Implementation of vehicle simulation model in a modern dynamometer test environment

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Abstract

The rapid development of digital technology makes it possible to expand the sustainability of the transport sector. With the development of digitalization, virtual tests play an increasingly important role in product design. With the development of computer technology, there is a more accurate and faster opportunity to save time, energy, and costs before the product is introduced to the market. In the early stages, vehicle simulation can be effectively used, which is a cost- and time-efficient solution. This study presents the transfer of a vehicle simulation model to an internal combustion engine dynamometer. Dynamometers allow the behavior of the real engine to be tested before the complete vehicle is available. Building the simulation model of the complete system including the dynamometer and the engine makes it possible to setup the variables of the real test environment resulting in decreased time and cost on the dynamometer. Furthermore, the system constructed in this way can be suitable for carrying out the tests that were previously carried out on the entire vehicle. With a vehicle simulation model, the level of simulation can be changed as needed during development until the developed real vehicle is fully realized.

1. Introduction

Today's modern software solutions offer new possibilities for expanding dynamometer tests with simulations. Petters shows an example of this by comparing different vehicle driving styles: the comparison was carried out in an office environment in order to minimize the time spent on the engine dynamometer (Petters, 2019). Cognitive Mobility (CogMob) investigates the entangled combination of the research areas such as mobility, transportation, vehicle engineering, social sciences, artificial intelligence, cognitive info-communication (Zöldy and Baranyi, 2021).

The applications cooperate using each other's advantages in order to generate timely analyses that can influence decision-making during planning. In their work, Dietrich and Rupfle created a reproducible environment on the test dynamometers, in which the selected components can be used using simulation applications (Dietrich, 2020). Pfister investigated the unification of powertrain combinations in a virtual test driving environment (Pfister, 2019). Jiang and his colleagues developed a method for creating a vehicle simulation environment in a real dynamometer environment. (Jiang et al., 2009). The present research was carried out in a test environment on an engine dynamometer. Along these aspects, the transfer of the vehicle simulation to the engine dynamometer test environment is a useful task, because the problems that may arise appear even before installation on the engine dynamometer.

Due to the ever tightening emission regulations, internal combustion engines need more complex systems (Baranyi and Csapo, 2010). Nyerges and Zöldy (2020) show an example of the role of modeling and simulation of an internal combustion engine.

When creating a vehicle simulation model, the dynamics, aerodynamics, kinematics, and the driving of the vehicle must be described in detail, translated into machine language. A basic requirement is that a model is created that can determine the engine load in real time. With this data, the dynamometer is able to load the engine as if it were in a real vehicle. The purpose of the dynamometer is to load the engine in real time depending on the input data of engine load, similar to that in a vehicle. The conversion and modification of the signals used to automate the test dynamometer and the processing of the signals of the intermediate systems are carried out by several software programs, which provide the control signals for all the elements in the automation circuit. The goal is for the engine load to be exactly the same in real time on the engine dynamometer as if it were operating in a passenger vehicle. This requires a vehicle simulation in which all elements are mapped that are not physically present at the engine dynamometer. The vehicle properties must be modeled in sufficient detail depending on the test objective (e.g. kinematics, aerodynamics, virtual track, maneuvers, driving style – driver, engine, transmission, drive parameters, tires, brakes, suspension, ambient temperature and pressure).

With a real engine, the engine's torque and speed can be directly, physically measured, , as well as the consumption and emissions of the internal combustion engine. During the validation, the simulation results may be compared to the measured results. During the rechecking (validation) of the results, the operation of the main parts that are present in the applied system, but different from a real vehicle, must be examined. The disadvantage of real testing is that urban conditions are always changing, so it is impossible to reproduce the results, which makes comparisons difficult. For example, the status of traffic lights, the traffic situation or the strength of wind gusts are constantly changing. Therefore, vehicle measurements on public roads cannot be reproduced.

The problem of reproducibility can be overcome, by using vehicle simulation on a dynamometer, for example. With this solution, different engines can be tested on the dynamometer under the same conditions, so there is a basis for their comparison. Vehicle simulation can be used effectively in the early stages of development, which is a cost-effective and quick solution. The behavior of the real engine can be tested even before the complete vehicle is available. The system constructed in this way can be suitable for carrying out the tests that were previously administered on the entire vehicle. With a vehicle simulation model, the level of the simulation can be applied as needed until the real vehicle under design is fully realized. Thereby, already in the early stages of development, partial results are available that have an influence on the direction of development.

When making decisions, more and more emphasis is placed on the processing of data created by vehicle simulation. An example of this is written by Bauer and his colleagues, where the effects of the vehicle configurations on emissions were investigated (Bauer et al., 2019). With the help of vehicle simulation, the development time is reduced, and fewer real tests are required. Therefore, the introduction of the product to the market can be accelerated. Moreover, the development cost and the environmental impact per unit of product is reduced. The raison d'etre of vehicle simulation is time, since shortening the product life cycle and reducing development costs is one of the basic conditions for the sustainability of competitiveness.
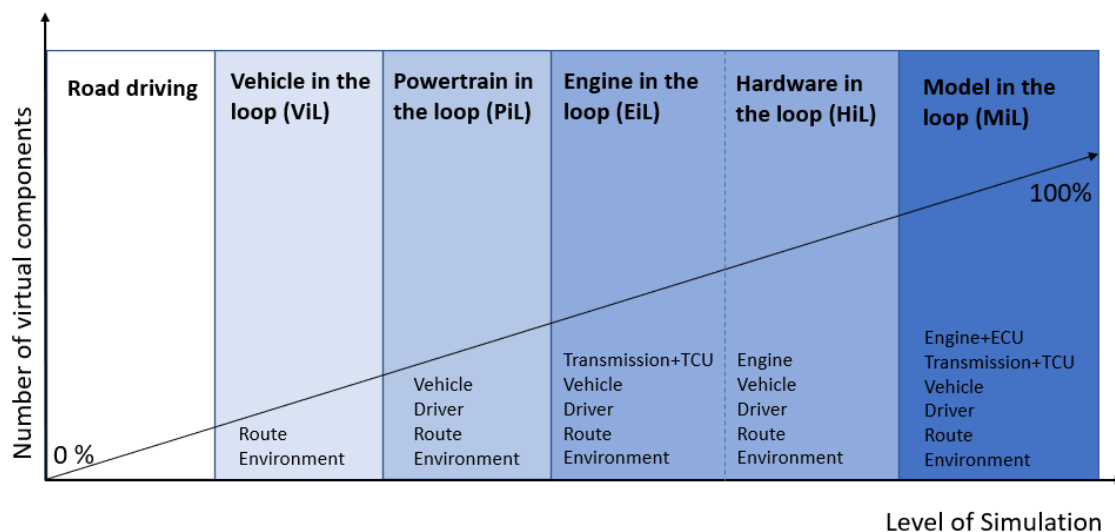

Figure 1. Overview of test environments (based on Jung et al., 2019).

The engine is in the test structure named EiL – Engine-in-the-loop, in which the control circuit provides an efficient environment where exact repeatability of the measurements is possible. Figure 1 shows how the level of simulation of the

development process grows with the use of simulation models and the need for the presence of physical elements during the tests. In the MIL (Modell-in-the-loop) phase, a completely virtual vehicle is tested, there are no physical devices at all during the virtual test. During the analysis, the engine control unit (Electronic Control Unit, ECU), the engine (Engine), the gearbox control unit (Traction Control Unit, TCU), the drivetrain, the driver, the drive track and the environment are modelled in detail. For the HiL (Hardware-in-the-loop) process, the tests are supplemented with the engine control unit, for EiL with the engine controller and the engine, i.e. real physical elements. In the further stages of testing, they are replaced with real components according to the level of simulation in Figure 1, until finally a test carried out on completely real equipment (Jung et al., 2019).

The purpose of this article is to describe the transfer of model in-the-loop (MiL) vehicle simulation to the dynamometer environment (EiL). Such a simulation produces results exactly as if the engine were with the real vehicle. With this solution, it is possible to prepare tests that previously required the presence of the entire vehicle.

2. Methodology

The creation of the internal combustion engine dynamometer test environment helps to validate the vehicle simulation, as well as to prepare for the real engine dynamometer test, since it is possible to carry out the preparations earlier. Thus, problems can be solved in advance, before they become apparent during the actual engine dynamometer testing. The transfer of the vehicle simulation model was carried out in the test environment of the engine dynamometer, where neither the internal combustion engine nor its controller are physically present. The vehicle simulation used in the engine dynamometer test environment includes the driver, track, vehicle (drivetrain, engine, gearbox) and environment models.

Figure 2 shows the general structure of the test environment the Model-in-the-Loop (MiL) system created in this way. A four-cylinder in-line gasoline engine is virtually integrated. The vehicle simulation and the test engine dynamometer fitting are done through a real-time simulation platform, which can connect simulation with real hardware: this is a co-simulation platform. Teuschl and his colleagues (2021) applied a similar model. Based on the entire vehicle model, the accelerator pedal control algorithm works in real time on the co-simulation platform, it transmits signals to the virtual dynamometer. The value of the gas pedal position determined by the vehicle simulation and the speed of the virtual engine are sent via the platform to the environment of the engine dynamometer test, on the basis of which a virtual torque is calculated and returned to the vehicle simulation model.
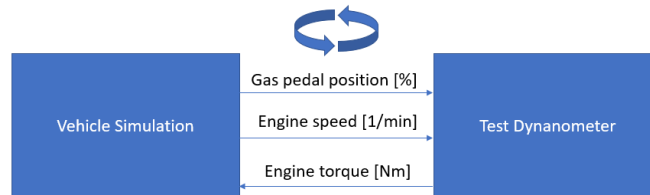

Figure 2. Control signals between vehicle simulation and the test dynamometer.

Figure 3 shows the MiL system created by integrating the virtual system, as a result of which the vehicle simulation model integrates the virtual vehicle into the virtual engine model integrated on the dynamometer of the test engine. For the dynamometer test station, the characteristic curve of the virtual engine is defined in the form of a look-up table.
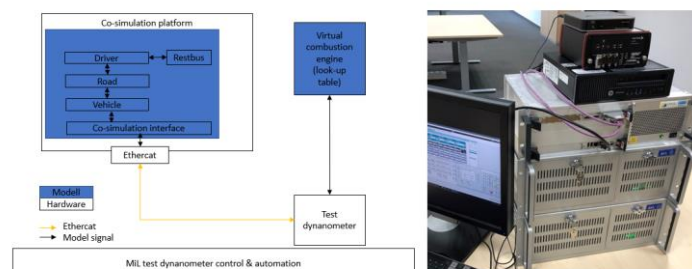

Figure 3. Conceptual diagram and actual environment of the test dynamometer at AUDI HUNGARIA Zrt..

By making settings in advance, it becomes possible to completely design the engine dynamometer test environment for the purpose of testing the vehicle simulation, and the fine-tuning can be much more prepared for the real engine dynamometer operation.

Yao and his colleagues have integrated MATLAB-based vehicle simulation into an environment that is also used on the engine dynamometer. In the MATLAB/Simulink environment, the CANoe communication module is added to the model through the CANoe-MATLAB interface. MATLAB starts the CANoe, then tracks the changing trends of each signal of the control model in CANoe. The accuracy of the control allocation algorithm is verified by co-simulation in CANoe-MATLAB (Yao et al., 2014).

The modelling and simulation starts in Simulink, by defining the model setting up the differential equations that describe the behavior of the system. These rules of behavior are formulated relying on the laws and principles of physics (Simulink). CANoe is an open environment for software development purposes, developed by Vector Informatik GmbH. Both the software and the associated necessary hardware are provided by Vector. CANoe allows to develop tests, analyze data and simulate each ECU (Electronic Control Unit), even in a dynamometer environment. CANoe is one of the programs that MATLAB can work with. Simulink is able to work together with programs written in CANoe, which also means that the vehicle model built in Simulink can also be used for software testing (Vector).

Vectrobox VN8900 is a high-speed system controller, which runs the simulation models and controls the test engine dynamometer, which is the central part of the MiL system (Vectorbox). Vectorbox VN8900 sends control commands to accelerator pedal position and engine speed at a rate of 1000 Hz. The vehicle and driver models, as well as the brake and accelerator control algorithms, were developed using MATLAB®/Simulink/Stateflow® MATHWORKS products in the form of a model block on the host computer. The S-functions of the system hardware and function modules were developed and incorporated into the block diagram. S-functions (system functions) provide a powerful mechanism for extending the capabilities of the Simulink® environment (Mathworks).

A user interface was created in AVL Puma Open 2 (AVL) software on the test environment of the engine dynamometer, where the most important information is available from the point of view of checking the operation of the vehicle simulation. The vehicle simulation was implemented in a completely virtual environment in the simulation environment on the dynamometer.

3. Results and discussion

Engine tests according to method EiL were prepared by defining the data to be measured, editing the user interface, preparing (virtual testing) the dynamometer program, and finalizing the CAN messages between the vehicle simulation and the test engine dynamometer, as well as checking the operation of the vehicle simulation model in the dynamometer test environment.

In order to analyze any errors that may arise during a real internal combustion engine dynamometer test, it is necessary to have information directly available in the test environment of the engine dynamometer, where communication data processing can be detected immediately. Complementing the Model-in-the-loop procedure, this facilitates the transition to the Engine-in-the-loop dynamometer test method. The secondary purpose of the user interface is, as can be seen in Figure 4, to make the process unified at the different test levels during the development of subsequent engine dynamometer tests (engine dynamometer, vehicle dynamometer, etc.). During the dynamometer measurements supplemented with vehicle simulation, the method of running the tests and the evaluation of the data should also be applied in a unified manner.
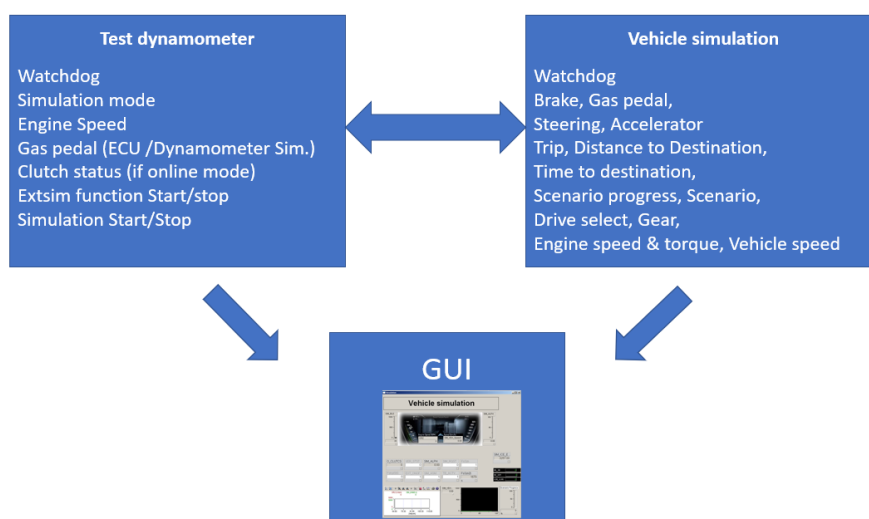

Figure 4. Vehicle simulation dialog – concept (GUI).

During its implementation, minimal modification is required to realize the transition from a fully virtual environment to an engine dynamometer.

Figure 5 illustrates the success of implementing the vehicle simulation on the virtual dynamometer. Validation and evaluation of the vehicle simulation and presentation of its results are not the goal of the present study. As Figure 5 demonstrates, the speed of the virtual engine and the speed of the vehicle simulation follow each other well, the implementation was successful.
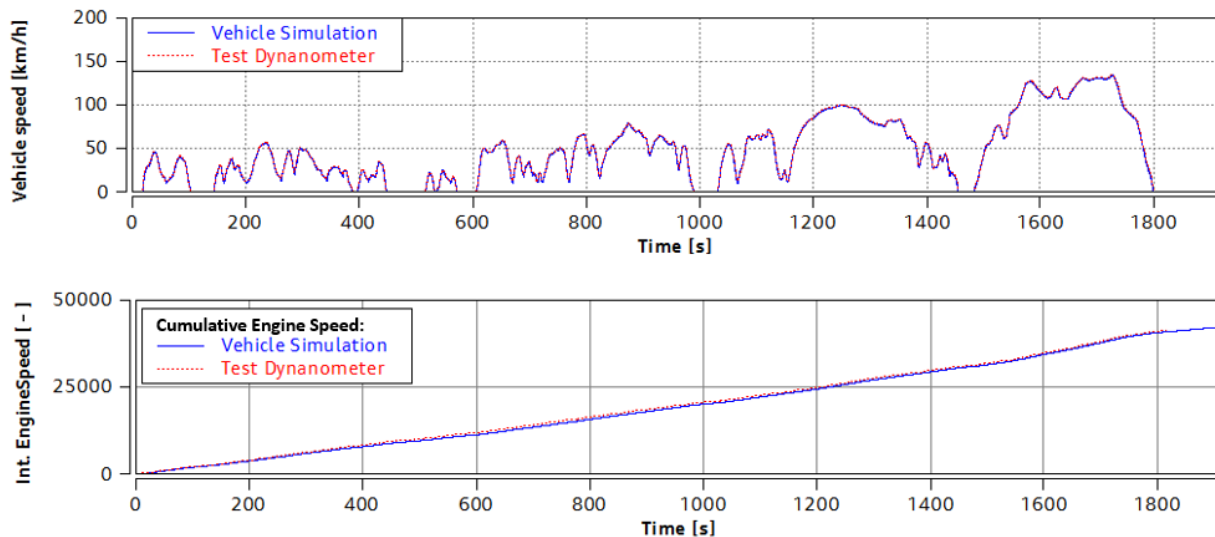

Figure 5. The result of implementing vehicle simulation on a test engine dynamometer.

By transferring the vehicle simulation of the test engine to the dynamometer, the time spent at the real dynamometer was reduced.

Based on tests performed in the engine dynamometer test environment, over 80% of the dynamometer settings can be used to carry out tests because of the application of the method EiL. It is also possible to implement the vehicle simulation in the engine dynamometer test environment with the help of a co-simulation platform.

The settings can be fine-tuned, the vehicle simulation can be operated in the test environment, and the operation description of the vehicle simulation can also be prepared for the motor dynamometer operator. Its application brings profit for later tests on a real engine dynamometer.

4. Conclusion

The application of the dynamometer test developed during this project is increasingly coming to use. It becomes possible to try different development alternatives even before the main components are physically available. The joint automation platform strategy effectively supports the implementation of shorter development processes. The unified automatization strategy between different levels of vehicle simulation makes transitions simpler and more efficient, while also supporting the integration of new methods and their applications. This significantly increases the utilization of the engine test dynamometer used in this way. Furthermore, due to the possibility of carrying out the tests earlier, the development time is reduced. The application of digital models further decreases development expenses, which increases the sustainability of the transportation sector.

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Software:

Simulink – URL: https://www.mathworks.com/products/simulink.html; (Downloaded: 11 August 2022)

Vector – URL: https://www.vector.com/int/en/products/products-a-z/software/canoe/simulation/; (Downloaded: 10 August 2022)

Vectorbox – URL: https://www.vector.com/at/de/produkte/produkte-a-z/hardware/netzwerk-interfaces/vn89xx/#c83149 ; (Downloaded: 27 June 2022)

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