HIGH FREQUENCY MEASUREMENTS OF THE BEAM POSITION MONITORS FOR THE TBL LINE OF THE CTF3 AT CERN

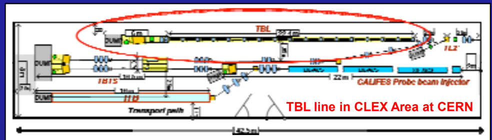
C. Blanch-Gutiérrez, J.V. Civera-Navarrete, A. Faus-Golfe, J.J. García-Garrigós, IFIC (CSIC-UV); B. Gimeno-Martínez, Dpto. Física Aplicada y Electromagnetismo, UV
Valencia, Spain

Abstract †

A series of Inductive Pick-Ups (IPU) for Beam Position Monitoring (BPM) with its associated electronics were designed, constructed and tested at IFIC. A full set of 16 BPMs, so called BPS units, were successfully installed in the Test Beam Line (TBL) of the 3rd CLIC Test Facility (CTF3) at CERN. Two different characterization tests, at low and high frequencies, were carried out on the BPS units: The low frequency test, in the beam pulse time scale (until 10ns/100MHz), determined the BPSs parameters directly related to the beam position monitoring and the high frequency test, reaching the microwave X-Ku bands around the beam bunching time scale (83ps/12GHz). In this paper we describe the results and methods used to obtain the longitudinal impedance in the frequency range of interest. This test is based on the S-parameters measurements of the propagating TEM mode in a matched coaxial waveguide, specifically designed for the BPS, which is able to emulate an ultra-relativistic electron beam.

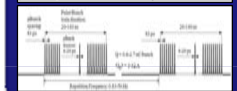
BPS in the TBL of the CTF3

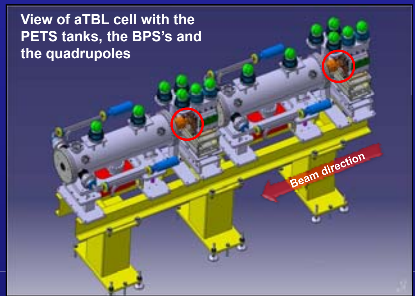
▪ The TBL is designed to study and validate the drive beam stability during deceleration in CTF3. The TBL consists of a series of FODO lattice cells and a diagnostic section at the beginning and end of the line to determine the relevant beam parameters. Each 1.4m cell is comprised of a quadrupole, a BPM (labeled as BPS) and a Power Extraction and Transfer Structure (PETS) [1].



TBL line in CLEX Area at CERN

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	≤1000 Gray/year
Emittance	150 μm
BPM Parameters	
Analog bandwidth	10 kHz-100 MHz
Beam position range	±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	≤5 μm
Overall precision	≤50 μm





View of aTBL cell with the PETS tanks, the BPS's and the quadrupoles

The BPS Monitor and its Longitudinal Impedance $Z_{||}$

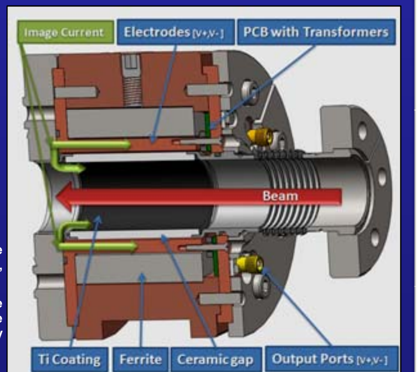
The BPS is an Inductive Pick-Up BPM

▪ The BPS inner vacuum pipe has a ceramic gap surrounded by gold plated cylinder which is divived along into four orthogonal strip electrodes. The wall current intensity induced by the beam flows through these electrodes at bigger wall diameter, and the beam position is measured by means of the image current distribution among these electrodes that will change according to the beam proximity to them. Thus the current level in each electrode is sensed inductively by their respective transformers, which are mounted on two internal PCB halves as part of the electrode outputs conditioning circuit [2].

The main benefits of IPUs: 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.

The BPS Longitudinal Impedance $Z_{||}$

▪ Apart from the main operation parameters for beam position monitoring [3], it is also needed to determine the longitudinal impedance of the BPS monitor for the high frequency components generated by the beam bunching frequency in the GHz range. This is important since every BPS monitor produces a longitudinal impedance, $Z_{||}$, in the line, and higher values of $Z_{||}$ will produce stronger wake-fields leading to beam instabilities.



Limitation of the BPS $Z_{||}$. Two different Paths for the Image Current:

1) Strip Electrodes Path of Minimum Resistance at Low Frequencies

▪ The wal image current follows the path through the electrodes for normal beam position monitoring and the BPS operational bandwidth is at the beam pulse time scale, from 10kHz (100μs) to more than 100MHz (10ns), to have a good pulse shape transmission at the electrodes outputs.

▪ The electrodes path have an inductive behavior, which increases linearly with frequency, introduced by the electrodes larger diameter step seen by the image current. If only the this path exists the $Z_{||}$ of the device would become too large for image current high frequencies components until the bunching frequency (12GHz), and higher harmonics extending beyond the microwave X band.

2) Ti-Coating Layer Path of Minimum Inductance at High Frequencies

▪ The inner wall of the ceramics was coated with a thin Titanium layer deposited by sputtering with an directly measured end-to-end resistance around 11Ω [4].
▪ This gives an alternative path of minimum inductance to the high frequency components of the image current, thereby limiting $Z_{||}$.

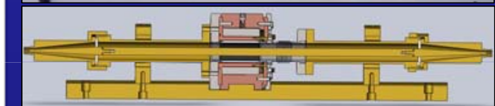
The Coaxial Waveguide Testbench. Measurement of $Z_{||}$

Method of $Z_{||}$ Measurement

▪ An ultra-relativistic beam has a closely transverse electromagnetic (TEM) field distribution, what is the case of the 150MeV TBL electron beam with β≈1, and it can be emulated with a coaxial structure having pure transverse TEM propagation modes to determine $Z_{||}$. The calculation method for distributed longitudinal impedance proposed in [5]:

▪ Z_L is the impedance of coaxial line testbench, S_{21} is the transmission coefficient of the testbench with BPS, and S_{21R} is the transmission coefficient of the reference measurement, with the BPS replaced by a drift tube to remove the testbench dependency.

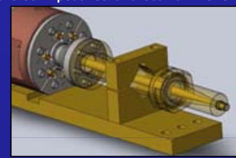
$$Z_{||} = -2Z_L \ln\left(\frac{S_{21}}{S_{21R}}\right)$$



Simulation and Design

▪ The testbench was made of 70/30 brass alloy and built as a coaxial airline of 50Ω transverse impedance along the structure. Geometrically depending on the outer and central conductors radius (or diameter), the transverse impedance of a coaxial line is written as:

$$Z_{coax} = \frac{c\mu_0}{2\pi\sqrt{\varepsilon_r}} \ln\left(\frac{r_o}{r_c}\right)$$



Main Testbench Design Features:

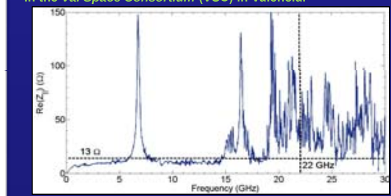
▪ APC-7mm Connectors (low reflection up to 18GHz).
▪ Interseries adaptor APC-7 to SMA(3.5) output ports.
▪ Smooth 50Ω Transition Coaxial Cones from connector dimensions to BPS 24mm aperture.
▪ Outer Coax Conductors: $\phi_0 \equiv 2r_0 = [7 \rightarrow 24]$ mm
▪ Central Coax Conductors: $\phi_C \equiv 2r_C = [3.04 \rightarrow 10.42]$ mm
▪ Transition Cones Length: 80 mm
▪ BPS Insertion Length: 126.15 mm
▪ Straight Section Length (cone to cone): 426.15 mm
▪ Full length (without connectors): 586.15 mm

FEST3D Simulation

▪ The main structure of the coaxial testbench, with the drift tube for reference measurements, was simulated using specialized microwave software FEST3D [6]. The key element in the structure simulation was the transition cones, essentially the cone geometry was loaded into the simulator by linking together short length (l_{step})coaxial waveguides of increasing diameters in a staircase pattern.
▪ Following the Condition: $l_{step} << \lambda_{max}$, to have no influence due to the staircase discontinuities at simulation f_{max}=30GHz.

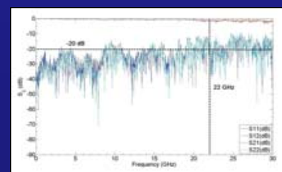
High Frequency Test* Results (up to 30GHz)

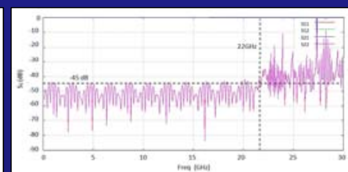
* Test performed at ESA's *European High Power RF Laboratory* in the *Val Space Consortium* (VSC) in Valencia.



S-parameters of the Reference Testbench

▪ Real Measured Testbench (left) and Simulated Coaxial Structure (right).
▪ Theoretical useful Bandwidth reduced to 22GHz due to TM modes propagation.





▪ $Z_{||}$ real part exhibit the expected saturation tendency. At low frequencies it increases linearly until the transition frequency, around 800MHz, when the Ti layer image current path becomes dominant for these frequency components limiting $Z_{||}$ below 13Ω. The limitation is continuously effective up to nearly 6GHz, when resonance peaks occurs (under study).

Conclusions and Future Work

A coaxial waveguide testbench was particularly designed and built at IFIC, which is suitable to emulate the TBL beam high frequency components in the microwave region above the bunching frequency until 18GHz, in order to determine the BPS longitudinal impedance, $Z_{||}$. The method, testbench simulations and design considerations as well as $Z_{||}$ test results were discussed. Also an alternative method based on ABCD matrix formulation is under study as future work.

References

[1] S. Doebert, et al. "Status report of the CTF3 Test Beam Line", CTF3 Note 076.
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[5] F. Caspers, "Impedance Determination from Bench Measurements", CERN-PS-2000-004 (RF).
[6] FEST3D-A Software Tool for the Design of Microwave Passive Components, Distributed by AURORASAT, www.fest3d.com

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Paper ID: TUPD16. Contact: Juan José García-Garrigós, jjgarcia@ific.uv.es