The influence of the electro-magnetic levitation and its control strategy on the vertical stability of the Hyperloop transportation system

Andrei B. Fărăgău*, Rui Wang*, Andrei V. Metrikine*, and Karel N. van Dalen*
*Department of Engineering Structures, Delft University of Technology, Delft, the Netherlands

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. Due to the very large target velocities, one of its challenges will be ensuring the system stability. This study aims to determine the velocity regimes in which the system is unstable, and, more specifically, is concerned with the influence of the electro-magnetic levitation and its control system on these velocity regimes. This study can help engineers designing the Hyperloop system avoid excessive vibrations that can lead to fatigue problems and, in extreme cases, to derailment.

Introduction

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 levitation (EMS) system, similar to the ones used by Maglev trains. By doing so, it can potentially reach much higher velocities than conventional railways, thus being a climate-friendly competitor to air transportation.

Some challenges faced by the Hyperloop system have already been identified and studied in the context of high-speed railways. However, the much larger target velocities will most likely lead to new challenges. One such a challenge is ensuring the stability of the system at large velocities. It is well known that the vibration of a vehicle travelling on an elastic guideway can become unstable when it exceeds a certain critical velocity [1, 2]. Consequently, knowing the unstable velocity regimes of the Hyperloop is of high importance for its design.

This study aims to determine the said unstable velocity regimes and focuses on the influence of the EMS and its control system on the instability velocity regimes. To this end, the Hyperloop system is modelled as an infinite beam continuously supported by a visco-elastic foundation subject to a moving mass (Fig. 1). The mass interacts with the guideway through a nonlinear electro-magnetic force governed by the EMS. A control strategy is necessary to ensure stability of the system even at quasi-static velocities. 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 derivative (D) of the air gap, in which the gains of each component are kept constant. Since the PD control can insert and extract energy from the system, its influence on the system's stability is currently unknown.

Preliminary results

If the control gains are appropriately chosen, instability occurs at very high velocities that are beyond the target ones, similar to high-speed railways. However, for some values that seem appropriate at low velocities can lead to a behaviour at large velocities which is very different to the mechanical counterpart (i.e., high-speed rail). For example, Fig. 1 shows that instability is onset slightly beyond the critical velocity, but stability is regained at even higher velocities. This seems to be a particularity of the present system since this is not observed in its mechanical counterpart. 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.

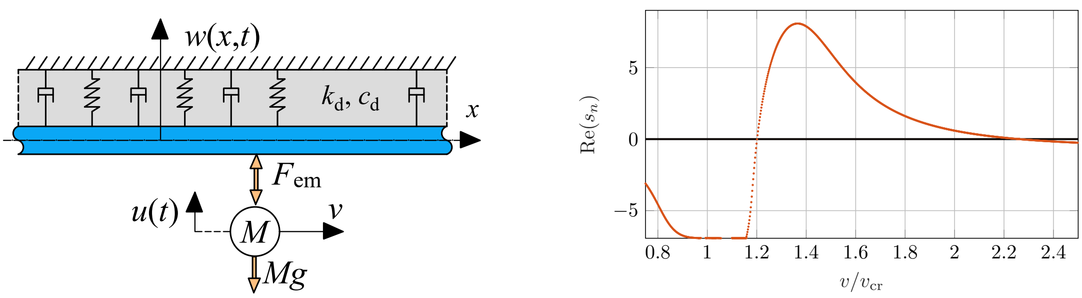

Figure 1: Schematics of the system (left panel) and eigenvalues of the linearised system versus relative velocity (right panel).

References

[1] Denisov G. G., Kugusheva E. K., Novikov V. V. (1985) On the problem of the stability of one-dimensional unbounded elastic systems. *J. of App. Math. and Mech.* **49**:533-537.

[2] Metrikine A. V. (1994) Unstable lateral oscillations of an object moving uniformly along an elastic guide as a result of an anomalous Doppler effect. *Acoustical Physics* **40**:85-89.