The influence of the frequency and velocity-dependent reaction force of the guideway on the vertical stability of the Hyperloop transportation system

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Abstract. Hyperloop is an emerging transportation system that minimises the air resistance by having the vehicle travel inside a de-pressurised tube and eliminates the wheel-rail contact friction by using an electro-magnetic levitation system. This work studies the vertical stability of the Hyperloop system and its novelty lies in considering the frequency and velocity-dependent reaction force provided by the infinite elastic guideway. Furthermore, by also modelling the secondary suspension that connects the electro-magnetic levitation system to the vehicle, the effect of its additional damping on the vertical stability of the overall system is investigated. This study can help engineers designing the Hyperloop system avoid undesired excessive vibrations that can lead to fatigue problems and, in extreme cases, to derailment.

Introduction

Hyperloop is an emerging transportation system that is still in the development stage. Compared to high-speed railway, its envisioned design presents two major improvements. Firstly, air resistance experienced by the vehicle is minimized by having it travel inside a de-pressurised tube (near vacuum). Secondly, the wheel-rail contact friction is eliminated by using an electro-magnetic levitation system (EMS) similar to Maglev trains. These two major improvements lead to the vehicle potentially reaching much higher velocities than conventional or even high-speed railways. Together with the fact that it runs solely on electricity, the Hyperloop transportation system can become a climate-friendly competitor to air transportation.

One Hyperloop design has the vehicle suspended from top of the de-pressurised tube, with the nonlinear electro-magnetic force acting always in attraction while the gravitational force acts in opposite direction (Fig. 1). Following this design, the system is inherently unstable and requires a control strategy to ensure stability even at quasi-static velocities. In the current work, a basic control strategy (i.e., PD control) is used that includes a component proportional (P) to the air gap and one proportional to the time derivative (D) of the air gap.

This work aims to study the vertical stability of the Hyperloop system following the aforementioned design. While the stability of similar systems has been previously studied (e.g., [1]), the novelty of this work lies in considering the frequency and velocity-dependent reaction force provided by the infinite elastic guideway. Furthermore, by modelling also the secondary suspension that connects the EMS to the vehicle, the effect of its additional damping on the stability of the overall system can be investigated. The Hyperloop system is modelled as an infinite beam continuously supported by a visco-elastic foundation subject to a moving two degree-of-freedom oscillator (see Fig. 1).

Preliminary results

If the frequency-velocity reaction force of the guideway is not accounted for, the vehicle velocity has no influence on the system stability. Consequently, in previous studies, the feedback gains were determining the stability of the system for the whole velocity regime. This works shows that a stable system at small relative velocities can loose stability at large velocities. More interestingly, Fig. 1 shows that an unstable system at small relative velocities can gain stability at higher velocities. This study can help engineers designing the Hyperloop system avoid undesired excessive vibrations that can lead to fatigue problems and, in extreme cases, to derailment.

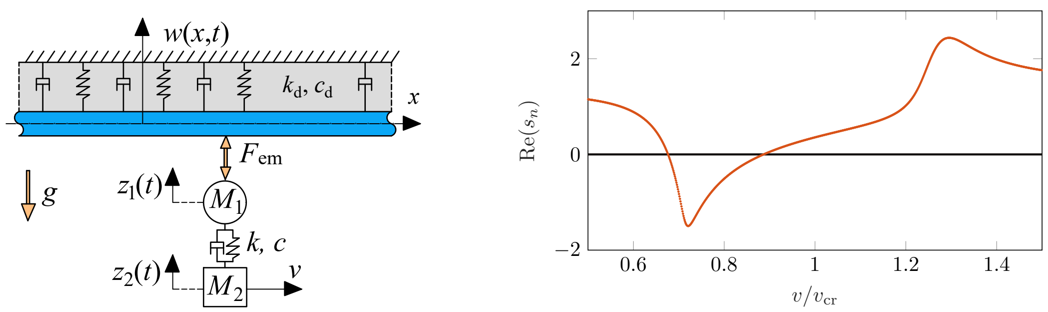

Figure 1: Schematics of the system (left panel) and eigenvalues of the linearised system versus relative velocity (right panel).

References

[1] Wu H., Zeng X., Gao D., Lai J. (2021) Dynamic stability of an electromagnetic suspension maglev vehicle under steady aerodynamic load. *App. Math. Modelling* **97**:483-500.