BEAM COUPLING IMPEDANCE MEASUREMENT AND MITIGATION FOR A TOTEM ROMAN POT

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Abstract

The longitudinal and transverse beam coupling impedance of the first final TOTEM Roman Pot unit has been measured in the laboratory with the wire method. For the evaluation of transverse impedance the wire position has been kept constant, and the insertions of the RP were moved asymmetrically. With the original configuration of the RP, resonances with fairly high Q values were observed. In order to mitigate this problem, RF-absorbing ferrite plates were mounted in appropriate locations. As a result, all resonances were sufficiently damped to meet the stringent LHC beam coupling impedance requirements.

THE TOTEM ROMAN POTS

The LHC experiment TOTEM [1] is designed for measuring the elastic pp scattering cross-section, the total pp cross-section and diffractive processes. These physics objectives require the detection of leading protons with scattering angles of a few μrad, which is accomplished using a Roman Pot (“RP”) system with stations at 147 m and 220 m from the interaction point 5 where also CMS will be located. Each station is composed of two RP units separated by a few metres depending on beam equipment integration constraints. Each RP unit consists of a vacuum chamber equipped with two vertical insertions (top and bottom) and a horizontal one (Fig. 1). Each insertion (“pot”) contains a package of 10 silicon detectors in a secondary vacuum. The pots can be moved into the primary vacuum of the machine through vacuum bellows. In order to minimise the distance of the detectors from the beam, and to minimise multiple scattering, the wall thickness of the pot is locally reduced to a thin window foil.

The low impedance budget of the LHC machine (broadband longitudinal impedance limit $Z/n \approx 0.1$ Ω) imposes a tight limit on the RPs’ beam coupling impedance.

IMPEDANCE MEASUREMENT WITH THE WIRE METHOD

Longitudinal Impedance

The beam coupling impedance measurement was performed with the wire method like with the first RP prototype in 2004 [2]. After pulling a 0.3 mm thick wire through the RP along its beam axis, a vector network analyser was used to measure the complex transmission coefficient $S_{21}(f, d_x, d_y)$ between the two ends of the RP (Fig. 2) as a function of the frequency $f$ and of the horizontal and vertical pot distances $(d_x, d_y)$ from the wire.

$$Z(f, d_x, d_y) = -2Z_C \ln \frac{S_{21}(f, d_x, d_y)}{S_{21}^{ref}(f)} \left[1 + i \frac{\ln S_{21}(f, d_x, d_y)}{4\pi f/e C}ight],$$

(1)

Figure 1: Left: the vacuum chambers of a RP unit accommodating the horizontal and the vertical pots and a Beam Position Monitor. Right: the pot with the thin window and a Ferrite collar (black).

Figure 2: Setup of the impedance measurements.

Fig. 3 shows the measurement result for all pots in retracted position and compares it with simulations based on two different programs. While the simulations describe qualitatively all main structures seen in the data, the resonances are shifted in frequency by up to 20%. This disagreement is attributed to the modelling of the bellows in the simulations. An exact model requires a very dense mesh of the volume which compromises the simulation convergence in an acceptable CPU time. Substituting the bellows with a longer smooth cylinder of an equivalent total metallic surface provides good agreement at the first mode frequency (~500 MHz), but does not succeed at higher frequencies. Improved numerical simulation models will be studied.

The longitudinal impedance $Z$ was calculated with the “improved log formula” [3]:
unperturbed beam pipe and perturbation (i.e. the diameter of the pot insertions). The resonance as a function of the distance of the vertical pots from the wire, with retracted horizontal pot. The transverse impedance was only measured for the configuration without ferrite tiles where resonances were visible. For technical reasons, neither the two-wire method nor a movable wire were practicable. Instead, the two vertical pots were moved asymmetrically, keeping their relative distance $D$ – the jaw width – constant. Then the longitudinal impedance was measured as a function of the eccentricity $y$, i.e. the position of the jaw centre with respect to the wire (Fig. 6 top and middle). After a parabolic fit $Z_L(y) = z_0 + z_1 y + z_2 y^2$, where ideally $z_1 = 0$ by virtue of symmetry, a combination of vertical transverse impedance $Z_{Ty}$ and detuning impedance $Z_{det}$ can be obtained from the curvature parameter $z_2$, like in the moving wire technique (2):

$$Z_{Ty} + Z_{det} = \frac{c}{2 \pi f} z_2 \cdot$$

Since there is only one horizontal pot, no analogous measurement of the $x$-component $Z_{Tx} - Z_{det}$ could be made, which would have enabled the elimination of $Z_{det}$. However, based on the calculations in Ref. [5] for different aperture geometries, the contributions $Z_{Ty}$ and $Z_{det}$ could be approximately disentangled. The result for the first group of resonances is shown in Fig. 6 (bottom) as a function of the jaw width $D$.

**Transverse Impedance**

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**Time Domain Studies – the Loss Factor**

The built-in Fourier transformation capability of the network analyser facilitated a transmission study in the time domain. Fig. 7 shows the transmission response to an injected Gaussian pulse with $\sigma = 0.6$ ns for two different position configurations of the horizontal and vertical pots.
\[ \int_{-2\sigma}^{2\sigma} I_{\text{ref}}(t) \, dt, \]

where the time integral extends over a range of \( \pm 2\sigma \) around the peak. \( I_{\text{ref}}(t) \) is the reference pulse measured with all pots in retracted position. As Fig. 8 shows, the loss factor does not change strongly with the addition of the ferrites.

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