# Development of a Cyber-Physical Test Bench for E-Powertrain Components

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## EXTENDED ABSTRACT

## 1 Introduction

Electric Vehicles (EVs) are complex systems made up of components with different nature and dynamic response. As such, they can be considered multiphysics systems, in which mechanical, hydraulic, electric, electronic, and thermal effects, among others, play an important role during operation and interact with each other. For instance, the performance of electrical and mechanical components in EV powertrains is intertwined with their thermal state. This complexity must be considered during the product development cycle and the operation time of the vehicle, not only at system level, i.e., from the point of view of the overall behaviour of the whole car, but also at component level. Traditionally, new automotive components, technologies, and designs have been validated by means of experimental tests with full-vehicle prototypes. This paradigm hinders the early detection of defects and design flaws, which are often revealed only after field tests have started. The profound and rapid transformations currently undergone by the automotive industry require, however, modern and flexible tools to test and validate new designs as early as possible, before vehicle prototypes are ready.

Model-Based System Testing (MBST) is emerging as an enabling technology to allow the experimental testing of components and algorithms from the early stages of product development cycle. MBST relies on the combined use of computer simulation and physical experiments to streamline both component and system design and testing [1]. Cyber-physical test benches, in which a real-world component under test is interfaced to a computer simulation of the overall system and its environment, are an application example of MBST technology. Figure 1 shows the conceptual scheme and flow of information of such a bench, aimed at testing electric motors for vehicle powertrains.

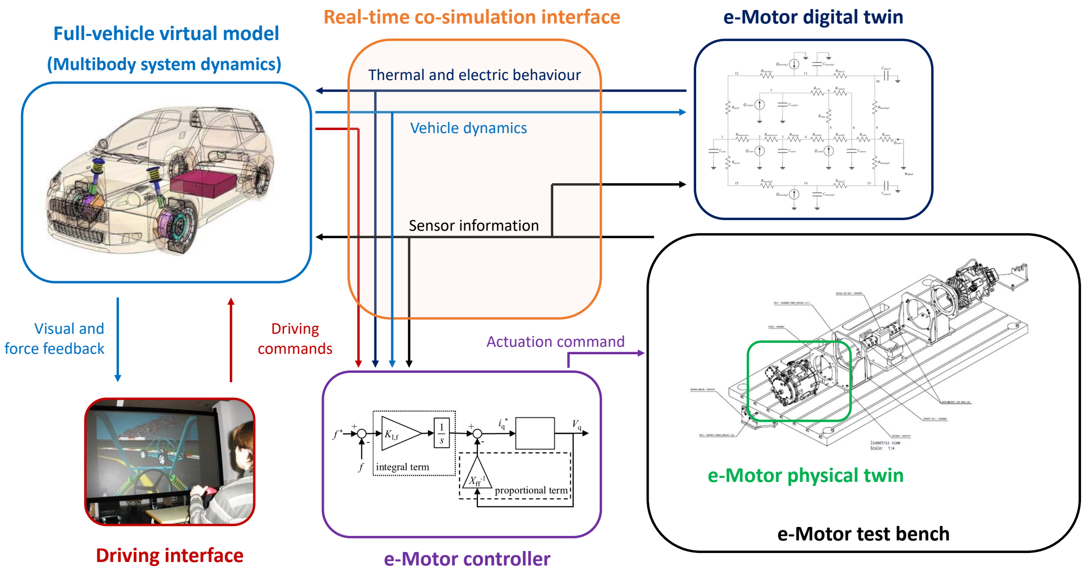


Figure 1: Elements of a cyber-physical test bench for e-powertrain motors.

In the test bench shown in Fig. 1, the motor under test is interfaced to a full-vehicle multibody system (MBS) dynamics simulation, which may reproduce a pre-defined manoeuvre or follow the commands of a human or virtual driver. The simulation determines the loads that the motor under test would have to bear during operation, and these are exerted by means of a second electric motor, in a back-to-back configuration [2]. Moreover, a digital twin (DT) of the motor is used to gain insight into the information provided by the sensors mounted on the system and monitor its behaviour beyond directly available measurements.

## 2 Research methodology

The operation of a cyber-physical test bench like the one described by Fig. 1 requires assembling together technologies from different engineering areas.

In the first place, real-time capable models, simulation methods, and implementations are a critical part in MBST setups. They must be detailed and accurate to guarantee reliable results, while complying with the predictability, compactness, and efficiency requirements of real-time applications. The proposed test bench requires this of the simulation of the MBS vehicle dynamics, and the electric behaviour and thermal effects within the motors [3].

The fidelity of computer simulations to the actual behaviour of the real-world systems that they represent needs to be ensured as well, so that the experimental results collected using the test bench correspond to the true performance of the components under test. The DT approach relies on a bi-directional exchange of information between the physical component and its virtual representation that enhances the accuracy of the latter, while enabling techniques like virtual sensing, which provide more information about the cyber-physical test bench than the one gathered by the system sensors alone or obtained from the simulation running on its own.

Finally, the physical-virtual interaction is orchestrated by means of a hybrid co-simulation environment, compatible with the Functional Mock-up Interface (FMI) standard.

## 3 Experimental setup

Our research team has designed and built two back-to-back cyber-physical test benches following the above-mentioned guidelines, as shown in figure 2.

Figure 2: MBST cyber-physical test bench for e-powertrain motors, currently under construction (left) and fully operational scaled prototype (right).

A full-size testing facility for automotive-grade electric motors is currently under construction. The operation principles and implementation details are presently being tested in an already operational scaled prototype for low-power electric motors.


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