Validation Procedure for Worldwide Harmonized Light Vehicles Test Cycle via Hardware in the Loop - Real Time Testing

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Abstract. This paper studies the behavior of a vehicle's power-train model developed using IPG CarMaker software applications and connected to the testbed with IC Engine by Hardware in the Loop (HiL) real time testing methodology, for the homologation (due date 2017) driving cycle Worldwide Harmonized Light Vehicles Test Procedures (WLTP).

The simulation task includes measuring the fuel consumption, power, and torque and pollutant emissions over the usual classical vehicle model for a WLTP driving cycle. Based on obtained results, a comparative analysis is performed for virtual vehicle model in IPG CarMaker and the real IC Engine on the testbed. Step-by-step simulation results are validated by integrating real-life data from on-board measurement via CAN Bus. The system captures various drivability related sensor and CAN bus signals. These input quantities were achieved from Puma Open testbed application and sent to be implemented on to the AVL InMotion equipment for further processing and analysis.

Keywords: HiL · AVL InMotion · IPG CarMaker · RT simulation · WLTP driving cycle

1 Introduction

A globally harmonized standard for the determination of levels of pollutants and CO_2 emissions, fuel or energy consumption, and electric range from light duty vehicles (passenger and light commercial vehicles) is defined through The Worldwide harmonized Light vehicles Test Procedures (WLTP).

With a final version under works, the WLTP is being developed by experts from the European Union under guidelines of UNECE World Forum for Harmonization of Vehicle Regulations [1].

The conditions regarding dynamometer tests and vehicle load, gear shifting, total car weight, fuel consumption, ambient temperature and pressure were provided through a strict guidance from the WLTP test procedure with WLTC test cycle.

The WLTC assigned to the highest power to mass ratio (PMR) vehicle category (class 3) is composed by four speed phases (low, medium, high and extra-high) [1]. This PMR parameter is representative for the vast majority of European vehicles [1].

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This paper verifies the accuracy and effectiveness of the HiL simulation and test platform for WLTC driving cycle, by comparing the real-time simulation of the motor driving system with the experimental results of the test bench, plus the analysis of the HiL simulation results of the entire vehicle model.

Procedures of the development and testing environment described in this article, to operate the vehicle under realistic conditions in the entire driving maneuver parametric space for WLTC driving cycle by means of driving tests on a chassis dynamometer in order to cover the consumption-relevant situations that occur during everyday real-world use. Maneuver and event-based testing is the name of the method used for the implementation of test cases on the AVL chassis dynamometer using AVL InMotion. The base of this method is essentially the idea that driving a vehicle - the ultimate driver of vehicle development - is a sequence of events and maneuvers [2]. Driver behavior, route and environmental conditions in combination with the real model of the vehicle (including the engine, powertrain and exhaust system) should be determined in order to perform a more realistic simulation.

AVL InMotion provides a platform for such a simulation, using physical models for each individual component of the vehicle. The use of physical models is a necessary prior condition to have the possibility of extrapolating the operating conditions besides the parameters required in the process of conducting a test [3].

2 Materials and Methods

2.1 Experimental Test Bed

The experimental test bed consists of an engine dynamometer coupled to an Internal Combustion Engine (ICE) and auxiliary equipment (Fig. 1).

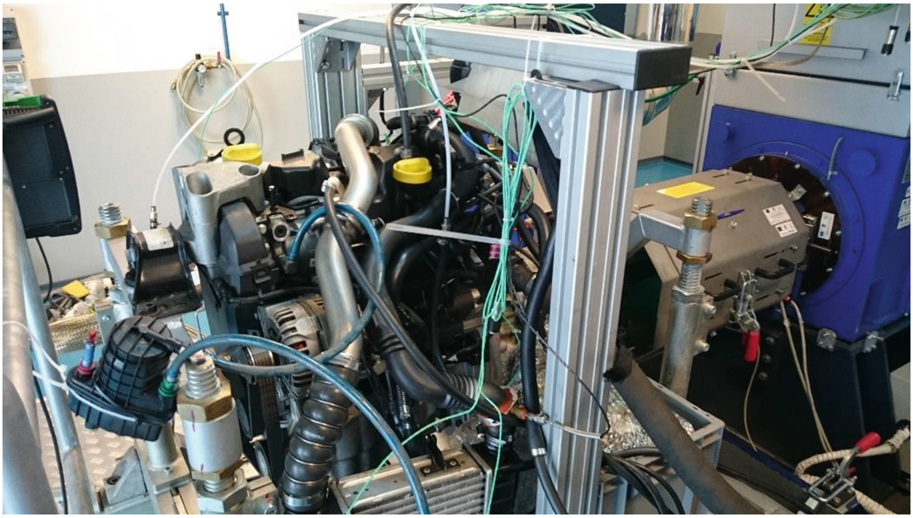

Fig. 1. Experimental test bed (Renault K9 K ICE and dynamometer)

The ICE used for this study is a Renault K9K. Engine's specifications and performance characteristics are: total displacement 1461 cm^3, maxim power 66 kW (at 4000 min^{-1}), maxim torque 220 Nm (at 2000 min^{-1}) and compression ratio of 15.5:1.

The DynoRoad 202 dynamometer is an asynchronous AC machine equipped with a converter power module IGBT (Insulated Gate Bipolar Transistor) for direct connection to mains voltage. Power module uses a hybrid interface that facilitates control over engine torque and speed.

2.2 Model in the Loop

The Model in the Loop (MiL) simulation captures the specified behavior of the model that is to be implemented in C code.

The V model (Fig. 2) represents a development process that may be considered an extension of the waterfall model, and demonstrates the relationships between each phase of the development life cycle and its associated phase of testing [4].

The basis for this development is the well-established V model that is one of the standard approaches in automotive software development [4].

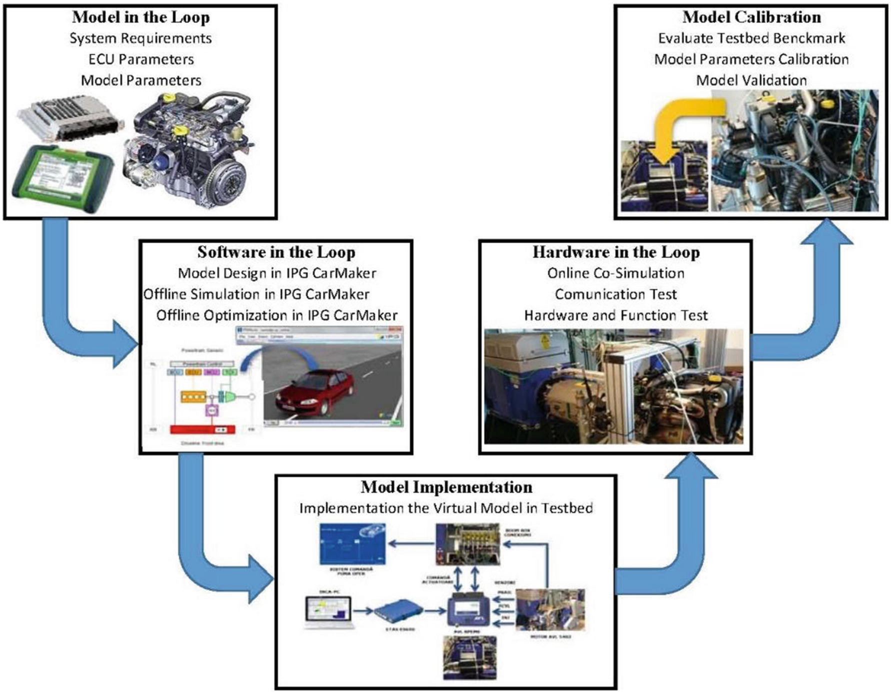

Fig. 2. Structure of the V model for X-in-the-Loop (XiL) simulation procedures

2.3 Software in the Loop

Software in the Loop (SiL) is the inclusion of compiled production software code into a simulation model. In SiL phase, the actual production software code is incorporated into the mathematical simulation that contains the models of the physical system. This is done to permit inclusion of software functionality for which no model exists, or to enable faster simulation runs.

SiL means the code is generated and it replaces the controller blocks in the same simulation model. The simulation results should be widely identical when compared to the results of MiL simulation.

The IPG CarMaker platform is a virtual driving environment that offers a wide range of applications from SiL operation to HiL tests. IPG CarMaker was designed to support the development process from an early conceptual stage to hardware prototype testing [5].

AVL InMotion is a solution for define the maneuver based on IPG CarMaker product to which AVL adds SiL interfaces for different kinds of Units Under Test UUT (Engine, Powertrain, Transmission etc.) [6, 7].

A virtual vehicle is a computer-modeled representation of a real vehicle with a behavior that matches that of its real world counterpart. The model is parameterized with data that relates directly to the vehicle to be studied (Fig. 3).

Linked to the models for the virtual vehicle AVL InMotion contains three-dimensional road models and a fully parameterized driver model (IPGDRIVER) that is able to perform closed loop maneuvers up to the stability limits. The simulation of arbitrary traffic scenarios allows the user to conduct virtual driving tests overland and in the city, that are exactly reproducible [8].

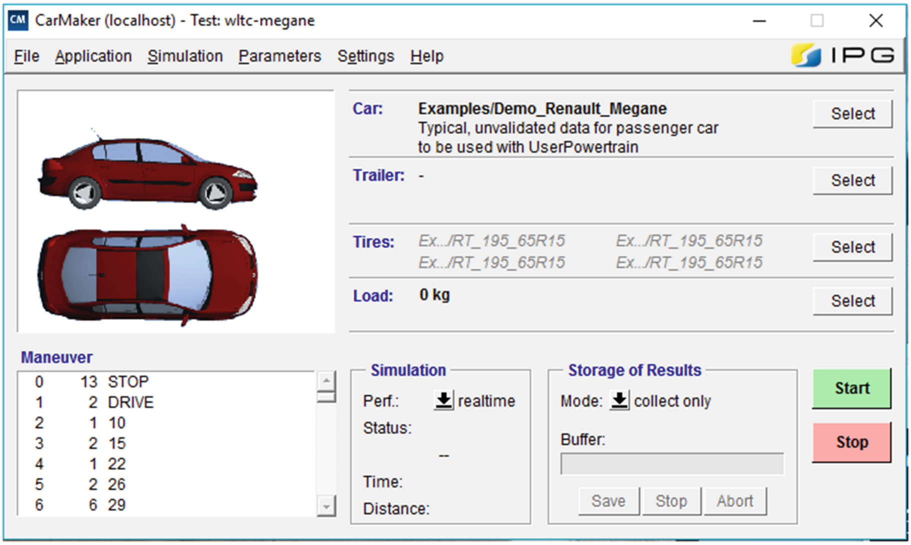

Fig. 3. IPG CarMaker simulation model

By this approach it is possible to use IPG CarMaker to test any vehicle with a validated parameter set, and to easily switch between virtual vehicles by changing the parameter data that are used in the vehicle model. The virtual vehicle contains all parts of a real vehicle, including powertrain, tires, chassis, brakes, etc. It is also easy to integrate real automotive controllers (ABS, ESP, and ACC) or software modeled controllers into the virtual vehicle by using HiL or SiL [8].

The main component of hardware is the real time computer running the IPG CarMaker. The executable is configured in way that not only allows communication between the host computer (network card) and test bench (I/O modules), but a third part is configured for communication with the AVL InMotion over a CAN bus to experimental test bed.

The second piece of hardware is the host computer. It is set up exactly as in the simple HiL configuration, except tools such as the AVL InMotion GUI or user defined scripts are used to control the actions of the AVL InMotion.

The third piece of hardware is the test bench, which has been modified to allow a direct connection to the real time computer, or to the AVL InMotion, or to a combination of both the AVL InMotion and the real time system. Adding or making changes to the cabling does the modification of simulation environment.

The fourth piece of hardware is the AVL InMotion, which is configured to allow the selected signals to be passed from the test bench to the real time system. The AVL InMotion is told what to do through CAN communication to the real time computer, which gets its instructions from user-defined commands or from the host computer through the AVL InMotion dialog controlled by mouse clicks [9].

2.4 Model Implementation

The main characteristics of the WLTC class 3 (ver. 5) are given in the Table 1, and the vehicle speed and acceleration are shown in Fig. 4 [10].

Table 1. Characteristics of the WLTC class 3 (ver. 5) [10]

Cycle phase	Cycle duration s	Stop time s	Distance m	Max velocity km/h	Mean velocity km/h	Min acceleration m/s^2	Max acceleration m/s^2
Low	584	156	3095	56.5	25.7	−1.47	1.47
Middle	433	48	4756	76.6	44.5	−1.49	1.57
High	455	31	7158	97.4	60.8	−1.49	1.58
Extra High	323	7	8254	131.3	94.0	−1.21	1.03
Total	1800	242	23262	–	–	–	–

WLTC class 3 was implemented by maneuvers. Maneuver is the concept of IPG CarMaker for the driving scenario (Fig. 5) and it is following maneuver definition, which is split into several maneuver steps (acceleration, braking, stop etc.) [8].

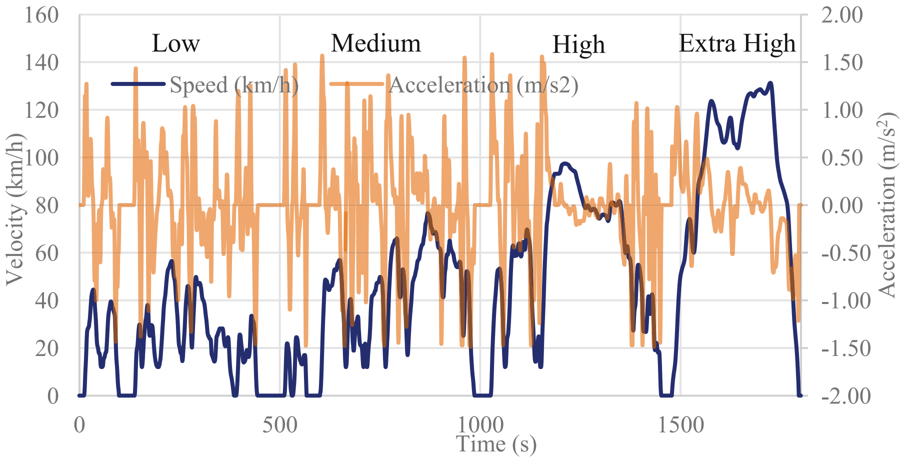

Fig. 4. WLTC class 3 (ver. 5)

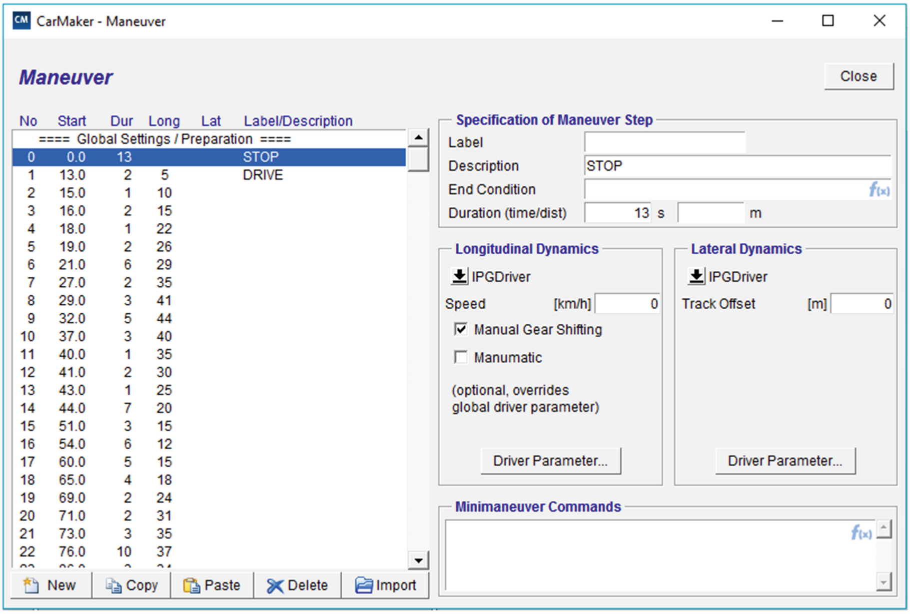

Fig. 5. Maneuvers for WLTC class 3

2.5 Hardware in the Loop

Hardware in the Loop (HiL) simulation is rapidly evolving from a control prototyping tool to a system modeling, simulation, and synthesis paradigm combining many advantages of both physical and virtual prototyping [11].

Through comparing the real-time simulation of the motor driving system with the experimental results of the test bench, as well as analyzing the HiL simulation results of the entire vehicle model, this paper verifies the accuracy and effectiveness of this HiL simulation and test platform.

HiL preceded the PiL (Processor in the Loop) is a real-time simulation technology which runs the simulation model using a real-time processor and simulates the motion state of the controlled object in conjunction with some hardware. It connects the under-test Electronic Control Unit (ECU) through an I/O port and conducts a real-time test to the control strategies and control algorithms that are constructed [12].

The communication between AVL InMotion and the experimental test bed is done using Controller Area Network (CAN) line (Peripheral-CAN). The Peripheral CAN line realizes the communication with powertrain components. In addition to this CAN line, several signals from sensors are fed into the system using analog and digital IO (and vice versa with actuator signals to powertrain components) [13].

The ECU receives signals from the sensors and controls the ICE (Internal Combustion Engine) of the experimental test bed. The dynamometer is an electrical drive controlled by AVL P400 EMCON and is used to establish the simulated rotational speed at the crankshaft of the ICE.

Puma Open is the operating system for command and control execution testing tasks at the experimental testbed [13]. Through the CAN communication interface the Puma Open system realizes the data exchange with the ECU and with the other interaction points in the communication process of the control and command system.

The difference between MiL, SiL, PiL and HiL during the simulation process are described in Table 2.

Table 2. The difference between MiL, SiL, PiL and HiL

Type	Technique	Controller	Explanations
MiL	Model in the Loop	Modelled ECU	All models are made in simulation tool
SiL	Software in the Loop	Code Generated ECU	Part of model in simulation tool, part in executable code (virtual ECU)
PiL	Processor in the Loop	Physical ECU	Part of model runs in Real Time simulator, part in physical hardware
HiL	Hardware in the Loop	Physical ECU and ICE	Part of model runs in Real Time simulator, part in physical hardware

HiL uses this proposed virtual model designing of a real time model, which will additionally generate engine speed as output, depending upon throttle valve opening percentage, gear position, vehicle speed, etc.

3 Conclusions

This paper underlines a number of advantages for MiL, SiL, PiL and HiL: reduce costs to build a model able to change the structure of the model at any stage of the project and adapt the characteristics of the model requirements imposed in a short time.

In the standard HiL configuration the hardware controller is interfaced to the system sends and receives data exactly in the same style as if installed in a real vehicle.

The paper present that there is a reliable solution available for future vehicle's homologation requirements, putting together hardware and software solutions (produced by different companies). The methodology presented in this paper aims to give a predictive solution, fast one, of the hottest theme in research at the moment. Using a "mixture" of road and laboratory test will be possible to achieve immediate data regarding the vehicle pollution level, in term of day-by-day use (according to usually route pattern).

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