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Comparison of HIL pantograph tests results with finite element simulations

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Abstract

This work uses a periodic catenary model to perform accurate HIL pantograph tests at different train speeds. The catenary representative span is discretized by the Finite Element Method, and the non-linear behavior of dropper slackening is considered. With the catenary model used in this work, the catenary response can be computed in advance so that test delays are easily dealt with. The contact force obtained in the HIL tests for different vehicle speeds is compared with finite element simulations using a linear lumped mass pantograph model.

Keywords: Catenary, Pantograph, Hardware-in-the-loop.

1 Introduction

When designing and installing a new railway catenary, it is usual to study its dynamic interaction with the pantograph by computational simulations before the system is experimentally homologated with in-line tests. Hardware-in-the-loop (HIL) tests put together a real pantograph and a virtual catenary reducing the gap between computational simulations and in-line tests. This kind of testing can help in reducing the high costs that in-line tests entail, as the dynamic performance of a given pantograph-catenary couple can be analyzed in the laboratory.

HIL tests require solving the catenary dynamic response in real-time which still remains a challenge if accurate results of the simulation are sought. The first works in this field [1, 2] alleviate the computational cost by using a truncated modal approach of a linear catenary model. In [3] the steady-state solution is obtained by concatenating a 3-span catenary linear model. This work was improved in [4, 5] including the non-linear behavior of droppers and the lateral displacement of the contact point over the pantograph strips. Another approach is found in [6] in which a moving coordinate formulation is used and an absorbing boundary layer is applied to reduce the reflected waves on the boundaries. The previous models use a limited number of spans to achieve real-time performance, which can be considered as an approximation of the real catenary. Additionally, another challenging issue of HIL testing is related to the delays produced in the measurement-simulation-actuation loop. These delays may worsen the accuracy of the test results or even make the test unstable.

In this work we use a periodic catenary model [8], discretized by the Finite Element method, which includes the non-linear behavior of dropper slackening, to perform accurate HIL pantograph tests at different train speeds. With the catenary model used in this work, the catenary response can be computed in advance so that delays in the test are easily dealt with. However, it is important to remark that, although it is very representative in the central spans of a catenary section, this catenary model is limited to the steady-state regime. Finally, the results obtained are compared with those from standard finite elements dynamic simulations in which a lumped mass numerical pantograph model is used.

2 Methods

The main elements of the HIL test rig are related to the measurement-simulation-actuation loop: the load cells, the computer unit, and the actuator. These elements must simulate the real catenary dynamic interaction with the pantograph. Figure 1 shows a picture of the whole HIL system with its main components and the transmitted information flow.

The simulation loop starts with the interaction force measure from the load cells. This force is acquired by the real-time controller that sends it to the PC having the computational catenary model, which is fully described in [8]. The catenary dynamic response under the contact force is solved to obtain the catenary contact point displacement, also considering the non-linear behavior produced by dropper slackening. The computed contact wire position is sent back to the real-time controller that sends this value to the actuator controller, making the linear actuator reach the desired position at the end of the loop. The loop time may cause the delayed system's response to be different from that of the original catenary.

In this work, a steady-state solution of the periodic catenary is used for HIL testing. The use of a steady-state model allows for dealing with delays because at each time step of the HIL test catenary response in the whole span is available. Thus, the contact point displacement sent to the actuator is the one that, when the actuator reaches that position, matches with the current contact point, and therefore the delay is fully compensated.

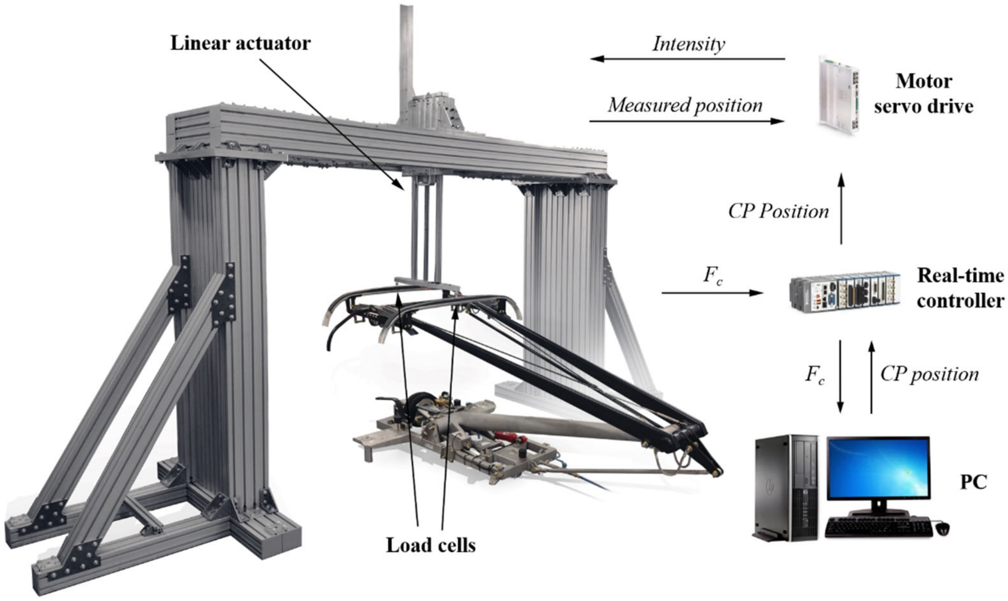

Figure 1: HIL pantograph test-rig components and information flow.

3 Results

The same catenary has also been computationally simulated interacting with a lumped parameters pantograph model (see [9]) to compare the accuracy of the HIL test results. The time step used for the catenary time integration is 2 ms. Regarding the delay, it has been quantified in 22 ms which are produced by the contact force filter (3 ms), the communication with the actuator (9 ms), and the control loop (10 ms). The catenary displacement is computed up to 25 Hz.

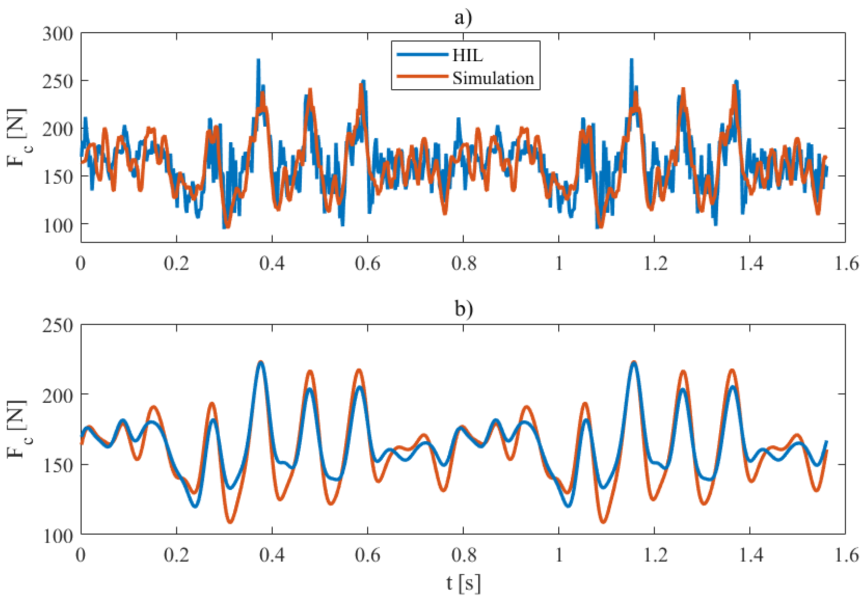

Figure 2: Comparison of HIL and simulation contact force at 300 km/h. a) Raw contact force, b) 20 Hz filtered contact force.

Figure 2 shows a comparison between the pantograph-catenary contact force from HIL tests and the finite element simulation when the pantograph runs at 300 km/h. The force of two consecutive spans is shown without filtering in a) and with a low-pass 20 Hz filter in b). An acceptable agreement can be observed between both results. The differences observed may be due to the linear lumped mass model of the pantograph used in the finite element simulations.

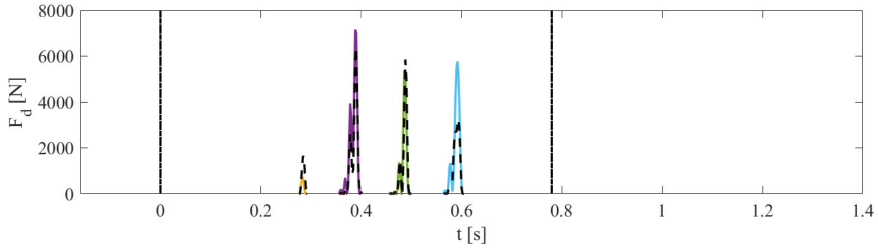

Figure 3: Comparison of slackened dropper correction forces between HIL tests (coloured solid lines) and simulation (dashed black lines).

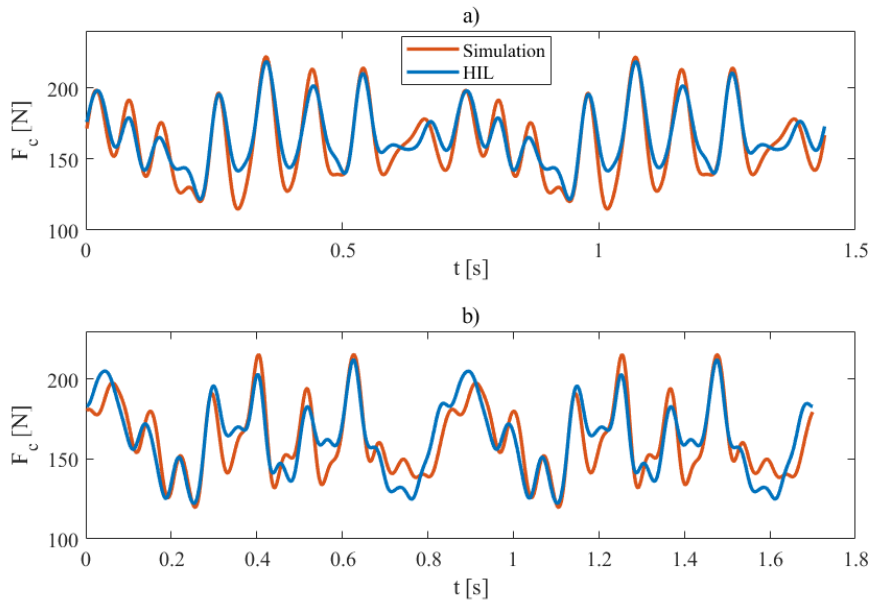

Figure 4: Comparison of HIL and simulation 20 Hz filtered contact force at a) 325 km/h and b) 275 km/h.

The slackened dropper correction forces are depicted in Figure 3 for both HIL tests (coloured solid lines) and simulation (dashed black lines). Note that droppers are considered for possible slackening certain steps before and after the pantographs pass through a given span (vertical dash-dotted lines in Figure 3). In this case, only four droppers slacken when the pantograph interacts with the contact wire near their position in the span. Again, an acceptable agreement between the HIL and simulation results is obtained.

Finally, the same catenary is tested for two additional train speeds, namely 325 km/h and 275 km/h. The 20 Hz filtered contact force is plotted in Figure 4 for both HIL and simulations.

4 Conclusions and Contributions

In this work, we present the results of HIL pantograph tests. The catenary model can simulate the steady-state response of the system and presents the same accuracy as complete finite element models in the central spans of a given catenary section.

The accuracy obtained by HIL tests when compared to finite element simulation results can be attributed to two main factors: i) non-linear dropper slackening is considered and ii) the delay of the measurement-simulation-actuation loop is counteracted by sending to the actuator a future contact point position.

The comparisons presented for the three different train speeds confirm the validity of the proposed approach. The little differences observed may be caused by the linear lumped mass pantograph model used in the simulations because it is not able to simulate the more complex dynamic behavior of the real pantograph.

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