Landau Damping for TMCI: with vs. without Transverse Damper

Elias Métral

CERN, CH-1211 Geneva, Switzerland

Summary

The Landau damping of the Transverse Mode-Coupling Instability (TMCI) is discussed both without and with a resistive transverse damper. In these two cases, a more involved treatment than the usual "stability diagram approach" is needed, as the modes cannot be considered independently. Considering the case of the "short-bunch" regime, where the mode-coupling takes place between modes 0 and -1 (such as in the CERN LHC) with zero chromaticity, it is shown that below the TMCI intensity threshold, the transverse damper is detrimental, whereas above the TMCI intensity threshold it is beneficial.

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1 Introduction

It has been known for a long time that, in the absence of a transverse damper, the TMCI is a very violent instability for zero chromaticity. This is why it is usually not stabilised by Landau damping as it would require too large a tune spread and below this tune spread Landau damping was even predicted to have a destabilising effect [1]. Considering the case of the "short-bunch" regime, where the mode-coupling takes place between modes 0 and -1 (such as in the CERN LHC) with zero chromaticity, it was also found in the past (and explained recently) that the resistive transverse damper (which is needed, and working very well for the coupled-bunch operation) is destabilising for the single bunch, leading to an instability without intensity threshold [2]. As in both cases, without or with a transverse damper, the instability mechanism involves the interaction of both modes 0 and -1 (see Fig. 1), a correct treatment of the Landau damping can only be done by considering (at least) these two modes. The detailed analyses for both cases are discussed in this note.

2 Landau damping with transverse damper

This case has already been analysed in Ref. [2] (see Fig. 2), where it was found that the result is quite close to the one-mode (i.e. usual "stability diagram") approach. This finding has been recently confirmed by macroparticle tracking simulations with pyHEADTAIL [3].

3 Landau damping without transverse damper

Using the same model as above [2], the effect of Landau damping on TMCI without transverse damper, has been analysed in detail and the results are depicted in Figs. 4 to 20 [4]. It can be seen that increasing the tune spread first reduces the TMCI intensity threshold, as observed in Ref. [1], down to a factor ≈ 2 for Δq=0.5, i.e. for a tune spread equal to half of the synchrotron tune. Then, the TMCI intensity threshold increases to reach about the same threshold (as without tune spread) for $\Delta q \approx 1$. To really increase the TMCI intensity threshold, we need therefore to introduce a tune spread larger than the synchrotron tune. The TMCI intensity threshold is a factor ≈ 2 higher for Δq=2 and a factor ≈ 3 higher for Δq=3.

4 Conclusion

The final result of this study can be found in Fig. 3 [5], where it can be clearly observed that the (resistive) transverse damper is detrimental below the TMCI intensity threshold as it leads to an instability without intensity threshold, which needs to be stabilised by introducing some tune spread. However, it is greatly beneficial above the TMCI intensity threshold as it then considerably reduces the necessary amount of tune spread required to
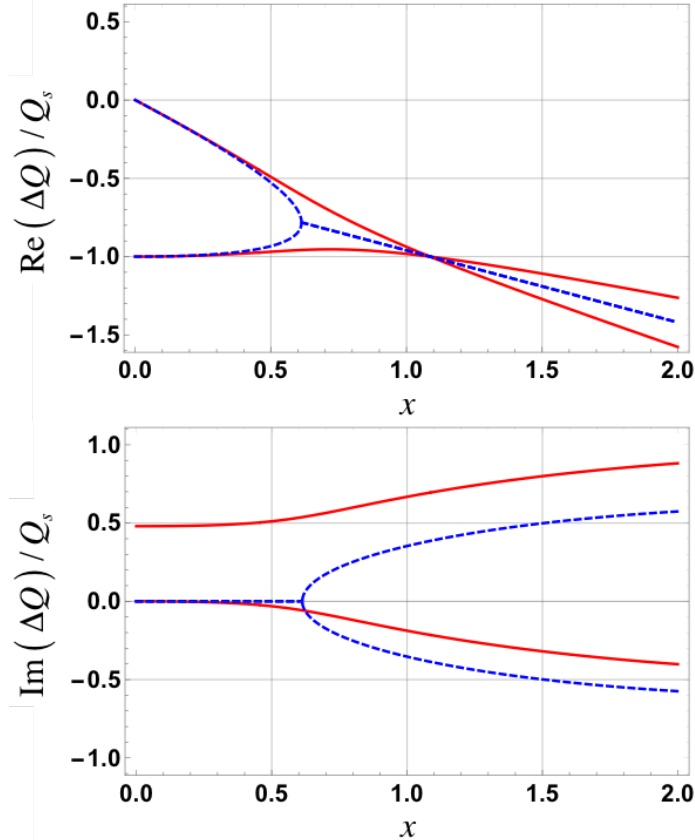
Figure 1: Destabilising effect of a resistive transverse damper (with the usual TMCI plots showing the real and imaginary parts of the normalised complex tune shift in red, compared to the case without damper in blue), considering the case of the "short-bunch" regime, where the mode-coupling takes place between modes 0 and -1 (such as in the CERN LHC) with zero chromaticity [2]. Here, x is the absolute value of the coherent tune shift from a constant inductive impedance normalised by the synchrotron tune Q_s [2], which is proportional to the bunch intensity and the beam coupling impedance, and the transverse coherent tune shifts ΔQ are also normalised by the synchrotron tune Q_s.

reach stability. The global picture of Fig. 3 seems to be reproduced by macroparticle tracking simulations [3] but this analysis needs to be finalised.

References

[1] Y.H. Chin, *Hamiltonian formulation for transverse bunched beam instabilities in the presence of betatron tune spread*, CERN SPS/85-9 (DI-MST), CERN, Geneva, Switzerland, 28/05/1985.

[2] E. Métral *et al.*, *Destabilising effect of the LHC transverse damper*, in Proc. 9th Int. Particle Accelerator Conf. (IPAC18), Vancouver, BC, Canada, Apr.-May 2018, pp. 3076-3079. doi:10.18429/JACoW-IPAC2018-THPAF048.
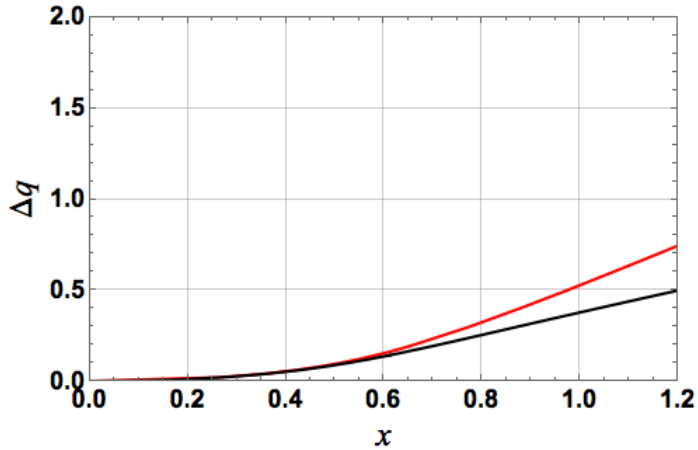
Figure 2: Required tune spread (normalised by the synchrotron tune Q_s and for the case of an elliptical distribution [2]) for the Landau damping of the instability discussed in Fig. 1 [2]: the two-mode approach is depicted in red while the one-mode (i.e. usual "stability diagram") approach is in black.

[3] A. Oeftiger, *Stability around $Q'=0$ ... and the LHC Damper Instability*, 146th HiLumi WP2 Meeting, CERN, Geneva, Switzerland, 16/04/2019, https://indico.cern.ch/event/804350/contributions/3394378/attachments/1830532/2997717/oeftiger_damper_instability.pdf

[4] E. Métral, *Update on Landau damping for LHC TMCI without ADT (with two-mode model)*, 168th HSC section meeting, CERN, Geneva, Switzerland, 04/02/2019, https://indico.cern.ch/event/794757/contributions/3302080/attachments/1788143/2915348/UpdateOnLandauDampingForTMCI_EM_04-02-19.pdf

[5] E. Métral, *Landau damping for TMCI: without vs. with Transverse Damper (TD)*, 173th HSC section meeting, CERN, Geneva, Switzerland, 25/03/2019, https://indico.cern.ch/event/807899/contributions/3362767/attachments/1816203/2971974/LDforTMCI_EM_25-03-2019_2.pdf
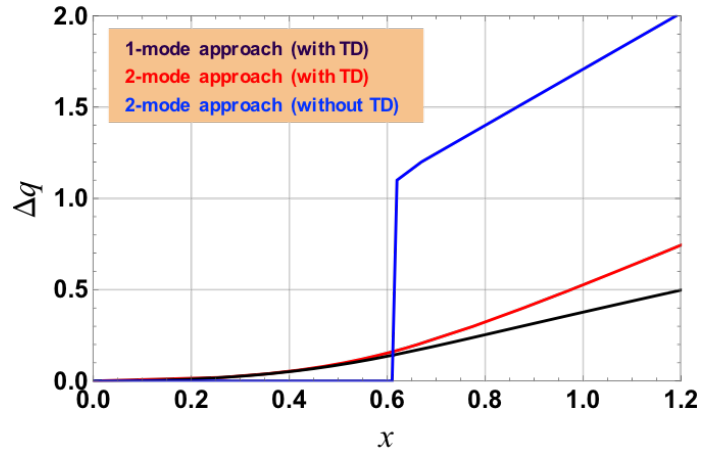
Figure 3: Required tune spread (normalised by the synchrotron tune Q_s) for the Landau damping of TMCI without and with Transverse Damper (TD), considering the case of Fig. 1 [2, 5].
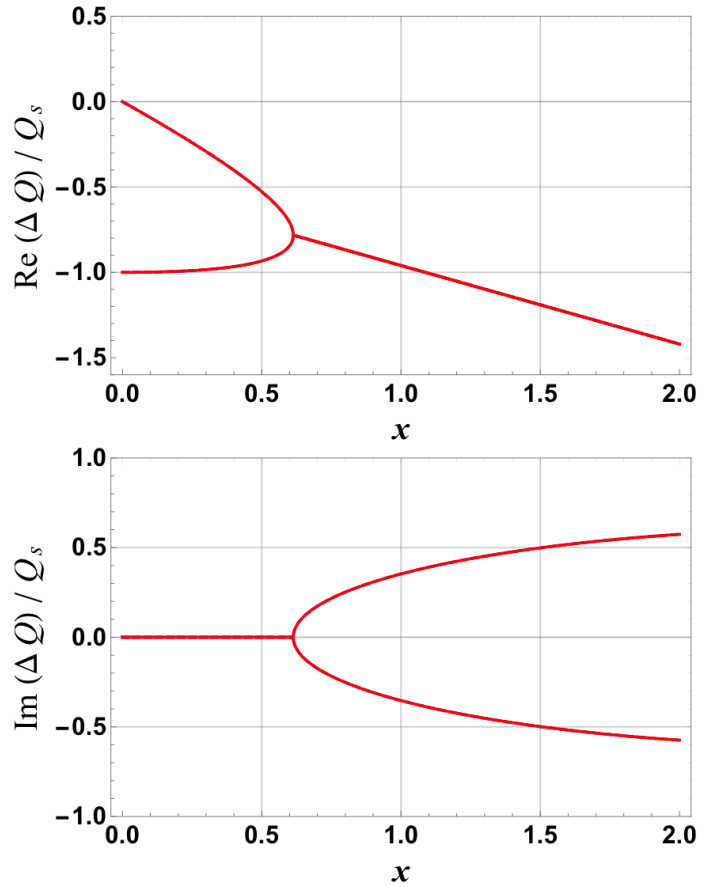

Figure 4: Effect of Landau damping on TMCI, using the same model as before but without transverse damper: $\Delta q = 0$.
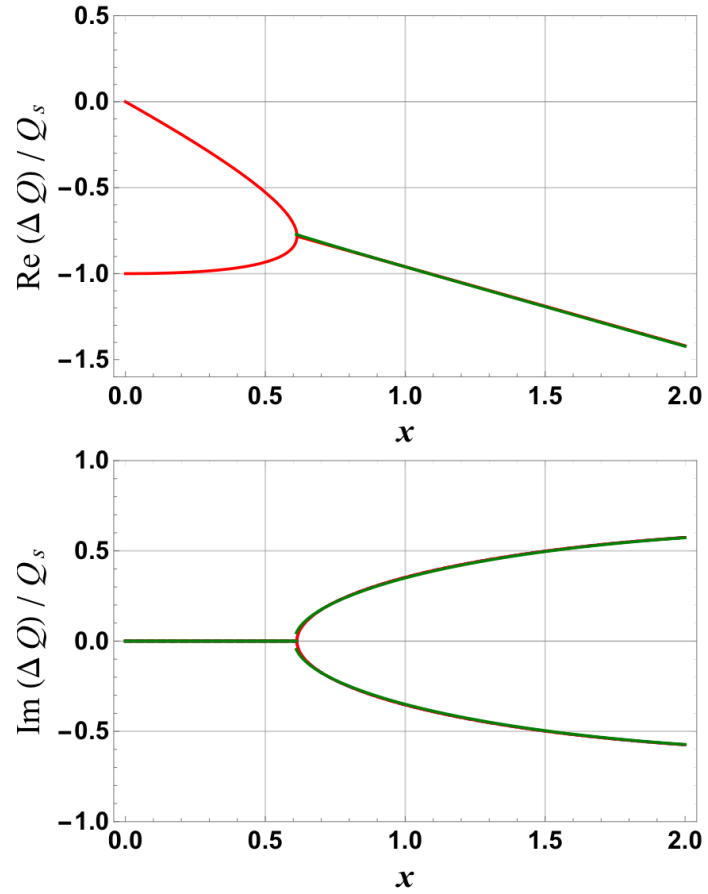
Figure 5: Effect of Landau damping on TMCI, using the same model as before but without transverse damper: Δq=0.1 (in green, compared to the case Δq=0 in red).
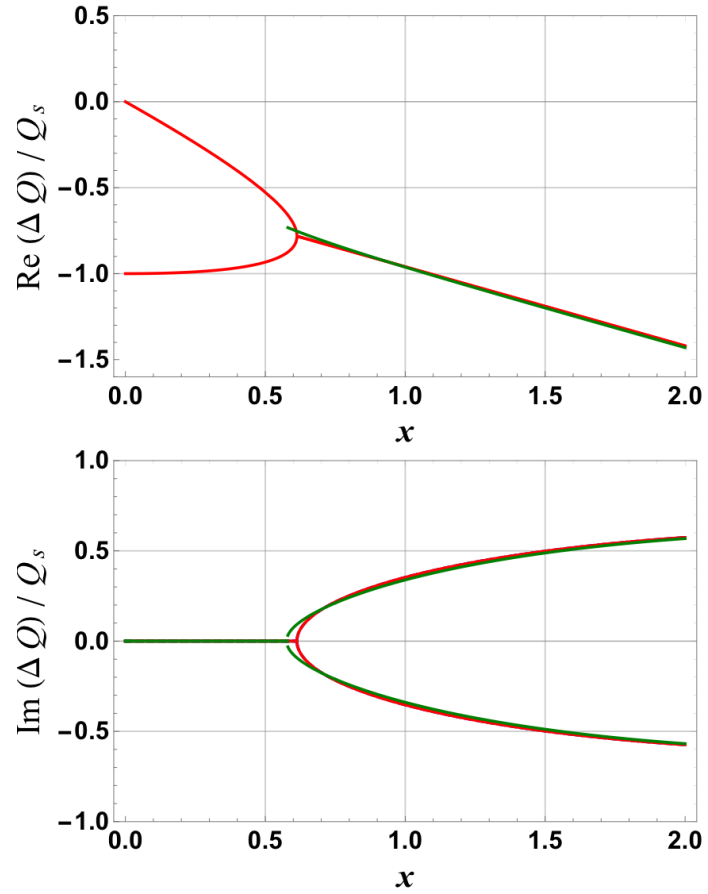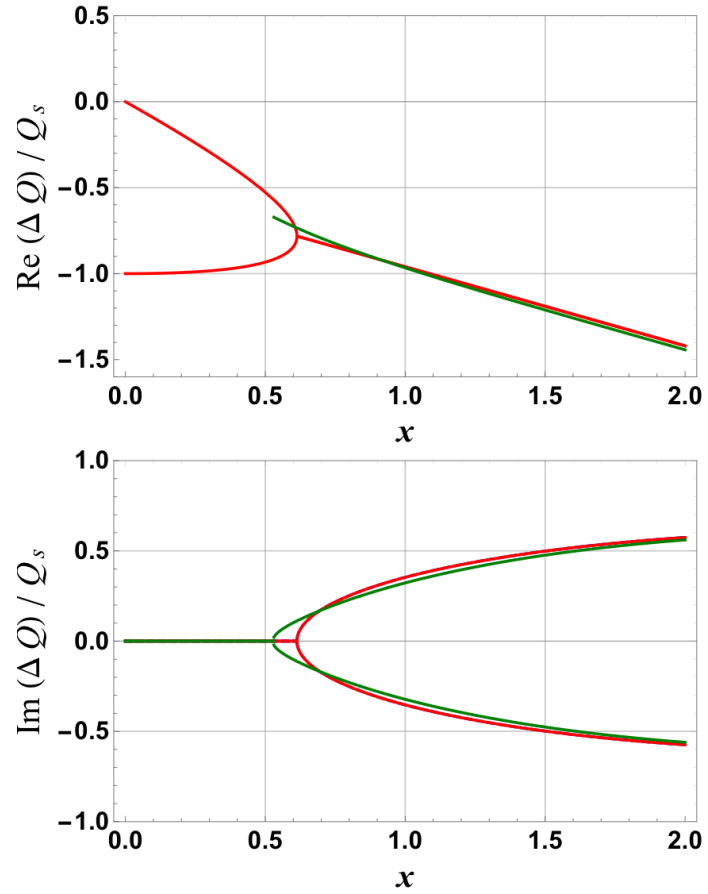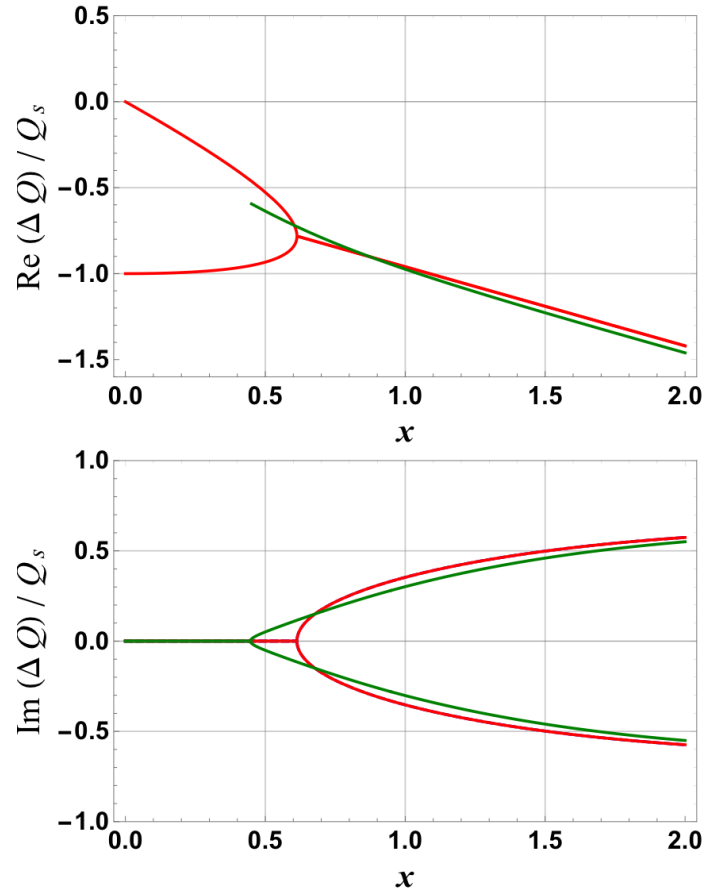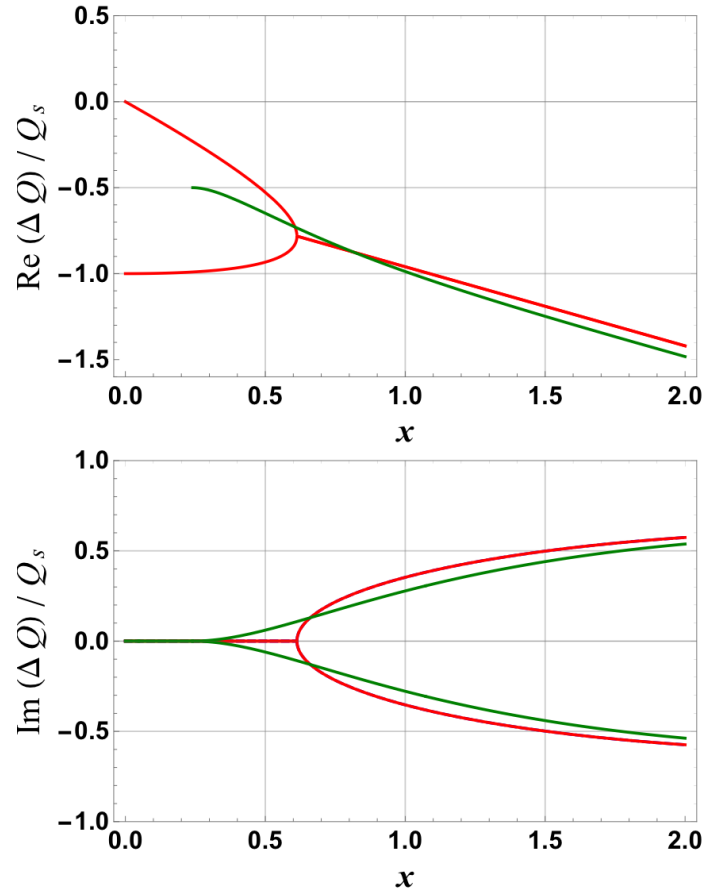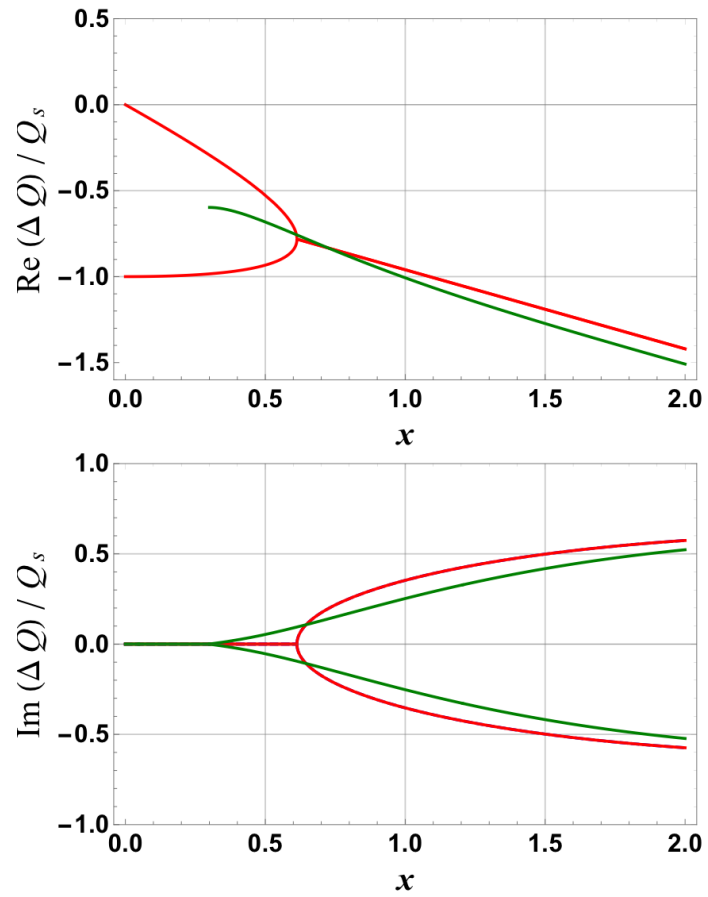
Figure 6: Effect of Landau damping on TMCI, using the same model as before but without transverse damper: Δq=0.2 (in green, compared to the case Δq=0 in red).
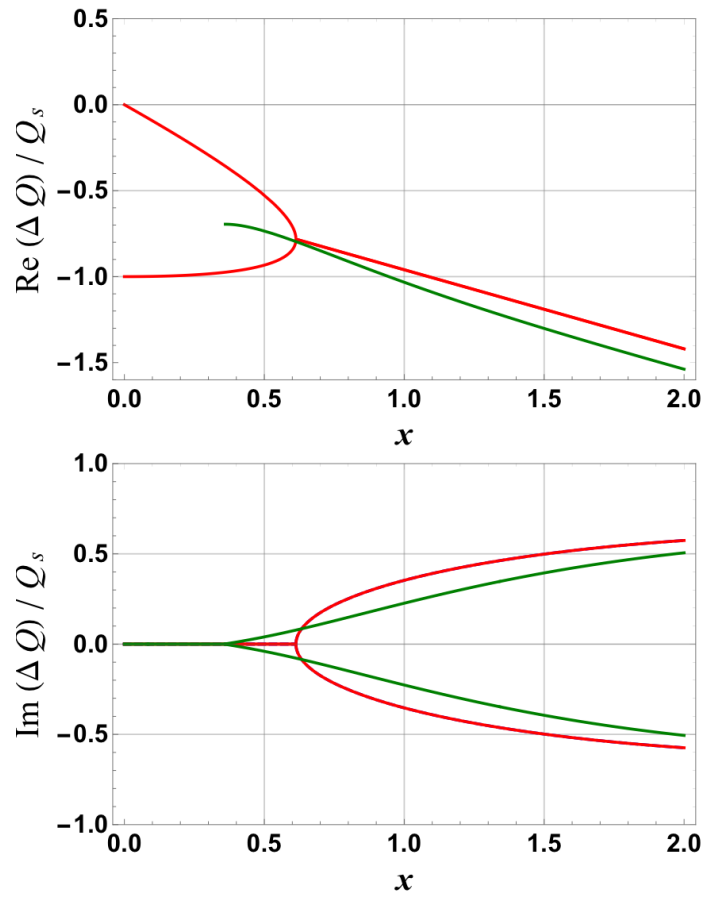
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Figure 9: Effect of Landau damping on TMCI, using the same model as before but without transverse damper: Δq=0.5 (in green, compared to the case Δq=0 in red).
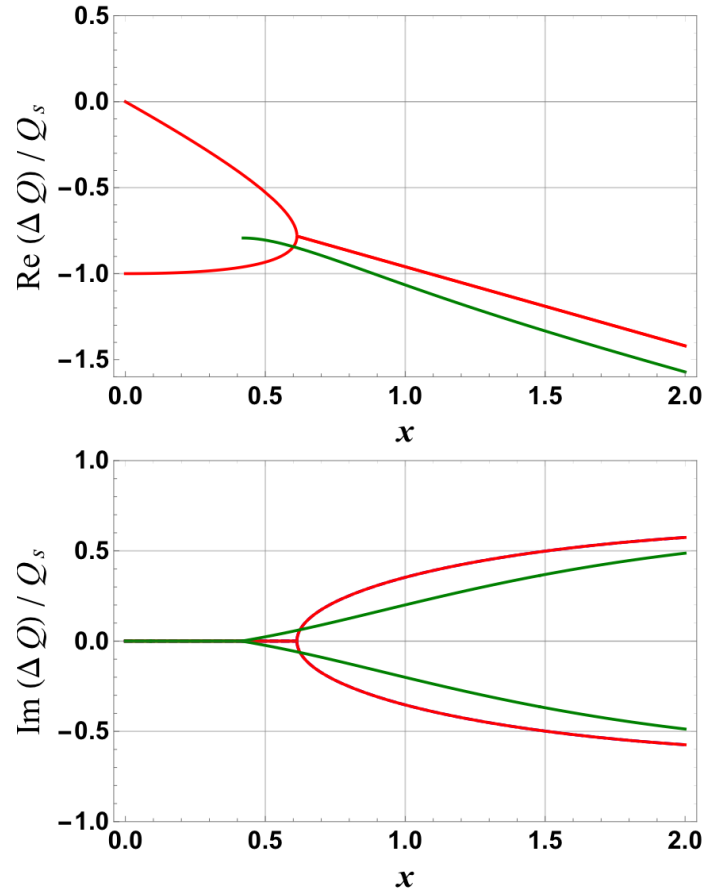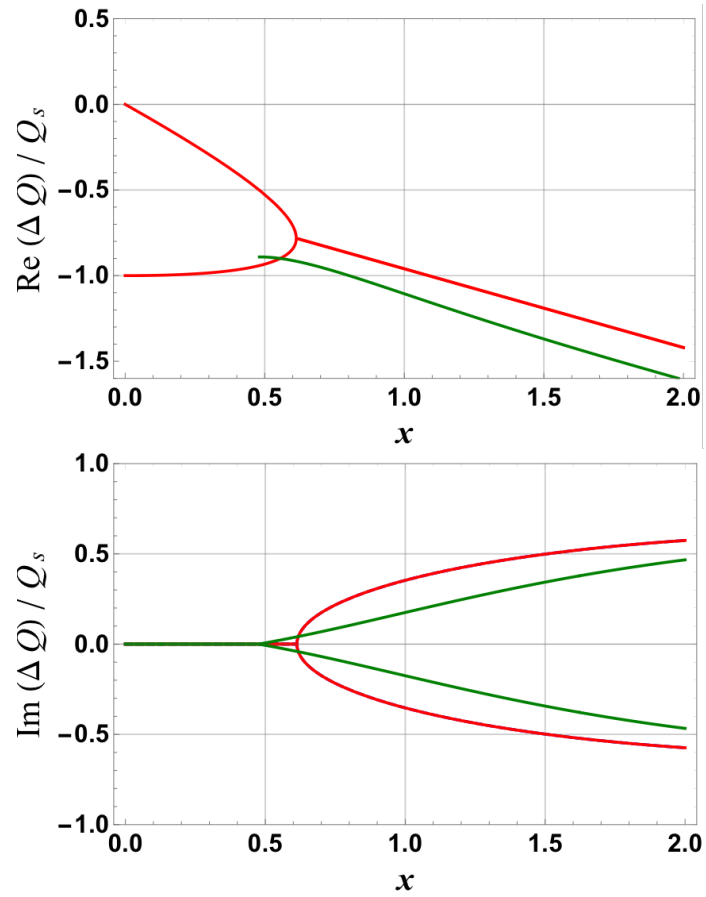
Figure 10: Effect of Landau damping on TMCI, using the same model as before but without transverse damper: Δq=0.6 (in green, compared to the case Δq=0 in red).
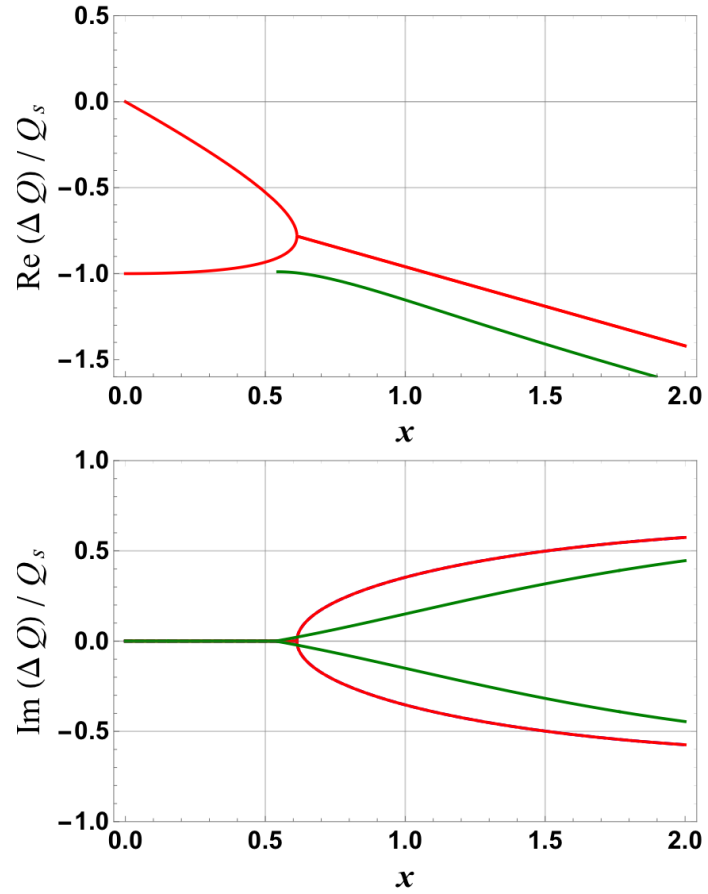
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Figure 13: Effect of Landau damping on TMCI, using the same model as before but without transverse damper: Δq=0.9 (in green, compared to the case Δq=0 in red).

Figure 14: Effect of Landau damping on TMCI, using the same model as before but without transverse damper: Δq=1.0 (in green, compared to the case Δq=0 in red).
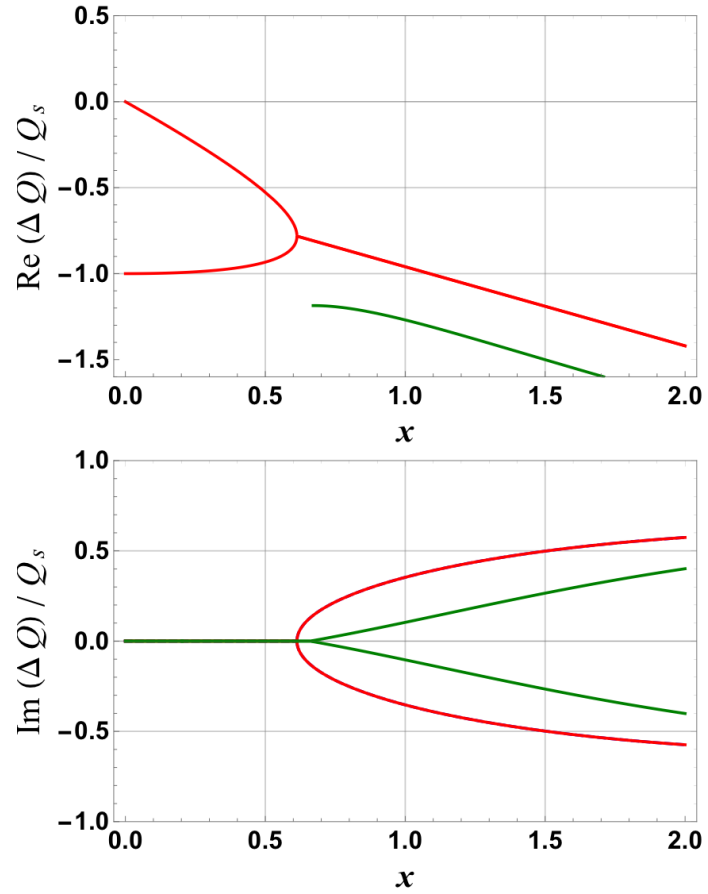
Figure 15: Effect of Landau damping on TMCI, using the same model as before but without transverse damper: Δq=1.2 (in green, compared to the case Δq=0 in red).
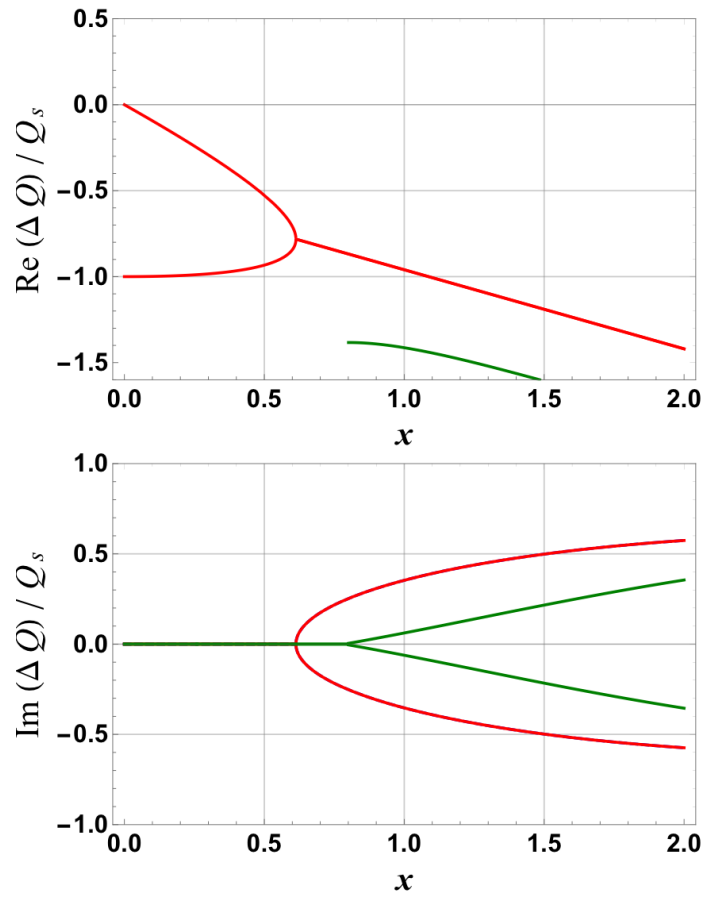
Figure 16: Effect of Landau damping on TMCI, using the same model as before but without transverse damper: Δq=1.4 (in green, compared to the case Δq=0 in red).
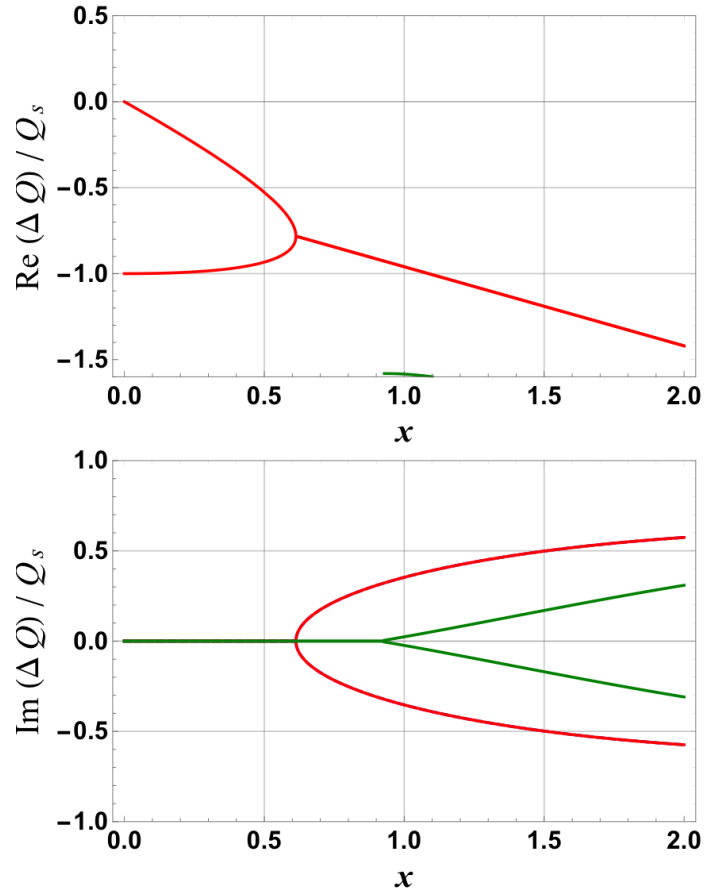
Figure 17: Effect of Landau damping on TMCI, using the same model as before but without transverse damper: Δq=1.6 (in green, compared to the case Δq=0 in red).
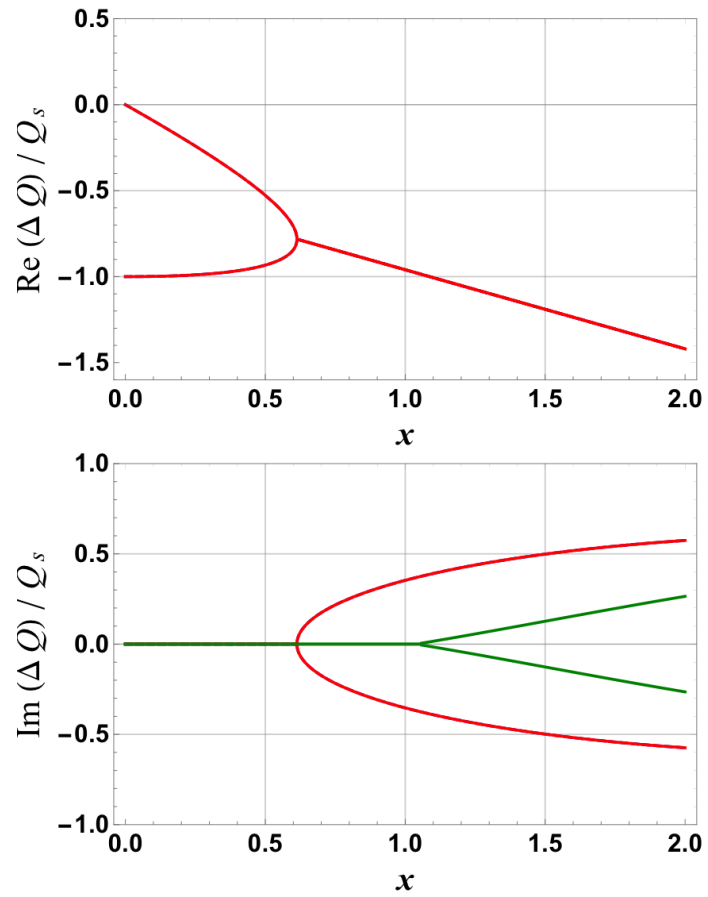
Figure 18: Effect of Landau damping on TMCI, using the same model as before but without transverse damper: Δq=1.8 (in green, compared to the case Δq=0 in red).
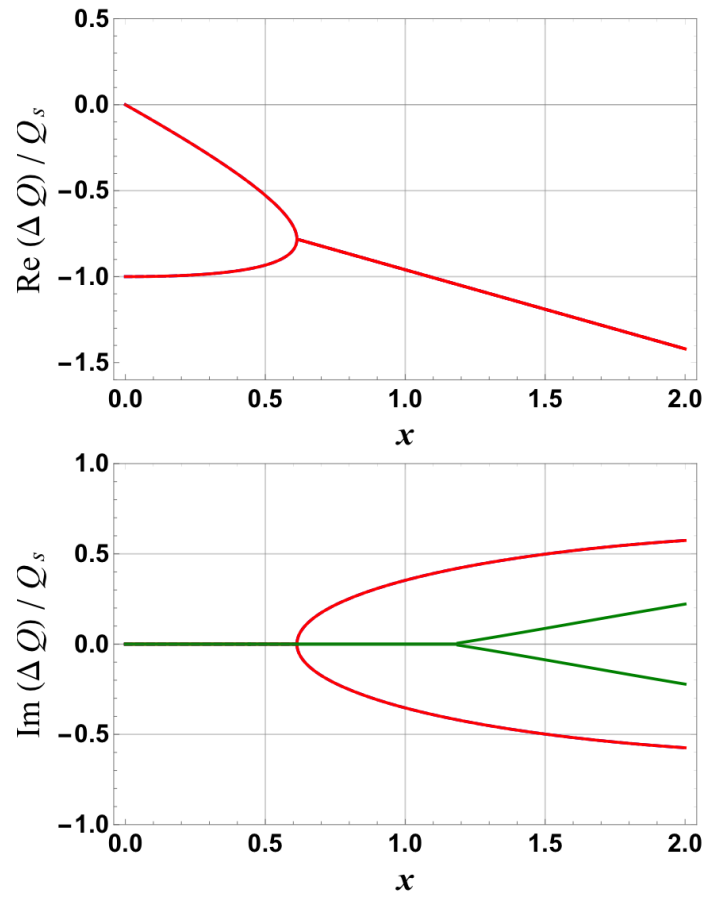
Figure 19: Effect of Landau damping on TMCI, using the same model as before but without transverse damper: Δq=2.0 (in green, compared to the case Δq=0 in red).
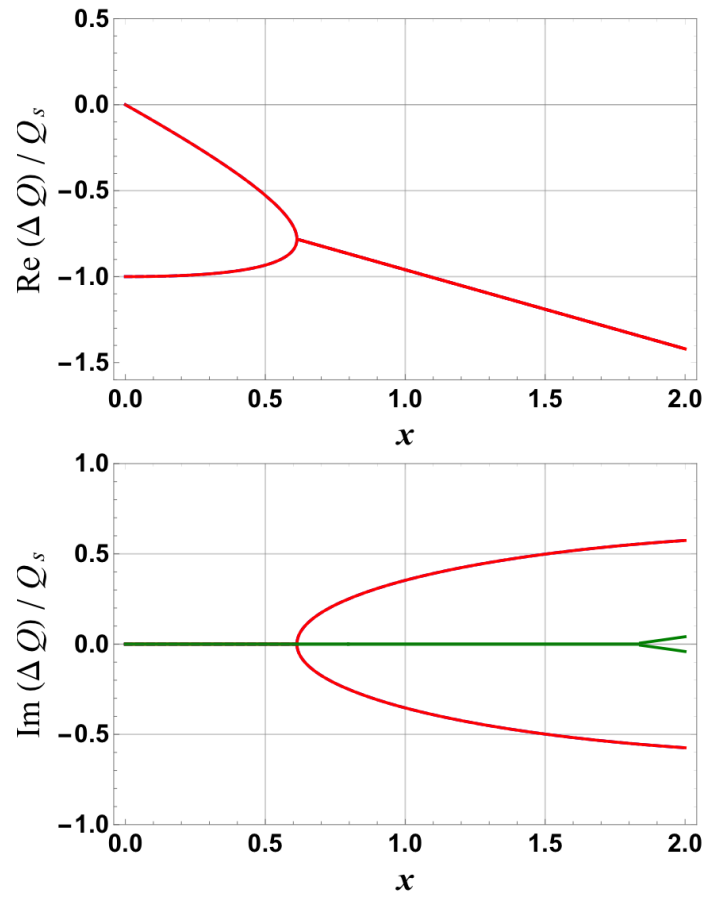
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