DESIGN AND CONSTRUCTION OF AN INDUCTIVE PICK-UP FOR BEAM POSITION MONITORING IN THE TEST BEAM LINE OF THE CTF3*

J.J. García-Garrigós, A. Faus-Golfe, J.V. Civera-Navarrete,
IFIC (CSIC-UV), Valencia, Spain

Abstract

A prototype of Beam Position Monitor (BPM) for the Test Beam Line (TBL) of the 3rd CLIC Test Facility (CTF3) at CERN has been designed and constructed at IFIC in collaboration with the CERN CTF3 team. The design is a scaled version of the BPMs of the CTF3 linac. The design goals are a resolution of 5μm, a overall precision of 50μm, in a circular vacuum chamber of 24 mm, in a frequency bandwidth between 10kHz and 100MHz.The BPM is an inductive type BPM. Beam positions are derived from the image current created by a high frequency electron bunch beam into four electrodes surrounding the vacuum chamber. In this paper we describe the mechanical design and construction, the description of the associated electronics together with the first calibration measurements performed in a wire test bench at CERN.

INTRODUCTION

The CLIC Test Facility will demonstrate the essential parts of the Compact Linear Collider (CLIC) drive beam generation scheme consisting of a fully loaded linac, a delay loop and a combiner ring. The final CTF3 drive beam is delivered to the CLIC Experimental Area (CLEX) comprising the Test Beam Line (TBL) and a two beam test stand. The TBL is designed to study and validate the drive beam stability during deceleration. The TBL consists of a series of FODO lattice cells and a diagnostic section at the beginning and end of the line to determine the relevant beam parameters. Each cell is comprised of a quadrupole, a BPM and a Power Extraction and Transfer Structure (PETS) [1]. A schematic of a TBL cell is shown in Fig.1. The available space in CLEX allows the construction of up 16 cells with a length of 1.4 m per cell. The BPM's will most likely be a scaled version of the Inductive Pick-Up (IPU) used in the main linac of CTF3 [2] and should reach a resolution of 5 μm. An IPU senses the azimuthal distribution of the beam image current. Its construction is similar to a wall current monitor, but the the pick-up inner wall is divided into electrodes, each of which form the primary winding of a toroidal transformer. The beam image current component flowing along each electrode is transformed to a secondary winding,which is connected to the pick-up output through a conditioning circuit on a Printed Circuit Board (PCB).The closer the beam is to the transformer-electrode, the greater is the induced signal in its secondary winding. This basic sensing mechanism is able to determine the beam position trough the transformers distributed orthogonally around the vacuum pipe. Table 1 summarizes the TBL beam parameters and the parameters of the BPM's. A set of two prototypes of the TBL-BPM with its associated electronics has been developed in the IFIC with the collaboration of CTF3 team at CERN. This paper describes the design, construction and calibration of the first two prototypes of the TBL-BPM's, in the following BPS's.

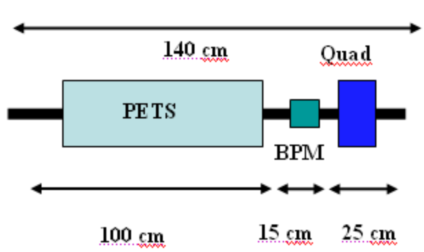

Figure 1: Schematic of a TBL cell.

Table 1: TBL Beam Parameters and BPM characteristics

TBL Beam Parameters	
Beam current range	1-32 A
Bunch train duration	20-140 ns
Injection beam energy	150 MeV
Microbunch spacing	83 ps(12 GHz)
Microbunch duration	4-20 ps
Microbunch charge	0.6-2.7 nC
Repetition frequency	0.83-50 Hz
Radiation level	$\leq$1000 Gray/year
Emittance	150 μm
BPM Parameters	
Analog bandwidth	10 kHz-100 MHz
Beam position range	$\pm$5 mm (H/V)
Beam aperture diameter	24 mm
Overall mechanical length	126 mm
Number of BPM's in TBL	16
Resolution at maximum current	$\leq$5 μm
Overall precision	$\leq$50 μm

MECHANICAL DESIGN AND CONSTRUCTION

The BPS components and the assembly are shown in Fig.2 and Fig.3. The BPS has a length of 126 mm with

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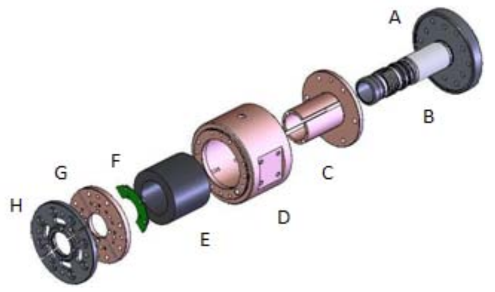

Figure 2: View of the BPS parts with the associated electronics (PCB).

Figure 3: View of the BPS assembled.

a external diameter of 100 mm and an inner diameter of 24 mm for the vacuum chamber. The vacuum assembly (A), consists of a ceramic tube (B) brazed to two Kovar collars at both ends, with one collar TIG welded directly to the downstream flange, and the other one electron welded to a bellow and a rotatable flange. In order to minimize the longitudinal impedance the tube is titanium coated, using the sputtering technique, on the inside [3]. The four electrodes (C) cover most of the circumference in order to make the BPS as transparent to the beam as possible. In order to decrease the low-frequency cut-off the electrodes are surrounded by a ferrite cylinder (E) inserted in the body (D). The plates (G) accommodate the PCBs (F) on which the four transformers are mounted. A screw passes through each transformer, connecting each electrode to the plate (G) with connectors screwed. To achieve good low frequency responses primary circuits parasitic resistances had to be kept below a mΩ, thus the body (D), the electrodes (C) and the plates (G) are made of copper. The plates as well as the beryllium copper screws are gold plated. The electrodes and the their supporting plates are machined in one piece to minimize contact resistances between small surfaces and to achieve good mechanical precision.

ELECTRONICS

The four output voltage signals (V_+, H_+, V_-, H_-) will drive an external amplifier to yield three signals for determining the beam position: sum signal ($\Sigma = V_+ + H_+ + V_- + H_+$), proportional to the beam current; and two difference signals ($\Delta V = V_+ - V_-$ and $\Delta H = H_+ - H_-$) for horizontal and vertical plane. There is also two input calibration signals, Cal+ and Cal-, to check the correct function of the sensing PCB halves.

Electric Model and Characterization Parameters

When the beam is in the pick-up center the current through the four electrodes will be uniformly distributed, so $I_{elec} = I_B/4$. This electrode current will vary when the beam is displaced from the center. In the equivalent electric model shown in Fig. 4, we see that each electrode current is transformed into a secondary current as $I_{sec} = I_{elec}/N$ where N is the transformer turns. Therefore, from the secondary circuit loaded with 50Ω, we obtain the output voltage signal $V_{sec} = \frac{R_{S1}}{2N} I_{elec}$, depending on the varying current electrode where V_{sec} stands for V_+, H_+, V_- or H_-. For obtaining the sum signal we would have, $\Sigma = \frac{R_{S1}}{2N} I_B$ which keeps constant in the pass-band of the pick-up. From the last relation the designed transresistance for N=30 turns is $\frac{\Sigma}{I_B} = 0.55\Omega$, thus for the nominal beam current $I_B = 30A$ we get a sum signal of $\Sigma = 16.5V$ and so the pick-up outputs for a centered beam will be $V_{sec} = \Sigma/4 = 4.125$V.

Due to the inductances L_Δ of the electrodes the frequency response of the difference signals for the vertical and horizontal plane, ΔV and ΔH, have a low cut-off frequency, f_{L_Δ}. Similarly, we have a different low cut-off frequency for the sum signal, f_{L_Σ}:

$$f_{L_\Delta} = \frac{1}{2\pi L_\Delta} (R_P + R_C) \quad (1)$$

$$f_{L_\Sigma} = \frac{1}{2\pi L_\Sigma} (R_P + R_C) \quad (2)$$

where the characteristic parameters for each primary electrode are the inductance L_Δ, the parasitic connection resistance R_c, and the input resistance seen by the primary of the transformer, $R_P = \frac{R_{S1}||(R_{S2}+R_{Load})}{N^2}$. For obtaining the Σ we must use the inductance L_Σ of the loops made up from the electrodes and the cooper body walls which enclose the ferrite cylinder. Turning to time domain, this low cut-off frequency produces a exponential droop of the flat-top pulse for the Δ and Σ signals, with time constant $\tau_{droop_\Delta} = 1/\omega_{L_\Delta}$ and $\tau_{droop_\Sigma} = 1/\omega_{L_\Sigma}$.

This parameter is very important since we must let pass the square pulse waveform of the beam with flat-top, to later on be sampled by the digitizer without problems. As a rule of thumb the time constant must be $\tau_{droop} \sim 10^2 \tau_{pulse}$ to have a flat-top pulse response. As a result N has to be chosen high to lower this cut-off frequency enough. Nevertheless N can not be too large because we would degrade the output levels with N^{-1}, having problems to sense small beam positions steps. Typical estimated values of L_Δ and L_Σ gives $f_{L_\Delta} >> f_{L_\Sigma}$, and so $\tau_{droop_\Delta} << \tau_{droop_\Sigma}$. As a consecuence, usually it's necessary to lower f_{L_Δ} by adding RC filters in the external amplifier Δ channels.

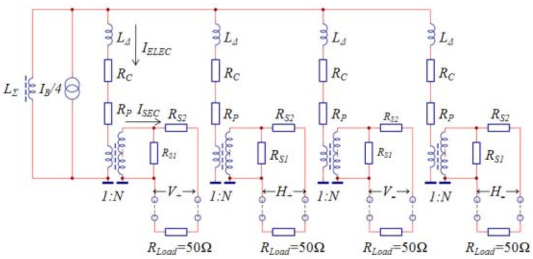

Figure 4: Low-frequency electrical model.

WIRE TEST CALIBRATION RESULTS

The main aim of the wire method test is to obtain measurements of the sensitivity, linearity and frequency response (bandwidth) of the BPS prototypes. This test is based on a test bench setup that allows moving the BPS with respect to a current wire that simulates the beam passing through the BPS under test.

Frequency Response

In Figure 5 it is shown the frequency response of the Δ signals, whose levels depend on the beam position, and the Σ signal, which keeps constant in the aperture. These signals were obtained without an external amplification by mixing the pick-up outputs in a network analyzer, and it was measured the characteristic low cut-off frequencies for them: $f_{L_\Delta} = f_{L_{\Delta V}} = f_{L_{\Delta H}} = 282$kHz and $f_{L_\Sigma} = 1.76$kHz. Because the pulsed beam of TBL will have a maximum τ_{pulse} of 140 ns, the specification for the f_{L_Δ} is set to 10 kHz to get $\tau_{droop_\Delta} = 10\mu s$ and thus, as we mentioned before, $\tau_{droop_\Delta}/\tau_{pulse} \sim 10^2$ allowing a good flat-top pulse transmission through the BPS outputs. Therefore the f_{L_Δ} will need to be lowered compensating the droop in the external amplifier Δ channels. The noisy behaviour of Δ signals below the cut-off was due to the low current in the wire. The high cut-off frequency is also important to let pass an output pulse without too much distortion like the overshooting. In spite of high frequency reflections in the wire, the high cut-off frequency could be determined to be over 100MHz.

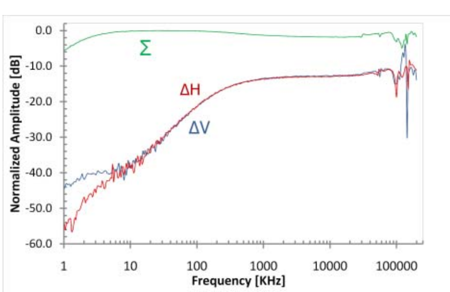

Figure 5: Frequency response of the BPS signals.

Sensitivity and linearity error

The thin wire was excited with a 1 MHz sinusoid signal and due to a resistor divider at the beginning of the wire setup, we could only had 13 mA current amplitude. A calibrated amplifier was used and the ΔV/Σ, ΔH/Σ and position signals were acquired with a network analyzer connected to a PC running LabVIEW through GPIB bus.

To determine the sensitivity a linear fit was done for both planes. The relevant parameters are the slope that defines the BPS sensitivity: S_V=(41.09±0.08)10^{-3}mm^{-1}, S_H=(41.53±0.17)10^{-3}mm^{-1}; and making the Δ/Σ signals equal to zero we get the electrical offset for vertical, EOS_V=(0.03±0.01)mm, and horizontal plane, EOS_H=(0.15±0.02)mm. The linearity error was obtained for several positions in the range of interest ±5mm (Figure 6), and also the rms linearity error for each plane, $\sigma_V = 80\mu$m and $\sigma_H = 170\mu$m, giving the uncertainty in the position measurements.

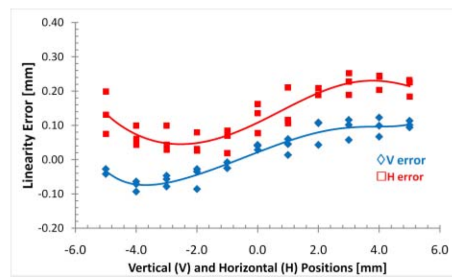

Figure 6: Linearity error for both planes.

CONCLUSION AND FUTURE TASKS

A set of two prototypes with the associated electronics were designed and constructed. The electric model and characterization parameters as sensitivity, linearity, electrical off-set and cut-off frequencies has been determined with a wire method test. The performed test yields good linearity results and reasonably low electrical offset from the mechanical center. A new improved setup will be built for testing the BPS's series. Prototype calibration with beam in CTF3 will be performed this coming fall.

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