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Publication date
2023

Document Version
Final published version

Citation (APA)
Fărăgău, A. B., Metrikine, A. V., & van Dalen, K. N. (2023). *The interplay between the electro-magnetic and wave-induced instability mechanisms in Hyperloop*. Poster session presented at Engineering Mechanics Symposium 2023, Arnhem, Netherlands.

The interplay between the electro-magnetic and wave-induced instability mechanisms in Hyperloop

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Background

Hyperloop is a new emerging transportation system that is in the development stage. Its design

- minimises the air resistance by having the vehicle travel inside a **de-pressurised tube** (near vacuum),
- and eliminates the wheel-rail contact friction by using an **electro-magnetic suspension**.

By doing so, it can potentially reach much higher velocities than conventional railways, thus being a climate-friendly competitor to air transportation.

Representation of Hyperloop transportation system. Source: https://hardt.global

Novelty of the study

One challenge that Hyperloop will face is to ensure the **dynamic stability** of the system at large velocities and avoid excessive amplifications of the response. This study aims to determine the unstable velocity regimes, and is concerned with the interplay between two instability sources, namely:

(i) the electro-magnetic suspension,

(ii) and the wave-induced instability.

Control dynamics

The electro-magnetic suspension can induce instability if not properly controlled

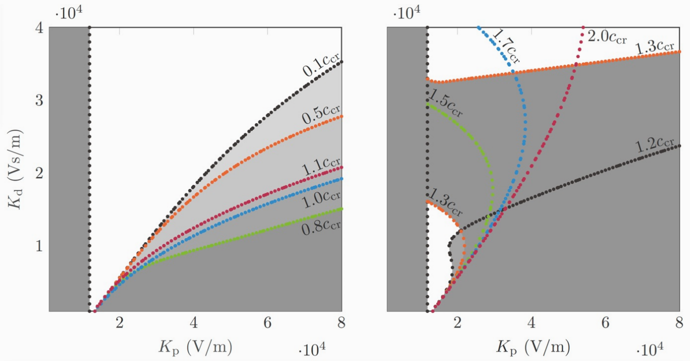
Structural dynamics

At large vehicle velocities, wave-induced instability can occur (studied in the context of high-speed trains)

The novelty of this study lies in the interplay between these two fundamentally different instability mechanisms.

Stability in control-parameter space

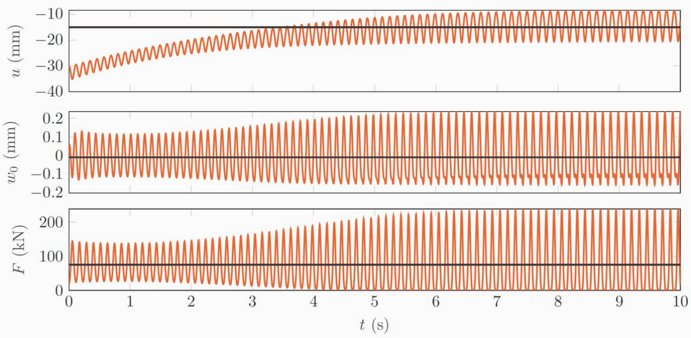
The stability spaces for sub-critical velocities (left panel) are qualitatively very similar. Instability for these velocities is solely caused by the electro-magnetic suspension system.



Hyperloop system stability in the control-parameter space for different velocities.

The stability-parameter space changes drastically above v=1.2-1.3 c_{cr} (right panel). While at lower velocities the stability domains slightly expand or contract without any qualitative change, at v=1.2-1.3 c_{cr} and above, the stability domain transits to a closed oval. The change in behaviour between the left and right panels does not originate from the control system, but is caused by its interplay with the second instability mechanism becoming present. More specifically, the energy radiated by the vehicle into the guideway is being fed back to the vehicle vibration through the anomalous Doppler waves.

Emergence of limit cycles



System response after the super-critical Hopf bifurcation.

To the right of the stability boundaries, the loss of stability occurs through a super-critical Hopf bifurcation. This leads to the emergence of limit cycles. If K_p is far away from the stability boundary, the control becomes very aggressive and overshoots, leading to the vehicle colliding with the guideway, moment at which the electro-magnetic force becomes infinite. This leads to the destruction of the limit cycles.

Conclusions

- Correctly accounting for the guideway is beneficial for mid-to-high sub-critical velocities due to stronger suppression of perturbations.
- Unlike purely-mechanical counterparts, limit-cycle oscillations can occur at sub-critical velocities
- At super-critical velocities, the stability parameter space drastically reduces due to the interaction between the electro-magnetic suspension and the wave-induced instability mechanism (anomalous Doppler waves)

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Post-Doc progress

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