

# REVIEW OF THE TRANSVERSE IMPEDANCE BUDGET FOR THE CLIC DAMPING RINGS

E. Koukovini-Platia\*, G. Rumolo, CERN, Geneva, Switzerland

## Abstract

Single bunch instability thresholds and the associated coherent tune shifts have been evaluated in the transverse plane for the damping rings (DR) of the Compact Linear Collider (CLIC). A multi-kick version of the HEADTAIL code was used to study the instability thresholds in the case where different impedance contributions are taken into account such as the broad-band resonator model in combination with the resistive wall contribution from the arcs and the wigglers of the DR. Simulations performed for positive values of chromaticity showed that higher order bunch modes can be potentially dangerous for the beam stability.

## IMPEDANCE MODEL

The beam interaction with the surroundings needs to be known in order to estimate the thresholds of coherent instabilities possibly limiting the achievable beam current. In order to define a total transverse impedance budget for the various elements that will be installed in the DR, single bunch simulations were performed assuming an impedance model made of the following components: one broad-band resonator (BBR) and three resistive wall (RW) components modelling the contributions from the arcs, the wigglers and the rest of the FODO cell of the DRs. It is a rather simplified model due to the current knowledge of elements and material to be used in the DRs.

For the BBR, the quality factor  $Q$  is equal to 1 and the resonant frequency  $f_r$  is 5 GHz. The transverse shunt impedance is the parameter scanned in order to define the instability threshold. The transverse wake functions for the resistive wall contributions are calculated with the Impedance-Wake2D package [1] used for multilayer axisymmetric or flat structures. In the case of arcs, the total length is 270.2m with 9 mm radius beam pipe and round geometry. The total length of the wigglers is 104 m (52 wigglers, 2 m long each) with 6 mm radius and flat structure. Last, the rest of the FODO cell is considered a separate contribution from the wigglers due to the different geometry (round) and radius of 9 mm but also different beta functions compared to the arcs. The chamber along the whole ring is considered as a two-layer structure made of stainless steel ( $\sigma=1.45 \times 10^6$  S/m) and coated with 2  $\mu\text{m}$  of Non-Evaporable Getter (NEG) ( $\sigma=1 \times 10^6$  S/m) or 1  $\mu\text{m}$  of amorphous carbon (aC) ( $\sigma=1 \times 10^3$  S/m).

The total transverse model summing the three wall contributions (dipolar and quadrupolar terms) of the arcs, wigglers and the rest of the FODO cell plus a broad-band model (assuming a transverse shunt impedance of 5 M $\Omega$ /m) is shown in Figure 1 for the NEG coating and in Figure 2 for the aC.

\* also affiliated at EPFL

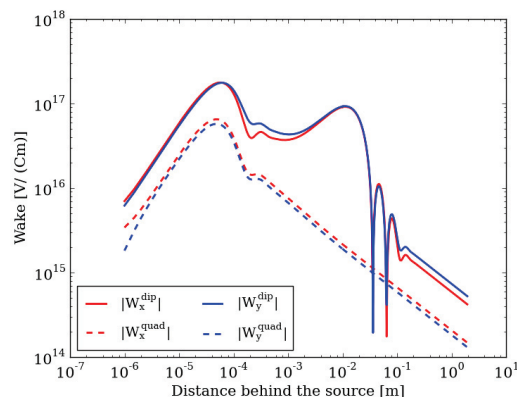


Figure 1: Transverse wake function model with NEG coating.

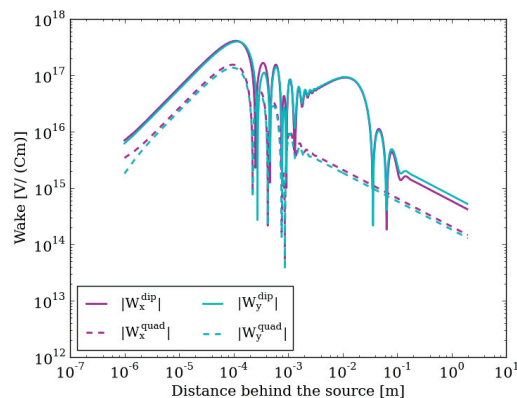


Figure 2: Transverse wake function model with aC coating

## DR Parameters

The parameters of the DR used for the macroparticle simulation are summarized in Table 1.

The HEADTAIL code [2] is used for the single bunch macroparticle simulations. The Sussix algorithm [3] is used on the simulated coherent bunch motion to obtain the mode spectrum.

## NEG COATING

It is a common strategy to use coating materials in accelerators to suppress some undesired collective effects. NEG is a good candidate for the electron damping rings against fast beam ion instabilities. However the use of coating does not come for free and its impact on the budget should be studied. The relative tune shift with respect to the zero-current tune and normalized to the synchrotron tune  $Q_s$  is plotted, for the case of zero chromaticity as a function of the transverse

Table 1: CLIC DR Parameters

Description [units]	3 TeV
Energy [GeV]	2.86
Hor./vert. norm. trans. emitt. [nm]	456/4.8
Bunch length [mm]	1.8
Momentum spread	$1.07 \times 10^{-3}$
Bunch population	$4.1 \times 10^9$
Circumference [m]	427.5
Mom. compact. factor	$1.3 \times 10^{-4}$
Hor./vert./long. tunes	48.35/10.4/0.0057
Hor./vert. damping times [ms]	2/2
RF frequency [GHz]	1
RF voltage [MV]	5.1

shunt impedance in Figures 3, 4. Uniform NEG coating of  $2 \mu\text{m}$  is assumed for all the ring.

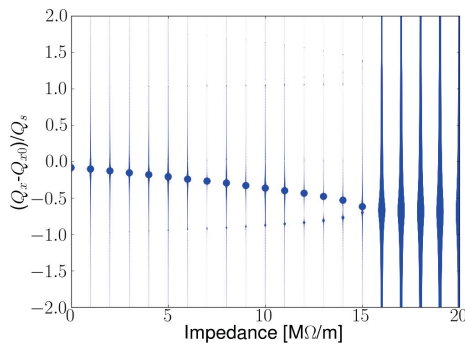


Figure 3: Mode spectrum of the horizontal coherent motion for zero chromaticity, as a function of the transverse shunt impedance. A TMCI is observed at  $16 \text{ M}\Omega/\text{m}$ .

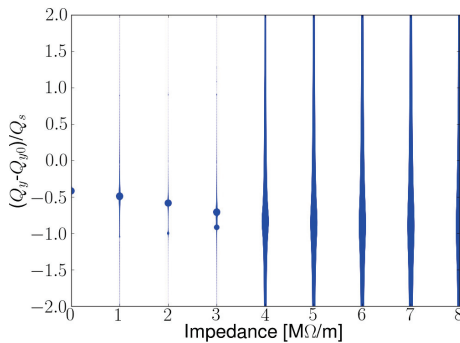


Figure 4: Mode spectrum of the vertical coherent motion for zero chromaticity, as a function of the transverse shunt impedance. A TMCI is observed at  $4 \text{ M}\Omega/\text{m}$ .

Modes 0 and -1 are observed to move and couple at  $16 \text{ M}\Omega/\text{m}$  and  $4 \text{ M}\Omega/\text{m}$  in the horizontal and vertical plane respectively, causing a transverse mode coupling instability (TMCI). The vertical plane, which is the most critical one, would therefore indicate that the remaining transverse

impedance budget is  $4 \text{ M}\Omega/\text{m}$  at operation with zero chromaticity.

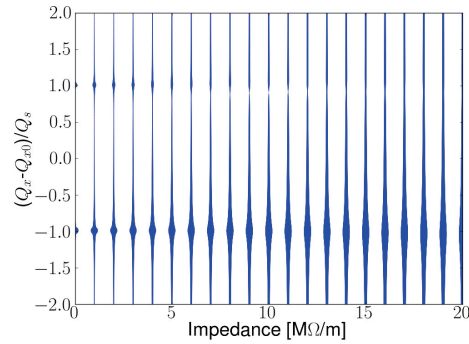


Figure 5: Mode spectrum of the horizontal coherent motion for positive chromaticity, as a function of impedance.

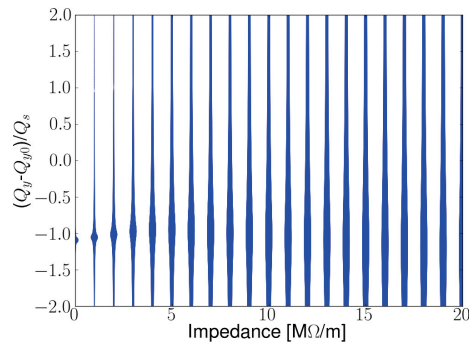


Figure 6: Mode spectrum of the vertical coherent motion for positive chromaticity, as a function of impedance.

In the case of positive chromaticity shown in Figures 5 and 6, higher order modes,  $m = -1$ , get excited whereas 0 mode is damped, showing that a head-tail instability develops. For the case of head-tail instability the calculation of its rise time is necessary to be compared with the damping time. If the rise time is lower than the damping time, the instability is faster than the damping mechanism. The damping time of 2 ms given by the DR parameters in Table 1, defines an instability threshold at  $2 \text{ M}\Omega/\text{m}$  for the horizontal and  $1 \text{ M}\Omega/\text{m}$  for the vertical plane if compared with the rise time of the instability (Figure 7).

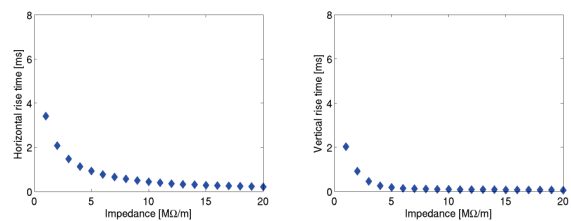


Figure 7: Rise time in the horizontal (left) and vertical (right) plane for positive 0.055 and 0.057 normalized to the machine tunes chromaticity,  $\xi_{x,y} = Q'_{x,y}/Q_{x,y}$

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## Amorphous Carbon Coating

In the case of the positron damping rings, coating the vacuum pipe with aC is an option against electron-cloud effects. In Figures 8 and 9, the mode spectrum results are illustrated for the transverse plane in the case of 0 chromaticity. A TMCI is observed at 14 M $\Omega$ /m and 4 M $\Omega$ /m in the horizontal and vertical plane respectively, leading to the same budget in the vertical plane as in the case of NEG.

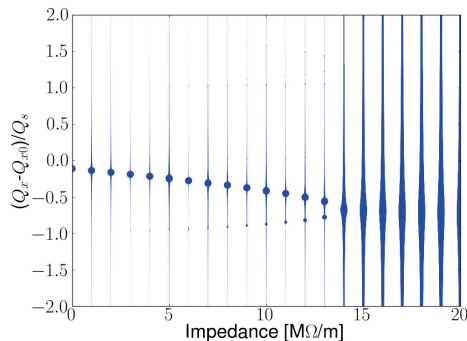


Figure 8: Mode spectrum of the horizontal coherent motion for positive chromaticity, as a function of impedance.

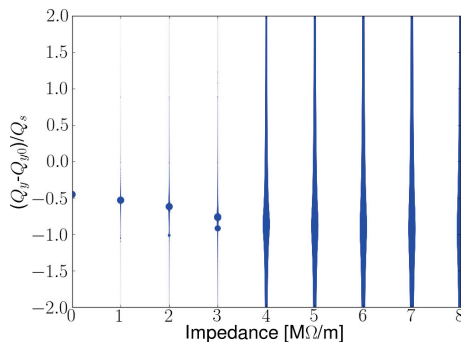


Figure 9: Mode spectrum of the vertical coherent motion for positive chromaticity, as a function of impedance.

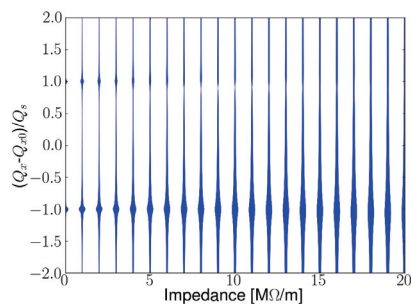


Figure 10: Mode spectrum of the horizontal coherent motion for positive chromaticity, as a function of impedance.

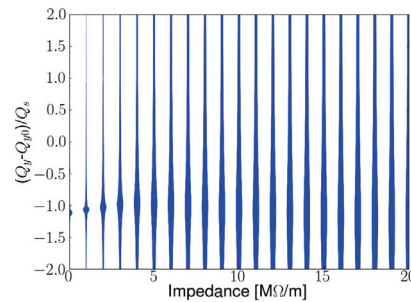


Figure 11: Mode spectrum of the vertical coherent motion for positive chromaticity, as a function of impedance.

For positive chromaticity the mode spectrum is illustrated in Figures 10 and 11. Comparing the rise time with the 2 ms damping time in the transverse plane, the budget is estimated at 2 M $\Omega$ /m and 1.5 M $\Omega$ /m in the horizontal and vertical plane respectively.

The transverse impedance budget results for the aC scenario are very similar with the NEG coating one. The thickness of coating does play a role [4] and it should be noted that the results presented in this paper are for aC thickness of 1  $\mu$ m and 2  $\mu$ m of NEG.

## CONCLUSION

The transverse impedance budget has been estimated for the CLIC DRs for two different coating scenarios with NEG and aC. From the instability thresholds it is concluded that the use of NEG or aC give very similar results in terms of budget which is 1 M $\Omega$ /m in the vertical plane regarding the most realistic case of operation with slightly positive chromaticity.

## ACKNOWLEDGEMENT

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