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Simulation of Geometrical Longitudinal Impedance of the TCDS diluter

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Summary

The results of wake-field simulations to estimate the geometrical longitudinal impedance of the TCDS are presented. This impedance is related to the shape and not to the ohmic losses of the surface. In particular, the contribution from the end transitions of the beam absorber blocks is calculated. Moreover, power loss due to the presence of trapped modes in the transitions is estimated.

1. Introduction

In this note, we present the results of a study to estimate the geometrical longitudinal impedance in the TCDS, which will be used in the LHC for MSD septum magnet protection in the case of asynchronous firing of the MKD kickers [1]. The main question addressed in the study is to calculate that part of the longitudinal impedance which comes from the shape of the end transitions of the beam absorber blocks.

In Fig. 1, the geometry of the TCDS is shown. It consists of two 3 meter long tanks. Inside each tank there are twelve 250mm long blocks and the gap between the blocks can vary between 0.7mm and 1.3mm (1mm gap with 0.7mm spacers). In addition, the TCDS has a beam screen which is connected to the blocks by rf contact fingers. The change from the cross-section C, shown in Fig. 1, which is without absorbing blocks to the cross-section D which has two absorbing blocks and two beam channels, provides a transition similar to the LHC recombination chamber. The longitudinal impedance of the transition is calculated using GdfidL [2], a time-domain code for wake-field simulations, without taking into account the resistivity of TCDS materials.

2. Longitudinal impedance of TCDS

There are 4 transitions from one cross-section to another, two in each tank. The longitudinal impedance has been calculated for 3 different geometries of the transition: without any taper and with the two different tapers shown in Fig. 2. Taper 1 is presented in Fig. 2 (top). It has a 5-degree angle, it is 200 mm long and has 25 mm curvature radius. Taper 2 is presented in Fig. 2 (bottom). It has a 9-degree angle, it is 200 mm long and has 17.5 mm curvature radius. The main beam position is also shown in Fig. 2.

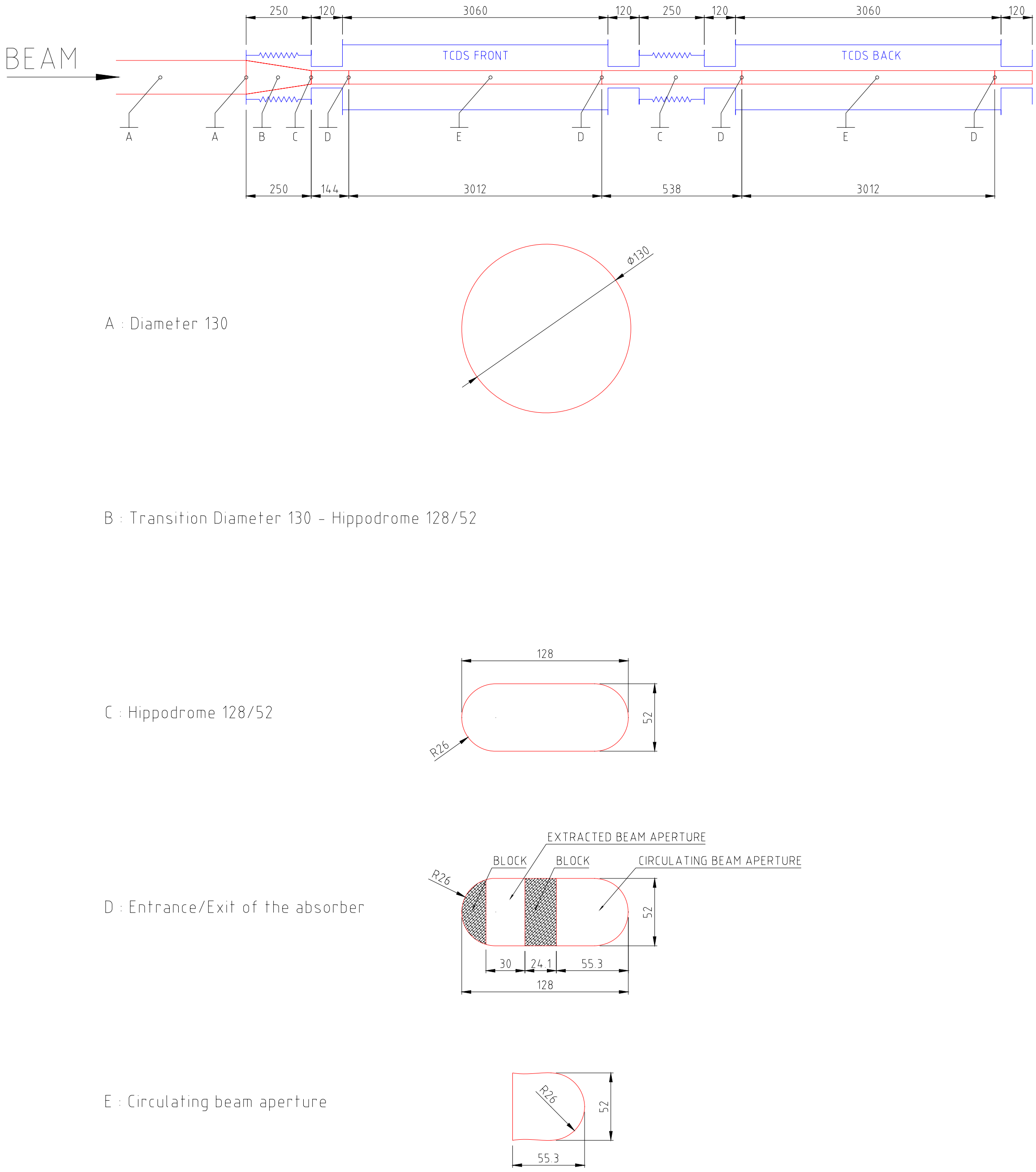

Figure 1 Geometry of the TSDS collimator.

The envelope of the longitudinal wake potential of a single transition is presented in Fig. 3 for the three different geometries described in the previous paragraph. The bunch length assumed in the GdfidL simulations is σ_z = 30 mm. The wake potential for the case of no taper at the transition decays exponentially with time (see blue line in Fig. 3). Fitting an exponential function: $A_0 \exp(-\pi f_0 t/Q_0)$ (black line in Fig. 3), the amplitude A_0 = 5 V/nC and quality factor Q_0 = 370 of a trapped mode which is confined in the transition region are determined. The frequency of the trapped mode f_0 = 3.015 GHz is found from the longitudinal impedance of the transition. From these three parameters the shunt impedance of the trapped mode is found as: $R_0 = \exp((\omega_0 \sigma_z / c)^2 / 2)\, A_0 Q_0 / \omega_0$ = 0.6 kΩ. Although the impedance of the trapped mode is rather high, the power loss for the LHC bunch of length σ_z^{LHC} = 80 mm is negligible because of the very high resonant frequency of the mode. Assuming the worse case when the frequency of the trapped mode coincides with one of the harmonics of the bunch repetition frequency f_b = 40 MHz, the power loss is estimated as $P_0 = 2(qf_b)^2 \exp(-(\omega_0\sigma_z^{LHC}/c)^2)R_0$ = 4 nW per one transition. Note that since here the ohmic quality factor of the trapped mode is not taken into account the above estimate of the power loss is the upper limit. Furthermore, Fig. 3 clearly demonstrates that both tapers reduce significantly the loss factor of the trapped mode.

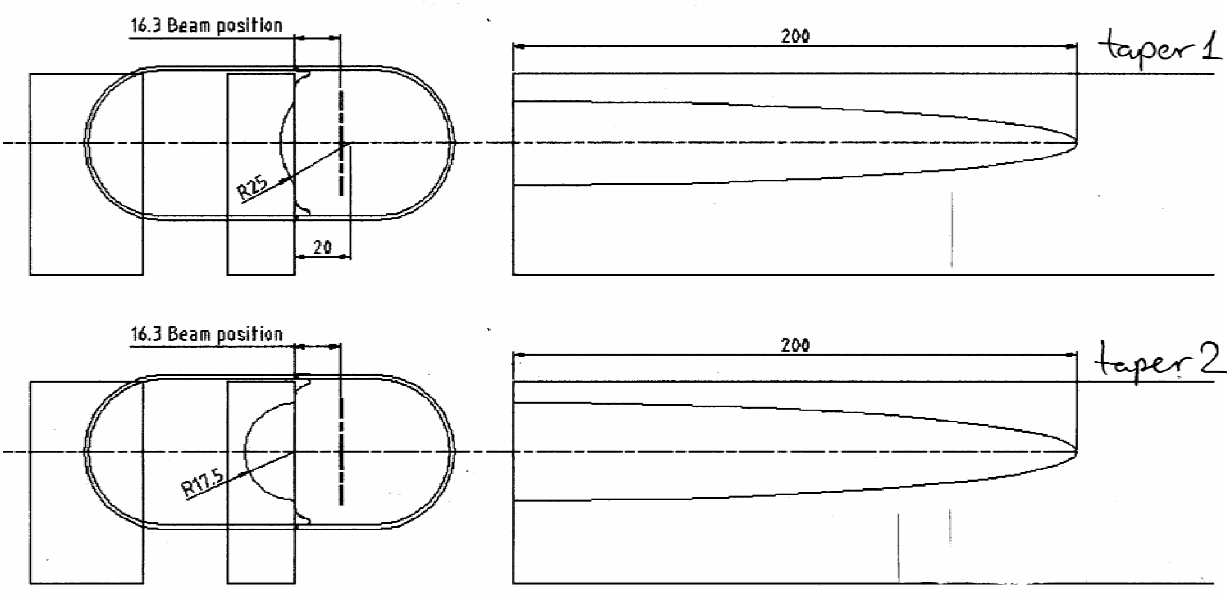

Figure 2 Geometry of the tapered transitions: taper 1 (top) and taper 2 (bottom).

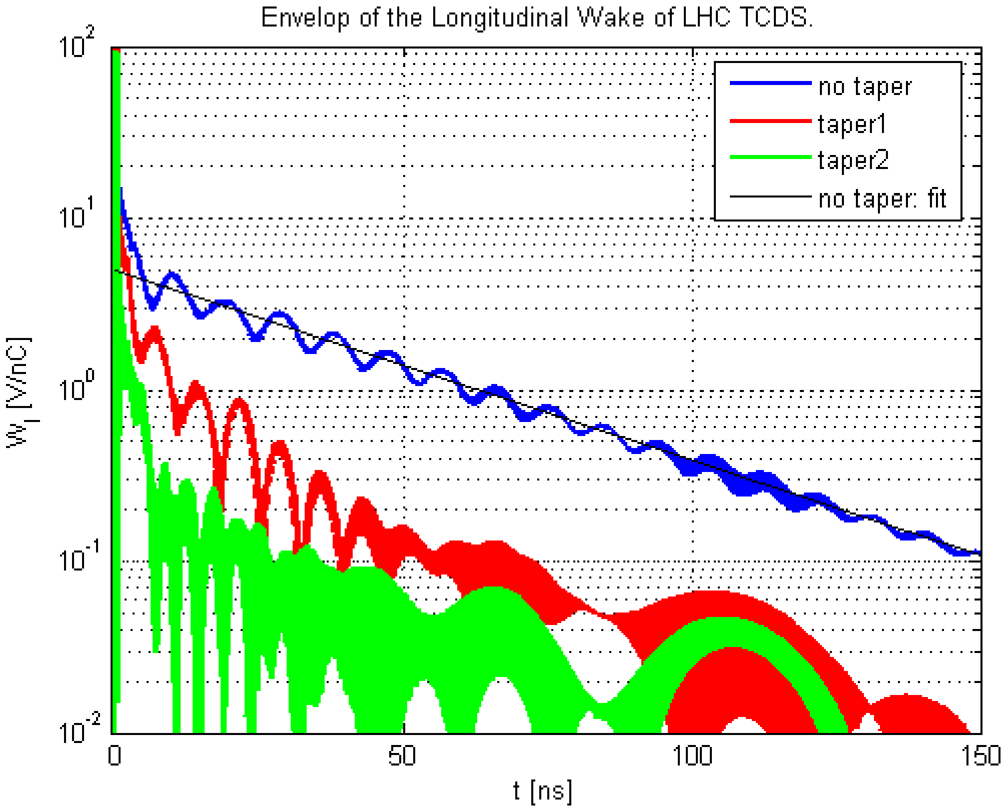

Figure 3 The envelope of the longitudinal wake potential of one transition for the three different configurations described in the text is presented. Bunch length used in the simulations is 30 mm.

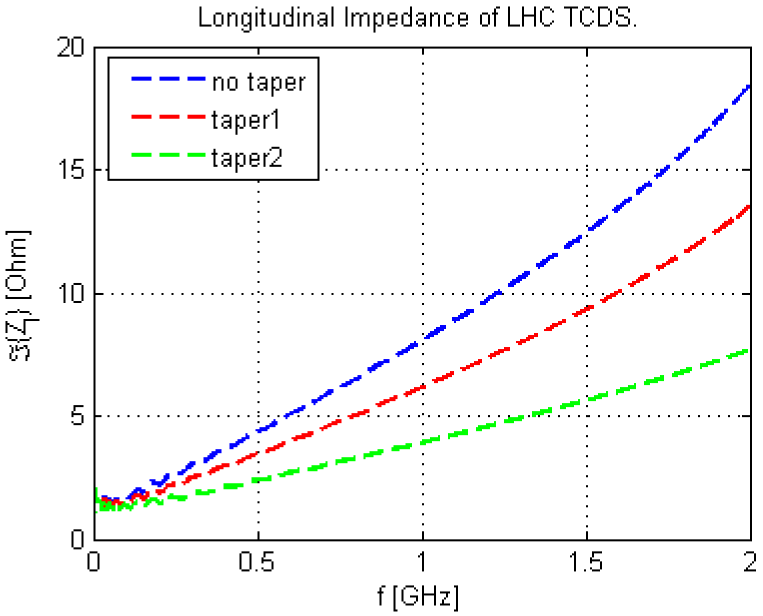

Figure 4 Imaginary part of the longitudinal impedance of one transition for the three different configurations described in the text is presented.

The imaginary part of the longitudinal impedance is shown in Fig. 4 for the three different geometries under consideration. Calculating the slope of the curves presented in Fig. 3 and multiplying it with the LHC revolution frequency, the Z/n is estimated to be 0.08 mΩ without any taper, 0.06 mΩ with taper 1, and 0.04 mΩ with taper 2.

In summary, the broad band longitudinal impedance related to the shape of the transitions is 0.08·4=0.32 mΩ, in the case of no tapers, which is small compared to the LHC broad band longitudinal impedance budget of ~70 mΩ [3]. The improved geometry of the transitions with taper 1 results in lower value of 0.06·4=0.24 mΩ. Moreover, taper 1 significantly reduces the power loss in the TCDS trapped mode, though it is already negligible due to the high resonant frequency of the trapped mode.

References

[1] W. Weterings and B. Goddard, ‘Functional specification of TCDS diluter to protect MSD septum magnets’, EDS document: LHC-TCDS-ES-0001.

[2] www.gdfidl.de

[3] LHC Design Report, vol. 1, CERN-2004-003, Sub-section 5.3.3, p103, 2004.