Development of a Hardware-in-the-Loop Test Bench for Validation of an ABS System on an e-Bike

N. Ramosaj¹, C. Fusco¹,², E. Viennet¹,*

¹School of Engineering and Architecture of Fribourg, HES-SO University of Applied Sciences and Arts Western Switzerland; nicolas.ramosaj@hefr.ch; christia.fusco@hes-so.ch; emmanuel.viennet@hefr.ch ORCID 0009-0004-0922-2934
²Dipartimento di Ingegneria Meccanica e Aerospaziale, Politecnico di Torino, Italy
*corresponding author.

Abstract:

Electrically assisted bicycles (e-bikes) have become increasingly popular and may facilitate active commuting. But this comes at the price of safety since e-bikers have a higher risk of traffic accidents than conventional cyclists (Haufe et al. 2022). However, the availability of electric energy onboard allows the emergence of active safety systems like antilock braking systems (ABS) that could help reduce the accident rate in the same way it was observed in the last decades for cars and motorcycles (Maier, 2018). ABS is a mechatronic device involving multi-domain expertise (electronics, mechanics, software) and conflicting objectives (cost, performance, perceived quality, safety of operation, safety of testing). This makes a model-based system engineering (MBSE) methodology a well-suited approach to develop such a device. In the MBSE context, simulation models are deployed all along the development cycle, from requirements down to testing phases (both verification and validation).

This paper presents the development of a test-bench that can be leveraged to validate an e-bike ABS for multiple bicycle geometry, loading and test scenarios. The approach consists in reproducing the dynamics of an e-bike thanks to a simulation model and interfacing it with a physical brake and the ABS hardware under test, thus obtaining a hardware in the loop (HiL) test bench as mentioned in (Heidrich et al., 2013) and (Pfeiffer et al., 2019). Figure 1 presents an overview of the installation whose core part is the real-time target machine running the virtual bike model. This setup allows the test engineer to first test and evaluate the ABS behavior in a safe place, before starting tests on the track.

Figure 1. Concept of the developed hardware-in-the-loop test-bench. The ABS hardware under test is interfaced to the real-time target machine that runs the virtual bike model.
The developed dynamic model represents an e-bike with a semi-rigid frame (front suspension only). The simulation model considers 6 degrees of freedom: longitudinal, vertical and pitch motion of the bike frame; front and rear wheel rotation; front suspension travel. The parameters of the model are either directly measured when feasible or reproduced from literature or identified indirectly from bicycle measurements. A fixed step solver is used for numerical integration with a time step of 1.0 ms, allowing the model to communicate real-time with the ABS and its control unit.

The fidelity of the model is assessed by comparing its results against measurements conducted on a physical test bike. The test bike is a Flyer Goroc 2 instrumented with various sensors including force at front brake lever, longitudinal and vertical acceleration (X axis and Z axis), pitch rate (Y axis), front and rear wheel speeds, suspension travel.

Figure 2 shows preliminary results obtained with the developed HiL test-bench where a physical ABS is interfaced to a virtual bike model running on a real-time target machine. The tested scenario is a hard front braking maneuver with an initial velocity of approx. 10 m/s, a soft front suspension and a flat road with low grip. When a slip condition is detected at the front wheel, the ABS triggers a release of the pressure in the hydraulic brake circuit, thus lowering the actual force measured at the front brake pad. When the front wheel does not slip anymore, the pressure in the hydraulic brake circuit rises again thanks to the pump integrated in the ABS system.

**Figure 2.** Preliminary set of results obtained with the HiL test-bench. Test scenario shows that ABS triggers a decrease of effective force at front brake when a slip condition is detected at the front wheel.

Further work investigates the impact of some bike parameters like geometry, loading, suspension stiffness and tire grip on the braking performance with the tested ABS.

**References**


