CHARACTERIZATION TESTS OF THE BEAM POSITION MONITOR SERIES PRODUCTION FOR THE TBL LINE OF THE CTF3 AT CERN*

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Abstract

A set of two Inductive Pick-Up (IPU) prototypes with its associated electronics for Beam Position Monitoring (BPM) in the Test Beam Line (TBL) of the 3^{rd} Compact Linear Collider (CLIC) Test Facility (CTF3) at CERN were designed, constructed, and tested by the IFIC team. One prototype and two units of the series production are already installed in the TBL line. In the first part of the paper we describe the characterization tests of these two prototypes carried out at CERN, and the first beam tests performed to one of them. The second part of this paper is dedicated to the description of the issues addressed by the start of the series production and the characterization tests of the first series units performed with a custom-made low-frequency wire setup. This setup which emulates the beam position variation allows to carry out the series tests in an automatized manner and with higher accuracy.

INTRODUCTION

The CLIC Test Facility will demonstrate the essential parts of the 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 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 (labeled as BPS) and a Power Extraction and Transfer Structure (PETS) [1]. A 3D view 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 BPS's are IPU type and the expected performances for a TBL beam type (current range 1-32 A, energy 150 MeV, emittance 150 μm, bunch train duration 20-140 ns, microbunch spacing 83ps (12GHz), microbunch duration 4-20 ps, microbunch charge 0.6-2.7 nC) are summarized in Tab. 1.

BPS PROTOTYPES

A set of two prototypes of the BPS's labeled as BPS1 and BPS2 with its associated electronics has been designed, constructed and characterized by the IFIC team with the collaboration of the CTF3 team at CERN. The BPS has

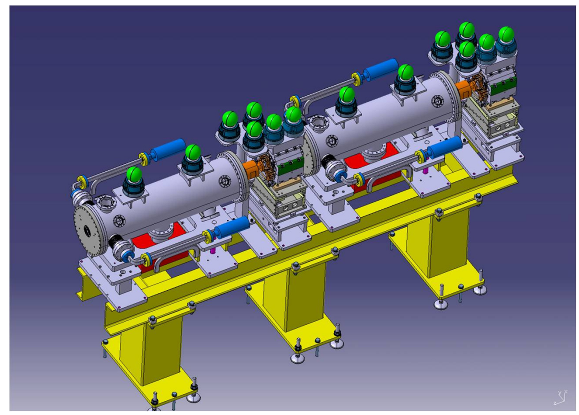

Figure 1: 3D view of a TBL cell with the PETS tanks, the BPSs and the quadrupoles.

Table 1: Expected BPS Characteristics

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 BPS's	16
Resolution at maximum current	$\leq$5 μm
Overall precision $\sigma_{H/V}$	$\leq$50 μm

four electrodes setting up the vertical and horizontal coordinate planes. The current intensity induced by the beam is distributed through these electrodes depending on the beam proximity. The electrodes current is then sensed by their respective transformers in a conditioning circuit placed in a internal PCB. This gives the four output voltage signals (V_+, H_+, V_-, H_-) that will drive an external amplifier to yield three signals for determining the beam position: sum signal ($\Sigma = V_+ + H_+ + V_- + H_+$), to get the beam current intensity; and two difference signals ($\Delta V = V_+ - V_-$ and $\Delta H = H_+ - H_-$) which are proportional to the horizontal and vertical coordinates of the beam position. There is also two input calibration signals, Cal+ and Cal-, to check the correct function of the sensing PCB halves. A detailed description of the mechanics, electrical model and the electronics of this two prototypes can be found in [2].

Prototypes Characterization Tests

The BPS characterization parameters for each coordinate plane: sensitivity, overall precision (accuracy), electrical offset and cut-off frequencies with its associated time constants; has been determined with the wire method test in the BI-PI labs at CERN. This test is based on a test bench

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setup that allows moving the BPS with respect to a current wire that simulates the beam passing through the BPS under test. The BPS1 prototype reference performance coming from the first characterization tests are summarized in the Tab. 2. From the linearity test, which fits the normalized $\Delta(V, H)/\Sigma$ signals to the wire position in each coordinate plane, are obtained the main BPS characterization parameters: the sensitivity, as the proportional factor between the BPS signals and the beam position coordinate; the electrical offset from the true mechanical center or zero position; and the accuracy, as the rms linearity error in the range of interest. The frequency response test of the BPS output signals gives the cut-off frequencies that define the needed bandwidth (see Tab. 1) to let pass the rectangular pulse signal without deformation induced by the pulsed beam structure. The pulse-time constants derive inversely from these cut-off frequencies. In the most relevant case of the exponential droop time constant, it has to be a factor hundred larger than the beam pulse duration (140 ns) to ensure the desired flat-top pulse output signals of the BPS.

The performed tests in the wire setup yield good linearity results and reasonably low electrical offsets from the mechanical center. From the linearity errors analysis can be stated that the overall precision results have to be ameliorated, considering the effect of the very low excitation current in the wire (13 mA) and the misalignment for the horizontal plane electrodes. Concerning the frequency response measurements, the low cut-off frequencies for the Δ signals, f_{l_Δ}, are equal for the vertical and horizontal planes, and they are given for performing the compensation of droop time constants with the external amplifier, decreasing so these cut-off frequencies down to the specified bandwidth lower limit (10 kHz). The low cut-off frequencies for the sum (Σ) signals, f_{l_Σ}, corresponding also to each electrode output frequency response, are the same for both cases wire/beam and calibration excitation ($f_{l_\Sigma[Cal]}$), and they are under specifications (below 10 kHz), as well as, the high cut-off frequencies, f_h and $f_{h[Cal]}$, that we could determine to be above the required 100 MHz. The fact that the f_{l_Δ} are much higher than f_{l_Σ}, is due to a coupling effect among the BPS opposite electrodes for a displaced wire/beam. This effect leaves the electrodes frequency response equal and constant in magnitude, becoming the Δ signals insensitive to a wire/beam displacement, only for the low frequency components. Moreover, it was measured a significant, and never seen before, difference of around 100 kHz between the Δ low cut-off frequencies for the wire/beam and the calibration excitations, f_{l_Δ} and $f_{l_\Delta[Cal]}$ respectively. In the attempt of eliminate this difference, both low cut-off frequencies were lowered changing the output resistor values in a new PCB version, but the difference between f_{l_Δ} and $f_{l_\Delta[Cal]}$ remained unchanged. Both effects involving the Δ signals are related, and a new electrical model for taking into account those effects will be investigated in a future work.

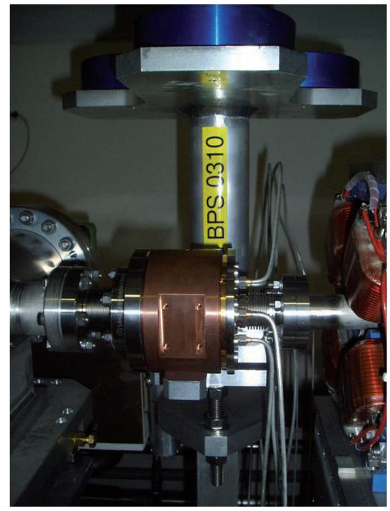

Figure 2: BPS1 and its support installed in the TBL line.

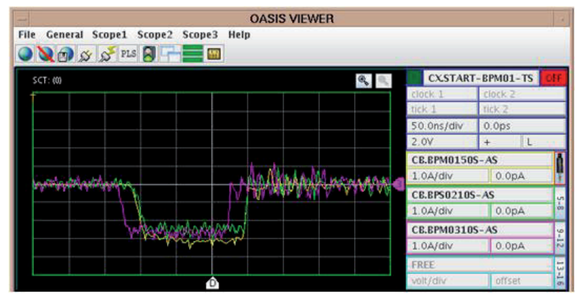

Figure 3: Σ beam pulse measurement of the BPS1 (yellow trace) in the TBL line.

First Beam Test

The BPS1 and its support was installed in the TBL line as it is shown in Fig. 2. In December 2008 some preliminary test with beam losses was performed. In these first series of measurements with beam we observed a ringing problem with calibration pulses which was investigated and solved in a collaborative effort. The results of the second series of beam measurements were satisfactory after solving the initial ringing problem and in Fig. 3 is shown the Σ signal corresponding to a beam pulse. The BPS2 remained at the IFIC labs for testing, performing the necessary improvements for the series and help in the design and construction of the new wire setup.

BPS SERIES PRODUCTION

The series production of the 15 unit (BPS1 + 15) has been started at the IFIC labs in November 2008. After solving some mechanical design adjustments based on the prototyping experience, the production of the different parts, described in [2], is finished. The PCBs for the full BPS series are also finished and validated, implementing the final version of the PCB design with some improvements with respect to the first prototype versions. Mainly, the redesign of the PCB was focused on trying to diminish the high coupling effects that exists between the BPS strip electrodes.

Table 2: BPS1 Prototype and BPS2/3 Series Performance

BPS1/2/3 Sensitivity and Linearity Parameters	
V Sensitivity S_V	41.09/43.16/43.70 m^{-1}
H Sensitivity S_H	41.43/42.60/42.10 m^{-1}
V Electric Offset EOS_V	0.03/-0.67/-0.84 mm
H Electric Offset EOS_H	0.15/0.50/0.52 mm
V overall precision σ_V ($\pm$5 mm)	78/89/94 μm
H overall precision σ_H ($\pm$5 mm)	109/90/98 μm
BPS1/2/3 Characteristic Output Levels	
Sum signal level Σ	16.5 V
Diff signals levels $\|\Delta V/H\|_{max}$	8.25 V
Centered beam level, $V_{sec}(0,0)$	4.125 V
BPS1/2/3 Frequency Response Parameters	
Σ low cut-off freq f_{l_Σ}	1.76/2.90/1.70 kHz
Δ low cut-off freq f_{l_Δ}	282/271/275 kHz
Σ[Cal] low cut-off freq $f_{l_{\Sigma[Cal]}}$	1.76/2.80/1.70 kHz
Δ[Cal] low cut-off freq $f_{l_{\Delta[Cal]}}$	180/163/171 kHz
High cut-off freq f_h	>100 MHz
High cut-off freq [Cal] $f_{h[Cal]}$	>100 MHz
BPS1/2/3 Pulse-Time Response Parameters	
Σ droop time const τ_{droop_Σ}	90/55/93 μs
Δ droop time const τ_{droop_Δ}	564/587/579 ns
Σ[Cal] droop const $\tau_{droop_{\Sigma[Cal]}}$	90/57/93 μs
Δ[Cal] droop const $\tau_{droop_{\Delta[Cal]}}$	884/976/931 ns
Rise time const τ_{rise}	<1.6 ns
Rise time const [Cal] $\tau_{rise[Cal]}$	<1.6 ns

The assembly of the full series, including the PCBs, is foreseen to start at the end of May 2009.

Due to installation schedule requirements two new units has been installed in the TBL line in advance of the rest of the series. The BPS2 which was previously manufactured as a second prototype, and the BPS3, a new assembled unit belonging to the series production, both incorporating the PCBs final version.

Series Characterization Tests

Prior to send these two units to CERN, their characterization test were performed at IFIC labs with the new low-frequency wire test setup (Fig. 4). It has been custom designed for the BPS series tests and built also at IFIC. The BPS2/3 characterization results are presented in Tab. 2.

The main features of this new test bench setup is that the BPS under test will be moved by a motorized XY and rotatory micromovers to change the relative wire position (0.25 mm) with respect to the BPS. For the sensitivity and linearity test the wire input is fed by a sinusoid signal in the pass-band of the BPS (1MHz) which comes from a Vector Network Analyzer (VNA) after passing through a current amplifier. The last will boost the wire current more than 250 mA, improving the signal to noise ratio of the previous tests made at CERN. The BPS external amplifier is connected to the BPS electrode outputs to send the Δ and Σ signals to the VNA. Then, a PC running LabVIEW acquire the $\Delta(V,H)/\Sigma$ and the wire position signals managing the VNA and the micromovers controller through GPIB bus. This allows to program the measurement of many samples for each BPS unit by automatizing all the equipment. The frequency and pulse response tests are performed in the same way but with the signals coming directly from the BPS outputs. Other setup characteristics are: the pneumatic isolation workstation to avoid wire vibrations, the 2/0.2 μm precision/resolution of the XY linear stages, and the rotatory stage with 0.2/0.009 μrad. These are enough features to obtain the desired accuracy in the position measurements and to estimate the minimum position resolution down to 5 μm according to TBL specifications. The critical part observed during these tests is that the wire must be aligned with the BPS very precisely. The BPS2/3 accuracy measures was affected by this issue, although both coordinate planes now show good balance. This will be corrected for the rest of the series characterization.

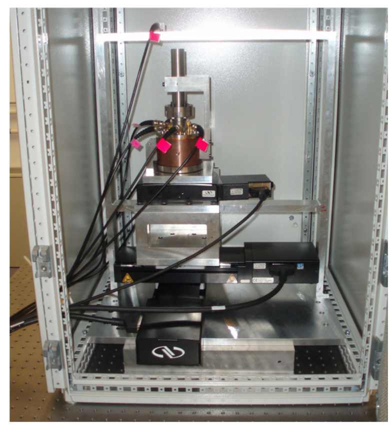

Figure 4: Low-frequency wire test setup in the IFIC labs.

CONCLUSION AND FUTURE TASKS

The series production of 15 units has already started. BPS1 prototype and BPS2/3 series units are already installed in the TBL. The rest of the series will be installed in July 2009. A custom low-frequency setup has been designed and constructed at IFIC labs to automatize the BPS series measurements. Furthermore, a high frequency setup is also being constructed at IFIC for measuring the longitudinal impedance in some of the series units.

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[2] J.J. Garcia-Garrigos et al "Design and Construction of an Inductive Pick-Up for Beam Position Monitoring in the Test Beam Line of the CTF3", EPAC08.