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Simulation of Geometrical Longitudinal Impedance of the TCDQ collimator

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Summary

The results of simulation of geometrical longitudinal impedance of TCDQ are presented. This impedance is related to the shape and not to the ohmic losses of the surface. In particular, contributions from the end transitions of the beam absorber blocks as well as from the transverse slots between the absorber blocks are calculated. Moreover, power loss due to presence of trapped modes in the transitions is estimated.

1. Introduction

In this note, we present the results of a study of geometrical longitudinal impedance in the TCDQ, which will be used in the LHC for quadrupole (Q4+) protection in the case of asynchronous dump failure [1]. The main question addressed in the study is to calculate the part of the longitudinal impedance which comes from the geometry of the end transitions of the beam absorber blocks and from the transverse slots between them. At the end, recommendations for reduction of the geometrical longitudinal impedance are given.

In Fig. 1, the geometry of the TCDQ is shown. It consists of two 3meter 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 TCDQ has a beam screen which is connected to the blocks by rf contact fingers. The beam screen has a racetrack shape before and after the absorber blocks (see cross-section C in Fig.1) and about half-racetrack in the part where the blocks are present (see cross-section E in Fig. 1). The beam is centered with respect to the racetrack cross-section which means that the distance between the beam and the absorber blocks is 5 mm. The longitudinal impedances of both gaps between the blocks and the transitions are calculated using GdfidL [2], a time-domain code for wake-field simulations, without taking into account the resistivity of TCDQ materials.

2. Longitudinal impedance of TCDQ

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 two different tapers shown in Fig. 2. Taper 1 is presented in Fig. 2 (top). It has 5-degree angle, it is 200 mm long and has 25 mm curvature radius. Taper 2 is presented in Fig. 2 (bottom). It has 15-degree angle, it is 65 mm long and has 17 mm curvature radius.

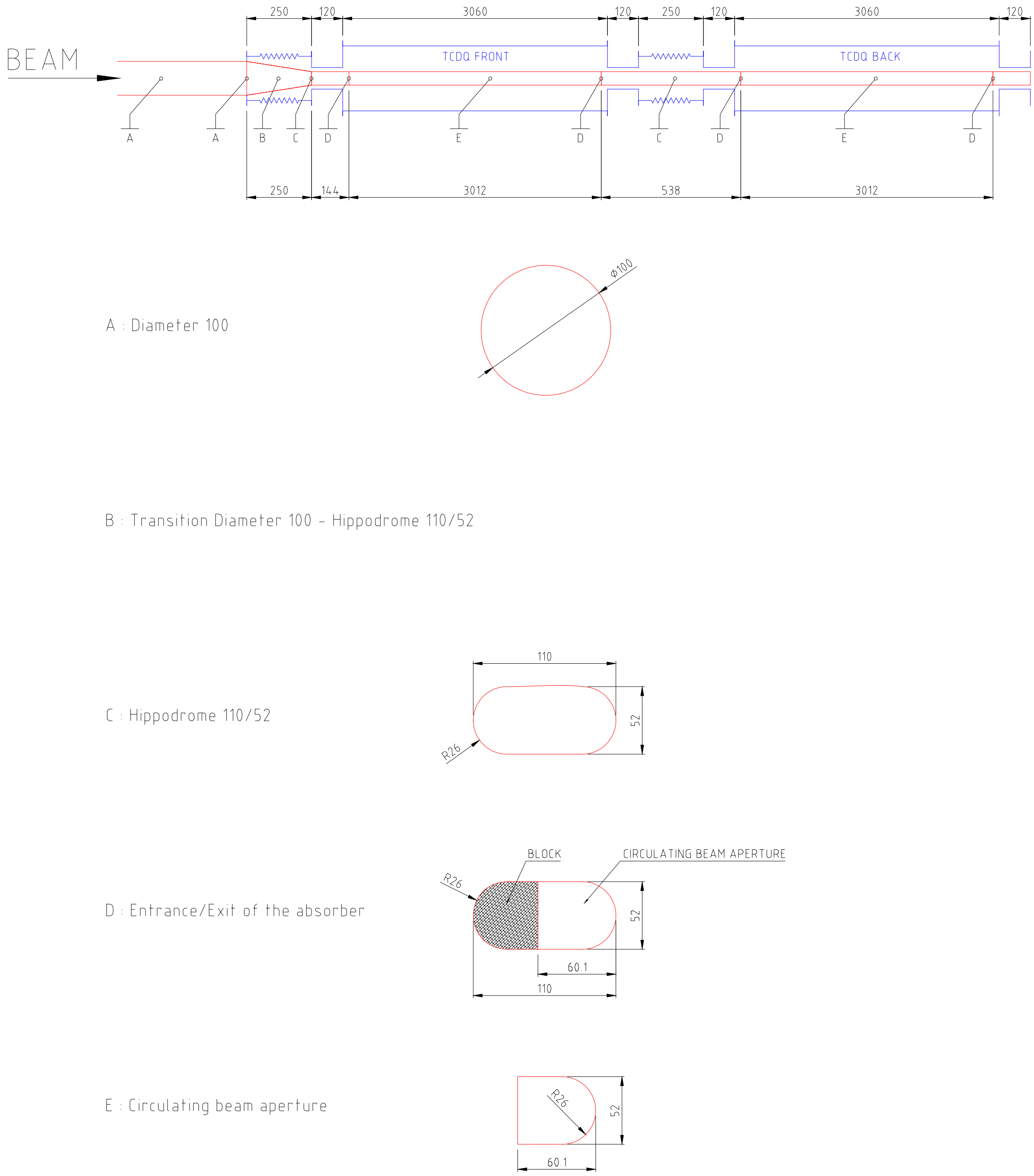

Figure 1 Geometry of the TSDQ collimator.

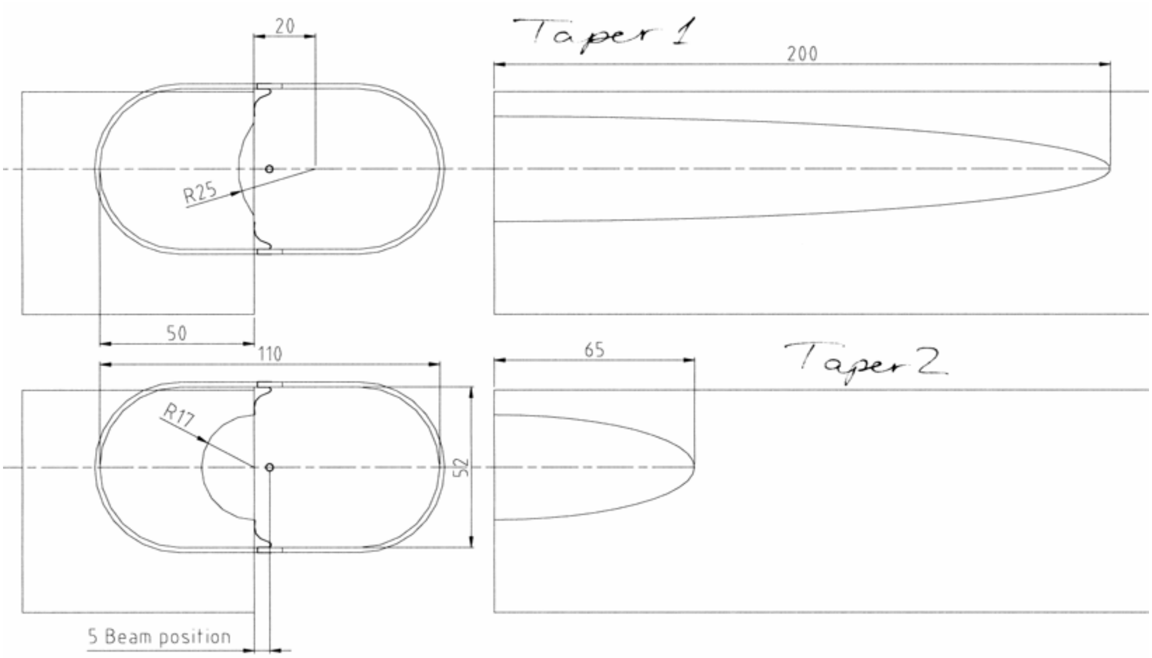

Figure 2 Geometry of the tapered transitions: taper 1 (top) and taper 2 (bottom).

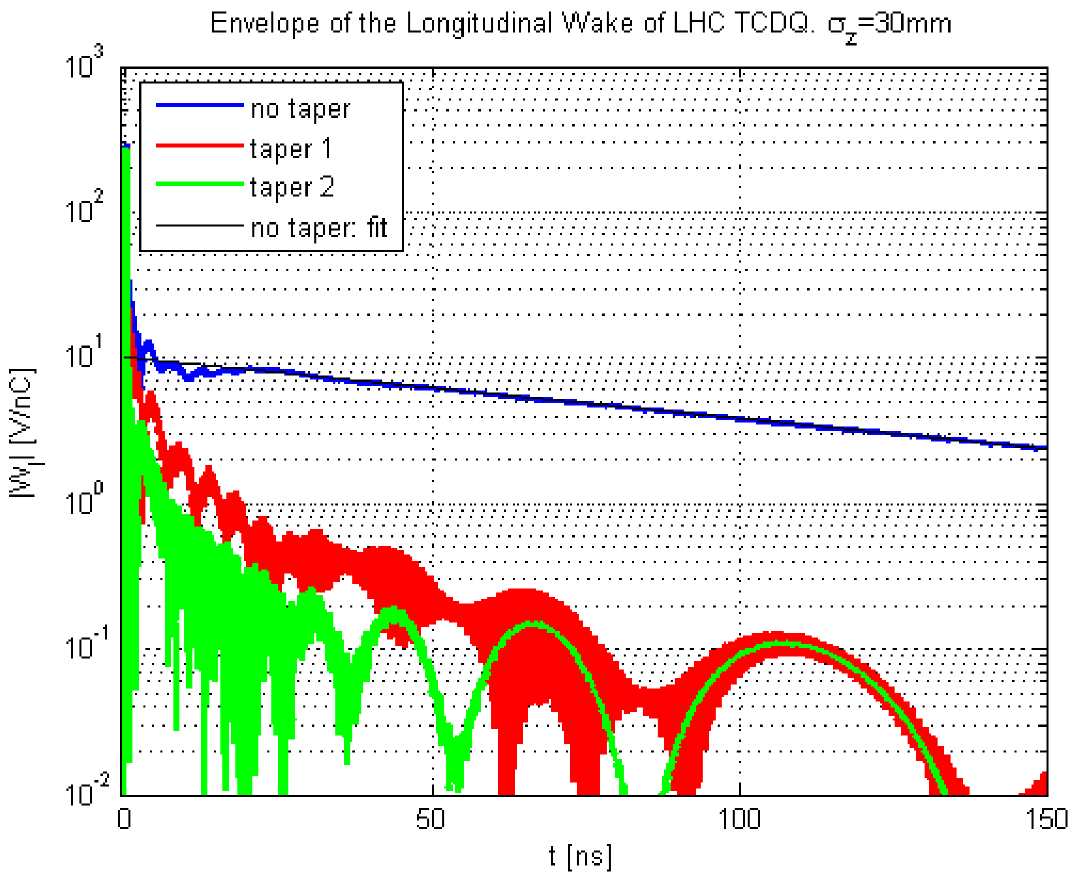

Figure 3 The envelope of the longitudinal wake potential of one transition for the three different configurations described in the text is presented. Bunch length used in the simulations is 30 mm.

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 exponential function: $A_0 \exp(-\pi f_0 t / Q_0)$ (black line in Fig. 3), the amplitude A_0 = 10 V/nC and quality factor Q_0 = 1000 of a trapped mode which is confined in the transition region are determined. Frequency of the trapped mode f_0 = 3.017 GHz is found from the longitudinal impedance of the transition. From these three parameters the shunt impedance of the trapped mode is found as: $R_0 = \exp((\omega_0 \sigma_z / c)^2 / 2) A_0 Q_0 / \omega_0$ = 3.2 kΩ. Although the impedance of the trapped mode is rather high, the power loss for the LHC bunch of the length σ_z^{LHC} = 80 mm is negligible because of 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 bunch repetition frequency f_b = 40 MHz, power loss is estimated as $P_0 = 2(q f_b)^2 \exp(-(\omega_0 \sigma_z^{LHC} / c)^2) R_0$ = 20 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.

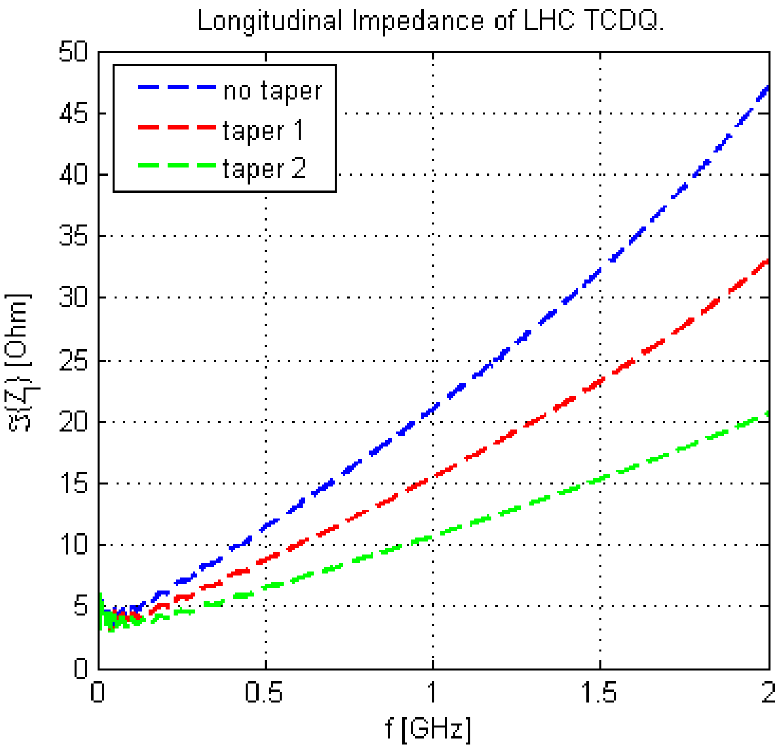

Figure 4 Imaginary part of the longitudinal impedance of one transition for the three different configurations described in the text is presented.

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 0.2 mΩ without any taper, 0.15 mΩ with taper 1, and 0.09 mΩ with taper 2. The geometrical longitudinal impedance is reduced by a factor 2 which is not a surprise since the transverse distance between the beam and the step-wise change of the beam screen geometry is increased significantly. In the last case, the distance is about 22 mm which is close to 26 mm - the half of the beam screen smallest dimension before transition. Thus, a general rule-of-thumb can be used later, to keep a step-wise transition at least as far from the beam as the half of the smallest transverse dimension of the beam screen before transition.

There are 22 gaps of about 1 mm size in TCDQ. The longitudinal impedance of a single gap between the absorber blocks in TCDQ has been calculated in the same way as for the transitions. For 1 mm gap the Z/n is about 0.03 mΩ.

In summary, the total broad band longitudinal impedance related to the shape of the absorber blocks and the beam screen is 0.2·4+0.03·22=1.46 mΩ, in the case of no tapers at the transitions, which is not negligible compared to the LHC broad band longitudinal impedance budget of ~70 mΩ [3]. The improved geometry of the transitions with taper 2 results in lower value of 0.09·4+0.03·22=1.02 mΩ demonstrating substantial reduction of the broad band impedance of the TCDQ. Moreover, taper 2 significantly reduces power loss in the TCDQ trapped mode, though it is already negligible due to high resonant frequency of the trapped mode.

References

[1] W. Weterings and B. Goddard, 'Functional specification of TCDQ collimator to protect the LHC against unsynchronized beam dumps', EDS document: LHC-TCDQ-ES-0001.

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