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BEAM COUPLING IMPEDANCE MEASUREMENT AND MITIGATION FOR A TOTEM ROMAN POT

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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 $Z/n \approx 0.1\,\Omega$) imposes a tight limit on the RPs' beam coupling impedance.

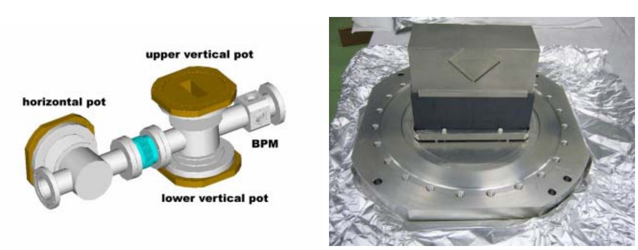

Figure 1: Left: the vacuum chambers of a RP unit accomodating the horizontal and the vertical pots and a Beam Position Monitor. Right: the pot with the thin window and a Ferrite collar (black).

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.

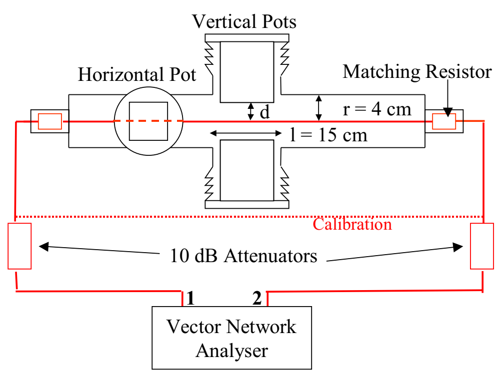

Figure 2: Setup of the impedance measurements.

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]

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

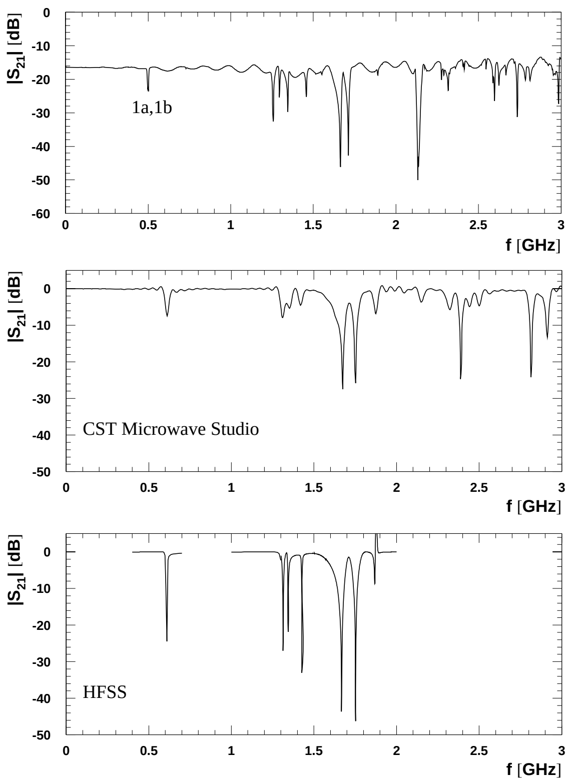

Figure 3: Comparison of the measured (top) and the simulated (middle and bottom) transmission coefficient $|S_{21}|$ with all pots in retracted position ($d_x = d_y = 40$ mm).

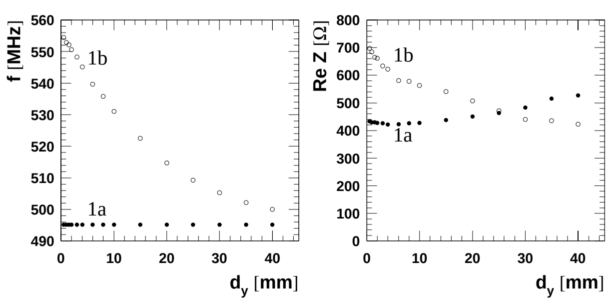

Figure 4: Frequency and impedance of the first double resonance as a function of the distance of the vertical pots from the wire, with retracted horizontal pot.

where $Z_C = 294\,\Omega$ is the characteristic impedance of the unperturbed beam pipe and $l = 15$ cm is the length of the perturbation (i.e. the diameter of the pot insertions). The measurement with all pots in retracted position served as reference measurement $S_{21}^{ref}(f)$ after removal of all resonances by interpolation in both modulus and phase.

The approximately Gaussian LHC bunch structure with $\sigma_t = 0.25$ ns leads to a Gaussian envelope with $\sigma_f = 0.63$ GHz in the frequency distribution of the LHC current with harmonics every 40 MHz. Hence the relevant resonances lie well below 1 GHz. Fig. 4 shows the evolution of frequency and longitudinal impedance of the first double resonance peak as a function of the vertical pot position d_y (for this measurement the top and the bottom pot positions were symmetrical w.r.t. the wire). The impedance value of $700\,\Omega$ for mode 1b at $d_y = 0.5$ mm corresponds to $Z/n = 14\,\mathrm{m}\Omega$, where $n = f_{reson}/f_{LHC} = 555\,\mathrm{MHz}/11\,\mathrm{kHz}$, or a dissipated power of about 200 W, which demonstrates the necessity of mitigating hardware modifications. The latter were realised in the form of a collar of ferrite tiles around the pot insertions (Fig. 1, right). They had the desired effect of smearing out all resonances beyond recognition (Fig. 5).

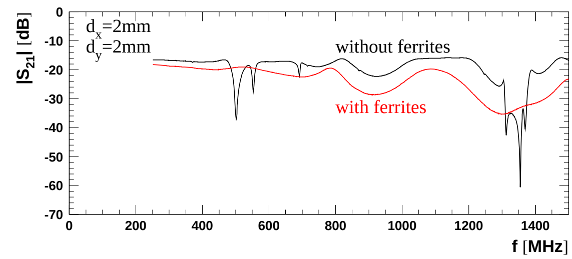

Figure 5: Frequency spectrum of the transmission coefficient $|S_{21}|$ before and after installation of the ferrite tiles.

Transverse Impedance

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 excentricity 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 [4]:

$$Z_{Ty} + Z_{det} = \frac{c}{2\,\pi\,f} z_2\,. \qquad (2)$$

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.

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.

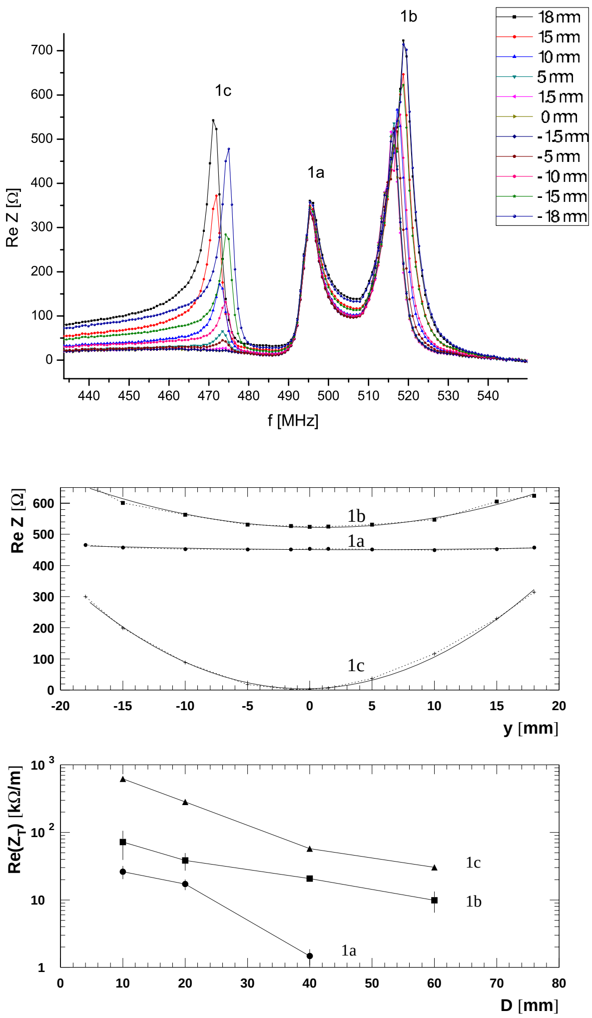

Figure 6: Study of the transverse impedance of the first resonance group. Top: Frequency spectra around the first resonance group for a fixed vertical RP aperture width $D = 40$ mm and different excentricities y of this aperture with respect to the wire; middle: longitudinal impedance as a function of the excentricity y for the fixed aperture width $D = 40$ mm; bottom: dependence of the transverse impedance on the aperture width D. For this entire study, the horizontal pot was in retracted position.

While without ferrites the resonant behaviour of the insertion cavities leads to oscillations extending beyond 25 ns after the main pulse, this "ringing" is suppressed by the ferrites after less than 10 ns.

Focussing on the main pulse, the loss factor can be calculated according to the formula [6]

$$k(d_x, d_y) = 2\, Z_C \, \frac{\int I_{ref}(t)\, [I_{ref}(t) - I(d_x, d_y, t)]\, dt}{\left[\int I_{ref}(t)\, dt\right]^2}\,, \tag{3}$$

where the time integral extends over a range of $\pm 2\sigma$ around the peak. $I_{ref}(t)$ 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.

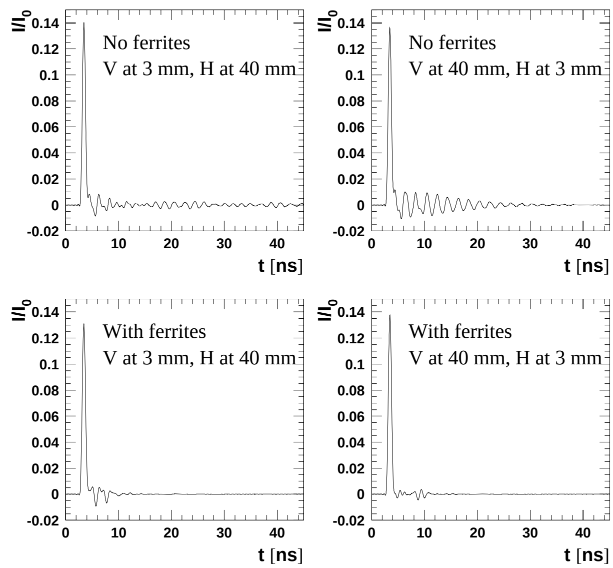

Figure 7: Transmission of a Gaussian pulse of magnitude I_0 without (top) and with (bottom) ferrites for two different combinations of the horizonal (H) and vertical (V) pot distances from the wire.

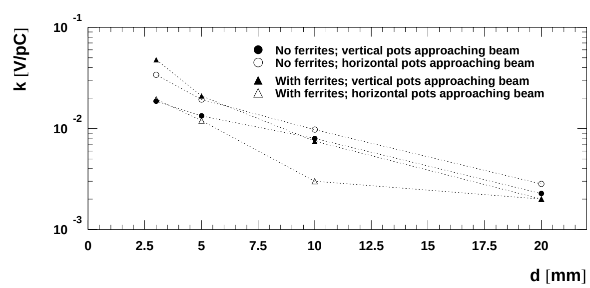

Figure 8: Loss factor as a function of the pot distance from the wire with and without ferrites, distinguishing movements of the vertical and horizontal pots.

ACKNOWLEDGEMENTS

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REFERENCES

[1] TOTEM, Technical Design Report, CERN-LHCC-2004-002.

[2] M. Deile et al., Tests of a Roman Pot Prototype for the TOTEM Experiment, Proceedings of PAC 2005, Knoxville, Tennessee, pp.1701ff. arXiv:physics/0507080.

[3] E. Jensen, PS-RF Note 2000-001, CERN 2000.

[4] T. Kroyer, F. Caspers, E. Gaxiola, Longitudinal and Transverse Wire Measurements for the Evaluation of Impedance Reduction Measures on the MKE Extraction Kickers, CERN-AB-Note-2007-028.

[5] H. Tsutsui, On single wire technique for transverse coupling impedance measurement, CERN-SL-Note-2002-034 AP.

[6] M. Sands, J. Rees, SLAC Report PEP-95, Aug. 1975.