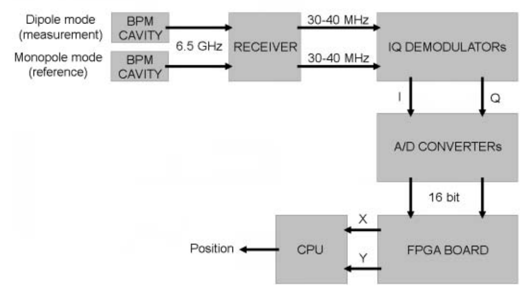

Figure 3: Architecture for test bench BPM electronics

$$m_{IF,y} = A_y e^{-\alpha_{110} t} \sin(\omega_{110,IF} t + \varphi_{110,y}) \quad (5)$$

$$r_{IF} = B e^{-\alpha 010 t} \sin(\omega_{010,IF} t + \varphi_{010}) \quad (6)$$

where the amplitudes A_x, A_y are proportional to amplitudes $V_{110,x}$, $V_{110,y}$ repectively and the amplitude B is proportional to amplitude V_{010}. In our test bench system the

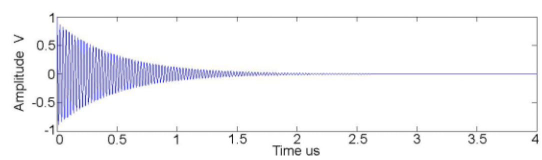

Figure 4: Simulated output from receiver [6].

IF signals are demodulated by two analog I-Q demodulators, one for each axis, providing two signals in baseband, shown in figure 5, one in-phase (I) and in one quadrature (Q):

$$I_x = C_x e^{-\alpha t} \sin(\varphi_{110,x} - \varphi_{010}) \quad (7)$$

$$Q_x = C_x e^{-\alpha t} \cos(\varphi_{110,x} - \varphi_{010}) \quad (8)$$

$$I_y = C_y e^{-\alpha t} \sin(\varphi_{110,y} - \varphi_{010}) \quad (9)$$

$$Q_y = C_y e^{-\alpha t} \cos(\varphi_{110,y} - \varphi_{010}) \quad (10)$$

where $\alpha = \alpha_{110} + \alpha_{010}$, the amplitude C_x is proportional to the amplitudes A_x and the amplitude C_y is proportional to the amplitude A_y.
In principle the beam displacement, from the axis considered, can be calculated by

$$s = \sqrt{I^2 + Q^2} \quad (11)$$

and the phase information is given by:

$$\vartheta = \arctan\left(\frac{I}{Q}\right) \quad (12)$$

Figure 6 show a more detailed block diagram for the receiver and I-Q demodulators. Finally the I-Q signals are digitalized by two A/D converters. Such A/D converters, indicated in figure 3, have a resolution of 16 bit and a sampling rate of 130 MSPS. The reference clocks are synchronized with the Linac timing reference. For the final version of the electronics, shown in figure 7, the A/D conversion is performed after the receiver and the I-Q demodulation

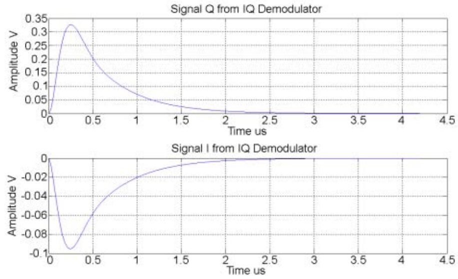

Figure 5: I-Q components [6].

is implemented digitally. This solution has the advantage of minimizing the typical errors of the I/Q detector, such as gain matching, DC offset, quadrature phase errors and carrier leakage.

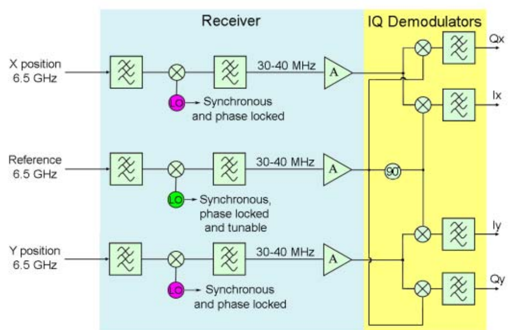

Figure 6: Receiver and I-Q demodulators block diagrams [8].

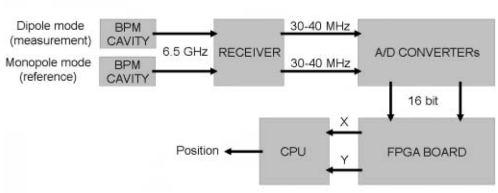

Figure 7: Block Diagram of final version.

CAVITY BPM WAKEFIELD BUDEGET

Longitudinal and transverse wake potentials of the reference and BPM cavities have been calculated using the GdfidL code [4]. For the BPM geometry, the minimal mesh size limited by the computer power is $0.25mm$. To obtain reliable results of the GdfidL calculation, the mesh size should be at least 5 times less than the bunch length. Thus the calculations were performed for a RMS bunch length of $5mm$ and $2mm$. Figures 8and 9 show a comparison between numerical and analytical longitudinal and transverse wake potentials, respectively. The analytical wake potentials are been obtained by means of the convolutions between longitudinal charge distribution and the wake functions given in [9]. It is worthwhile to note that the waveguides have an influence in the wakes calculation. This point is handled in the reference [10].

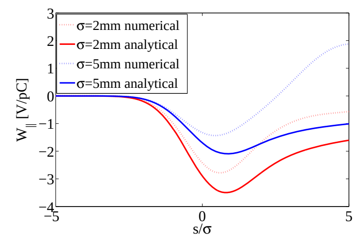

Figure 8: Comparison between numerical and analytical longitudinal wake potentials.

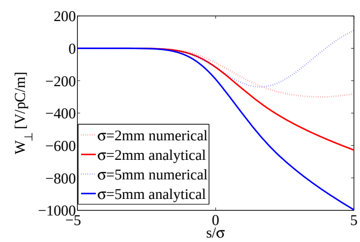

Figure 9: Comparison between numerical and analytical transverse wake potentials.

CONCLUSION

In this paper the prototype of the cavity BPM developed for the FERMI@elettra facility has been presented. To meet the stringent requirements on RF parameters the machining tolerance was fixed to $\pm 10\mu m$ for cavities, waveguides and their relative positioning. Furthermore, the design of the prototype electronics for the acquisition and the processing of the signals from the BPM cavities is also presented. The adopted scheme consists of a down converter from the C-band to an intermediate frequency followed by an IQ demodulator to generate the base-band signal which is proportional to the transverse beam position. Preliminary longitudinal and transverse wakefield estimations have been performed. As a results, it seems likely that the waveguides on the BPM have an influence in the calculation.

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