DEVELOPMENT AND TEST BENCHMARKS OF THE BEAM POSITION MONITOR SERIES FOR THE TBL LINE OF THE CTF3 AT CERN*

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Abstract

A set of 17 Inductive Pick-Ups (IPU) for Beam Position Monitoring (BPM) with its associated electronics were designed, constructed and characterized at IFIC for the Test Beam Line (TBL) of the CLIC Test Facility (CTF3) at CERN. In October 2009 the full set of IPUs, labelled as BPS, was successfully installed in the TBL line. In this paper, we summarize the series production phases of the BPS units, focusing in the analysis derived from their characterization tests. A custom-made test bench used for the characterization tests based on the wire-method test for emulating the beam position was also described in detail. This test bench helped us to determine the performance parameters at beam pulse time scale (from 100μs/10kHz to 10ns/100MHz), with high precision and in an automatized way for every unit of the BPS series.

INTRODUCTION

The CTF3 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 the Two Beam Test Stand (TBTS). The TBL is designed to study and validate the drive beam stability during deceleration in the power extraction process. The TBL consists of a series of FODO lattice cells and a diagnostic section at the beginning and at the end of the line to determine the relevant beam parameters. Each cell is comprised of a quadrupole, our BPM (labeled as BPS) and a Power Extraction and Transfer Structure (PETS) [1]. A TBL module with installed PETS, quadrupole and the BPS in the CLEX area at CERN 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 monitor is an IPU type and the expected performances for a TBL beam type (current range 1-30 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 a resolution (at maximum current) $\leq$5 μm and an overall precision (accuracy) $\leq$50 μm. The main benefits argued for using IPUs in the TBL are: position and current intensity measurements in the same device, less perturbed from the high losses in linacs, high output dynamic range for beam currents in the range of interest, broad bandwidth for pulsed beams and short total length.

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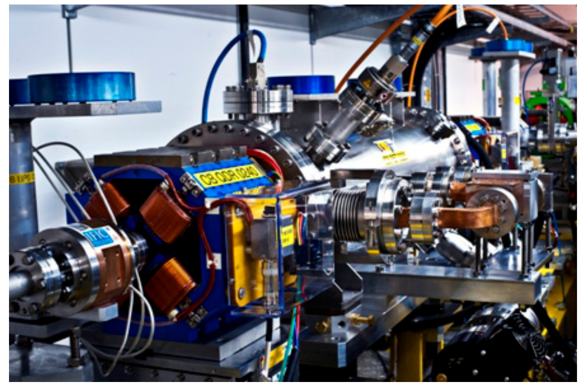

Figure 1: View of a PETS tank, a quadrupole and a BPS in TBL line at CLEX area.

THE BPS MONITOR

Basic Working Mechanism

The BPS inner wall is divided into four electrodes setting up the vertical and horizontal coordinate planes for measuring the beam position. The wall current intensity induced by the beam is distributed through these electrodes depending on the beam proximity to them. The current in each electrode is then sensed inductively by their respective transformers which are part of the internal conditioning circuit on the two PCB halves. In Fig. 2 the BPS transversal cut shows the vertical plane and the wall current flowing through the vertical electrodes followed by the toroidal transformers mounted on the PCBs (same for the horizontal plane).

From the PCB circuits, the output SMA connectors give four voltage signals (V_+, H_+, V_-, H_-) that will drive an external amplifier to yield the three signals for determining the beam position and intensity: the 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. Thus obtaining the beam position vertical and horizontal components from the normalized signals, $x_{H,V} \sim \Delta H, V/\Sigma$. There is also two input calibration signals, Cal+ and Cal-, to check the proper operation of the sensing PCB halves. A detailed description of the mechanics, electrical model and the electronics of the BPS-IPU monitor can be found in [2].

Characterization Tests and Parameters

Every BPS unit must be characterized by its specific parameters for the correct beam position determination and

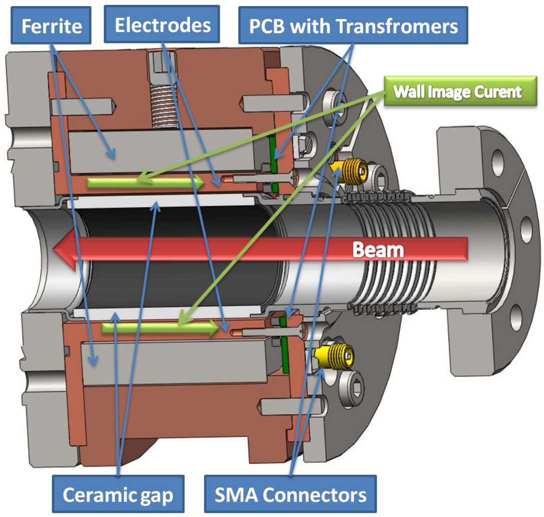

Figure 2: Cross section of a BPS monitor showing the wall current flow.

they need to fulfil the specifications for the TBL [3]. The normalized $\Delta H,V/\Sigma$ signals have to show a good linear behavior for the beam position variation within the central region of the BPS aperture, so these output signals will be related to the beam position components by the linear relation:

$$\frac{\Delta H,V}{\Sigma} = S_{H,V}\, x_{H,V} + n_{H,V} \tag{1}$$

The parameters of these relations are obtained from the characterization tests. These tests are based on a specific designed test stand which allows moving the BPS under test with respect to a thin and stretched wire carrying the excitation current and emulating the beam passing through the BPS. The sensitivity or linearity test is performed by acquiring the wire $x_{H,V}$ position coordinates and the $\Delta H,V/\Sigma$ output signals in the test stand. Thus a linear fit on these data is done to get the sensitivity parameter (slope) for each coordinate component, $S_{H,V}$, as shown in the eq. 1. The intercept $n_{H,V}$ is related with the electric off-sets from the true BPS mechanical center or zero position, $n_{H,V} = -E_{offH,V}/\Sigma$. Concerning the overall precision or accuracy in the measurement of the absolute position components, $\sigma_{H,V}$, they can be specified as the root mean square of the horizontal and vertical position deviations from the linear fits, or alternatively, as the maximum deviation at the extreme positions in the range of interest (± 5mm).

The BPS frequency response has a bandpass profile, limited at the lowest frequency components because of its inductive behavior and due to stray capacitances at the highest. Therefore, the frequency response test on the BPS $\Delta H,V$ and Σ output signals is made to get their low and high cut-off frequencies, $f_{l\Sigma,\Delta}$ and $f_{h\Sigma,\Delta}$ respectively. These characteristic frequencies define the bandwidth to let pass the rectangular pulse signal, induced by the pulsed beam structure, without deformation. The pulse-time constants, $\tau_{droop\Sigma,\Delta}$ and $\tau_{rise\Sigma,\Delta}$, derive inversely from the low and high cut-off frequencies and represent a droop in the pulse flat-top and a pulse rise time limitation respectively. Since the beam position are finally determined in the digitizer by sampling the $\Delta H,V$ and Σ pulse signals and making the ratio $\Delta H,V/\Sigma$, the flat-top pulse must be as good as possible in both signals to avoid extra inaccuracies. This can be accomplished if we demand $\tau_{droop}/\tau_{pulse} \sim 10^2$, or equally, $f_{l\Sigma,\Delta} < 10kHz$, for a maximum beam pulse duration of 140ns [2]. By design the $f_{l\Sigma}$ is far below the 10kHz but, in the case of Δ signals, the inherent coupling between opposite electrodes increases the f_{l_Δ} above the specified frequency. As a consequence, the $f_{l\Delta}$ is lowered, compensating then for the pulse droop, in the external amplifier Δ channels.

BPS SERIES DEVELOPMENT OUTLINE

The Series Production

In a first stage a set of two prototypes of the BPS labelled as BPS1 and BPS2 with its associated electronics were constructed and tested at IFIC, BPS1 has been installed in the TBL and tested successfully with beam on December 2008 [4]. The series production started in November 2008. From the point of view of the mechanics there are no major changes compared with the prototypes. Concerning the electronics an improvement was made from the first prototype BPS1. Mainly the redesign of the PCB was focused on trying to decrease the coupling effects between the BPS strip electrodes. Two more units, labelled as BPS2 and BPS3, implementing the improved electronics were installed in the TBL on May 2009. The rest of the series were installed in October 2009. The first beam tests made on December 2009 show a very positive results. The complete calibration with beam will be made at the end of 2010.

The Characterization Test Stand

The main features of this new test bench setup, shown in Fig. 3 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 [2]. The BPS external amplifier is connected to the BPS electrode outputs to send the $\Delta H,V$ and Σ signals to the VNA. Then, a PC running LabVIEW acquire the $\Delta H,V/\Sigma$ 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

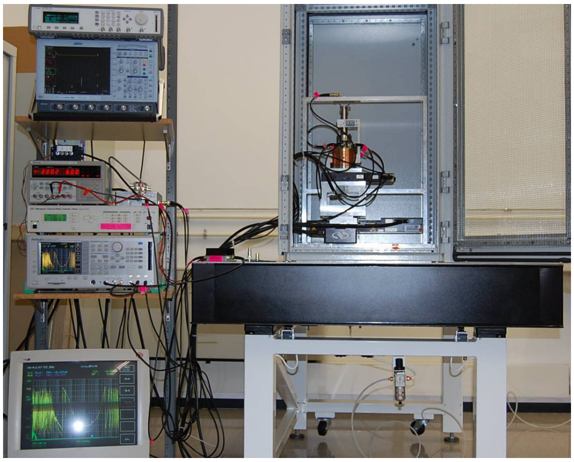

Figure 3: Test bench setup at the IFIC labs.

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 showed good balance.

BPS SERIES TEST BENCHMARKS

In Tab. 1 are presented the main parameters averaged over the full series extracted from the characterization tests performed on every BPS unit. The BPS characteristic parameters are quite sensitive to the mechanical and electronic fabrication tolerances, specifically those involved in the position determination, because of the needed accuracy and electrical off-sets compensation, as well as the low cut-off frequencies for compensating properly the pulse droop. In consequence it was needed to characterize each BPS unit to ensure the performances demanded by the TBL line. From the results in Tab. 1 it can be seen small relative deviations of the characteristic parameters from the average, and also a good balance between the horizontal and vertical plane parameters, which shows successful fabrication process of the BPS series. Moreover, the stability of these results along all the BPS tested units points to a good test stand design and test procedures. Further analysis on additional data acquired for different BPS orientations inside the test stand will be performed to take into account for possible characterization parameters bias due to test stand misalignments and imperfections out of ideality.

CONCLUSION AND FUTURE TASKS

The production of all the BPS needed for the TBL line was finished successfully with the installation of the BPS series in October 2009. A test with calibration signals was

Table 1: BPS full series average performance.

BPS Sensitivity and Linearity Parameters	
H Sensitivity S_H	$41.5\pm0.6\times10^{-3}$mm^{-1}
V Sensitivity S_V	$41.1\pm0.5\times10^{-3}$mm^{-1}
H Electric Offset $E_{off,H}$	0.01 ± 0.08 mm
V Electric Offset $E_{off,V}$	0.17 ± 0.11 mm
H Overall precision σ_H (±5 mm)	32 ± 8 μm
V Overall precision σ_V (±5 mm)	28 ± 6 μm
H Linearity error (±5 mm)	0.9 ± 0.3 %
V Linearity error (±5 mm)	0.9 ± 0.2 %
BPS Frequency Response Parameters	
Σ low cut-off freq $f_{l\Sigma}$	2.4 ± 0.3 kHz
Δ low cut-off freq $f_{l\Delta}$	281 ± 15 kHz
Σ[Cal] low cut-off freq $f_{l\Sigma[Cal]}$	2.4 ± 0.3 kHz
Δ[Cal] low cut-off freq $f_{l\Delta[Cal]}$	168 ± 5 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 $\tau_{droop\Sigma}$	69 ± 11 μs
Δ droop time const $\tau_{droop\Delta}$	568 ± 30 ns
Σ[Cal] droop const $\tau_{droop\Sigma[Cal]}$	68 ± 11 μs
Δ[Cal] droop const $\tau_{droop\Delta[Cal]}$	951 ± 26 ns
Rise time const τ_{rise}	<1.6 ns
Rise time const [Cal] $\tau_{rise[Cal]}$	<1.6 ns

carried out just for proving correct performances of the series in the TBL. Beam tests will be performed at the end of 2010 allowing to test the resolution at maximum current. Furthermore, a test of the longitudinal impedance with a high frequency coaxial setup is being performed at IFIC.

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