Light Vehicles Test Procedures on an Automated Engine Test Bed

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Abstract: The vehicle test procedure provides a strict guidance regarding the conditions of dynamometer tests and road load, gear shifting, total car weight, fuel quality, ambient temperature, and tire selection and pressure. Designed as a tool for testing vehicles fuel consumption and emission these tests are usually conducted on expensive and infrastructuraly demanding road dynamometers. This paper presents a method for conducting tests like NEDC or WLTC on an automated engine test bed equipped with high dynamic dynamometer in a manner which provides very similar testing environment. Particularly from the educational point of view, this approach, combining simple mathematical modelling, automated engine test bed and software testing and measurement environment like AVL Cameo, provides numerous possibilities in demonstrating engine operation in a virtual but, by performance, fully realized vehicle.

Keywords: Cameo, Engine test bed automation, Engine testing and measuring, LabVIEW, NEDC, WLTC.

1. Introduction

Around the world, road vehicles have to comply with limit values for their fuel consumption and pollutant emissions. Hence, there are many driving cycles, such as NEDC, FTP75, US06 SFTP, JC08, *etc.* [1], derived from numerous research projects in Europe, Japan, India and USA in the past forty years. Light duty vehicles and motorcycles are tested on a chassis dynamometer test bench and heavy duty vehicles on the engine test bench.

In this paper, only NEDC and WLTC Class 3, version 5.3 will be analyzed, as a typical example of applied driving cycle on an automated engine test bed in the past few years.

Because of the nature of these driving cycles, *i.e.* their dynamics, especially upcoming WLTC driving cycle, it is impossible to simulate any of the driving cycles by using such manual methods of engine testing. Therefore, the whole test bed system has to be fully automated in order to perform the predefined engine testing procedure.

Hence, the Internal Combustion Engines Department (ICED) at the Faculty of Mechanical Engineering (FME), University of Belgrade, recently obtained ROTRONICS engine test bed with SCHORCH AC asynchronous machine [2], it is now possible physically to perform both, static and dynamic engine testing, which is the main prerequisite. So, to make this test bed fully automated, AVL CAMEO software [3] for engine testing and measurements and calibration is used, together with NI LabVIEW software that provided entire MODBUS TCP/IP protocol [4] communication between CAMEO and ROTRONICS. Table 1 [5] shows some of the main characteristics of the analyzed driving cycles.

Table 1. Driving cycles

Cycle name	Total time [s]	Distance [km]	Average speed [km/h]
NEDC	1180	11,013	33.6
WLTC Class 3	1800	23,266	46.5

2. Driving Cycles

The NEDC driving cycle is used as reference one for homologating vehicles until Euro 6 norm in Europe [6]. It consists of an urban part, called ECE, which is repeated four times and extra urban part, called EUDC.

This driving cycle is widely criticized for its inconsistency with real driving conditions. As a matter of fact, accelerations are very soft, there are a lot of idle events and constant speed cruises. This means that is impossible to obtain certified values when the vehicle is driven in real life conditions. That is why the new test cycle and procedure are being developed, and it will probably appear for the upcoming norm Euro 7.

The WLTC driving cycle is developed by experts from the European Union, Japan, Korea and India [7] with a final version expected by October 2015. It is divided into three classes [5] depending on the Power To Mass Ratio (PMR) of the vehicle:

- Class 1, PMR<=22 kW/t.
- Class 2, 22 kW/t <PMR<=34kW/t.
- Class 3, PMR>34 kW/t.

For the current vehicle stock in Europe, Class 3 is of highest importance and therefore is the object of analysis in this paper. There are two versions of this cycle, 5.1 and 5.3, depending on vehicle's maximum speed. Since that limit is 120 km/h, it is clear that most of the manufactured vehicles in Europe are beyond this limit, hence belong to version 5.3.
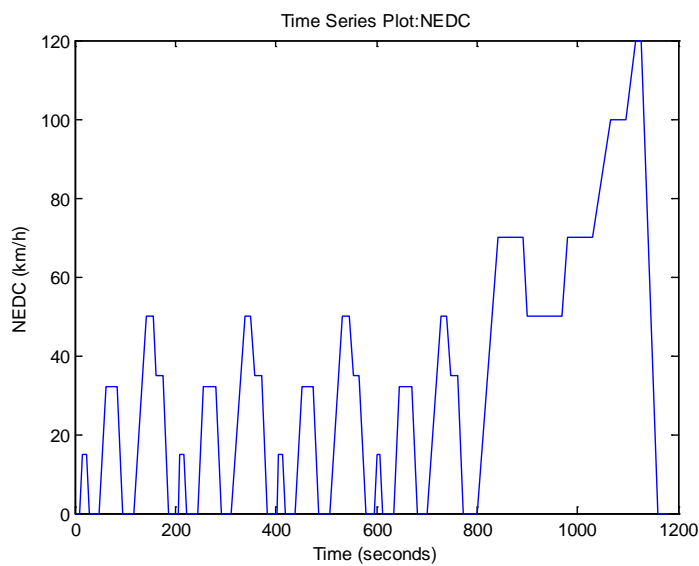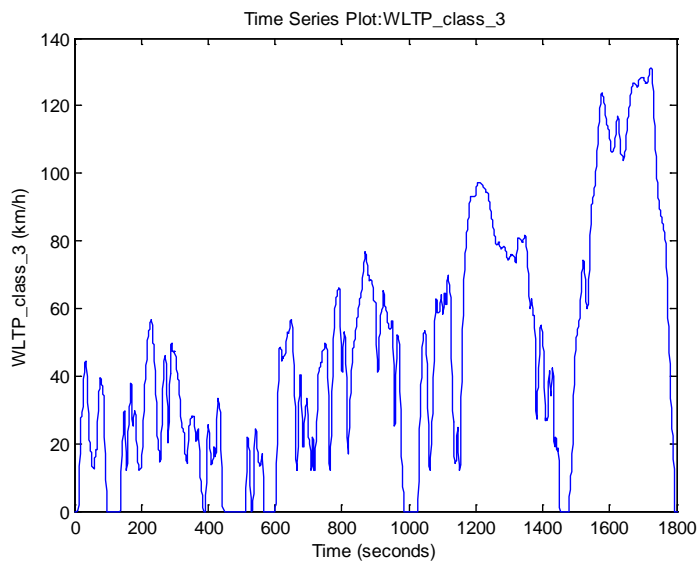

Figure 2.1. NEDC driving cycle

Figure 2.2. WLTC driving cycle

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It is evident that these two driving cycles have very different dynamics and therefore, the WLTC cycle causes bigger fuel consumption and pollutant emissions.

2.1. Cycle Modeling

Since all driving cycles are given as vehicle speed versus time function, for light duty vehicles, it is necessary to transform that dependence into effective or indicated engine torque versus engine speed in order to define entry parameters for AVL CAMEO. Depending on a number of variables included, models can be very complex. Here will be used simple methods of mathematical modeling of the driving cycles to make the transformation process more efficient and less time consuming.

The model is created in MATLAB programing environment. The MATLAB code performs the transformation process consequently in two stages. First stage consists of defining new vector, which represents engine RPM (Revolutions Per Minute), for the given vehicle's speed. The calculation is done backwards, from the vehicle's wheel to the engine crankshaft, for the given vehicle's configuration, *i.e.* gear shift ratios and the moments of gear shifts, defined by the driving cycle. For the purpose of showing the functionality of the calculation, it is conducted for the data of Citroen C1 1.4 HDI, 2005 vehicle [8].

The second stage of the calculation is carried out in order to define the vector of engine effective torque, depending on the vehicle's speed. Using the vehicle equation of motion, it is possible to determine losses due to vehicle motion.

$$m_v \cdot \frac{dv_v}{dt} = F_t - \left[F_a + F_r + F_g + F_d \right]$$ (1)

Based on defined losses, the required traction force can be calculated. For the constant vehicle speed, the first component of the equation is 0. When the tractive force is finally defined, required power on the wheels can be obtained and after that, again using backwards calculation, engine effective power and torque is eventually determined.

In the end, the final two vectors, derived from previous calculations, are the engine effective torque and engine speed. They form the required map, or lookup tables, as an input to AVL CAMEO software.

In order for more influencing factors to be taken into account during simulation, a parallel set of data is prepared through a high-fidelity vehicle simulation conducted in the AVL CRUISE environment. Sketch of the vehicle and powertrain model is presented on the Fig. 2.1.1., while the engine speed – torque data dependency, obtained through simulation, is presented on the Fig. 2.1.2.
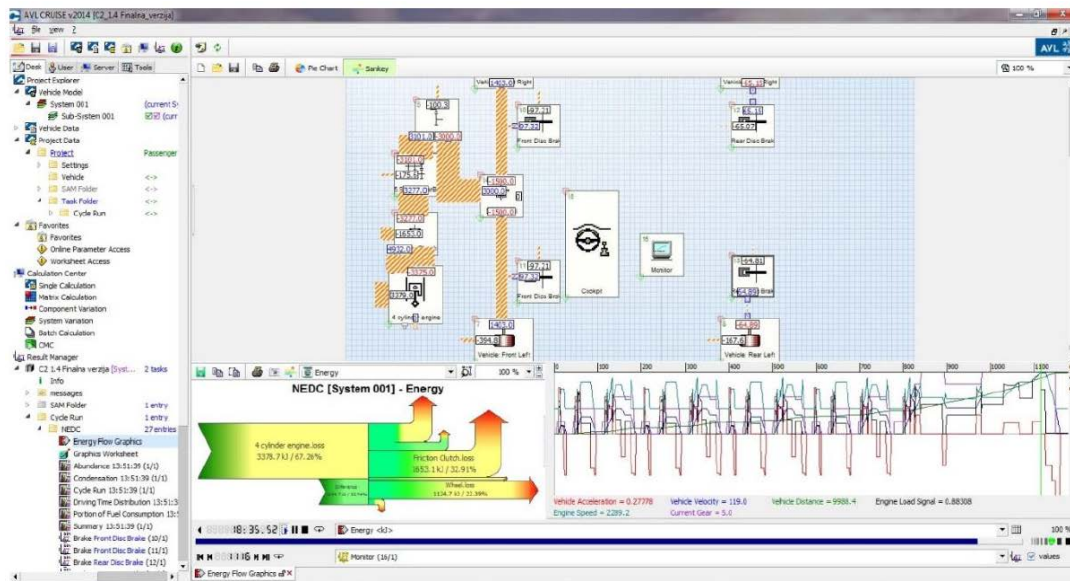

Figure 2.1.1. AVL CRUISE working environment (Energy flow analysis of the simulated model)
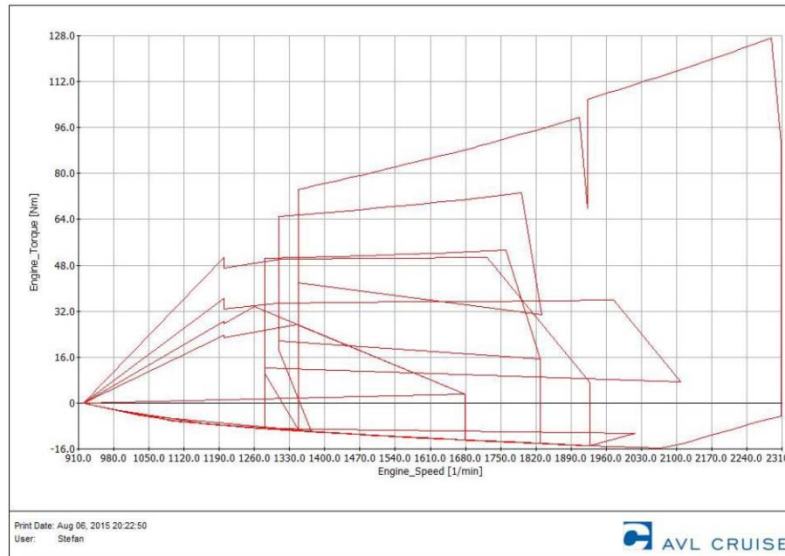
Figure 2.1.2. Obtained engine torque and speed demand values through the AVL CRUISE model simulation

2.2. Cameo

AVL CAMEO is a powerful tool that gives you one window onto handling various tasks in terms of engine testing, measuring, calibration, *etc.* For the purpose of engine testing by predefined driving cycle, AVL CAMEO Test&Measure software is used. It contains all the best-in-class features required to run automated tests created using design of experiments (DOE) method.

Whatever is done in CAMEO, it is recorded in predefined database, without which is impossible to enter into the first step of CAMEO workflow. There are four steps in CAMEO workflow [3]. The first step represents *Project Administration* and it enables you to create projects, designs, tests, test configurations and sequences, connection to the particular external system and eventually model evaluation after successful execution of the test. Every test defined in the project needs a system to be assigned. In the system settings, communication to the automation or application   systems is established. Here, it is also possible to import and manage system and its data and all channels through which CAMEO communicates with the *e.g.* automation system like ROTRONICS. Creating a test is done also in the first step. Here can be set procedure of the DOE, *i.e.* one or multilayer designs, and its numerous variants. Through the TCP/IP protocol, CAMEO can also communicate with the LabVIEW, which is the main communication block between CAMEO and ROTRONICS in the ICED laboratory.

Preparing test is the second step which allows test run parameters and global parameters to be specified. It defines every operating regime of the test through the engine passes. It is the trickiest workflow step in CAMEO because any irregularly specified parameter could lead to fatal breakdowns of the engine and automation system. Fortunately, CAMEO possess always active pre-processor that constantly searches for those irregularities and prevents the test from being executed. There are also numerous settings, such as ramp and stabilization time, limits and actions in case of reaching some critical value, that significantly contribute to safety of engine testing.

After the successful completion of preparing test workflow step and test execution, all measuring channels, previously set to be recorded in Prepare Test step could be viewed and analyzed by the user. Those channels can also be monitored during the test itself. From the point of view of engine testing in educational purposes, this part of the CAMEO fully satisfies requirements from the user and represents only small part of the actual abilities of CAMEO. But speaking of modern methods of engine testing, e.g. online calibration of ECU parameters, that is the point from which CAMEO shows full spectrum of its possibilities [3]. Therefore, performing the test defined upon NEDC or WLTC driving cycle in educational purposes is greatly simplified.
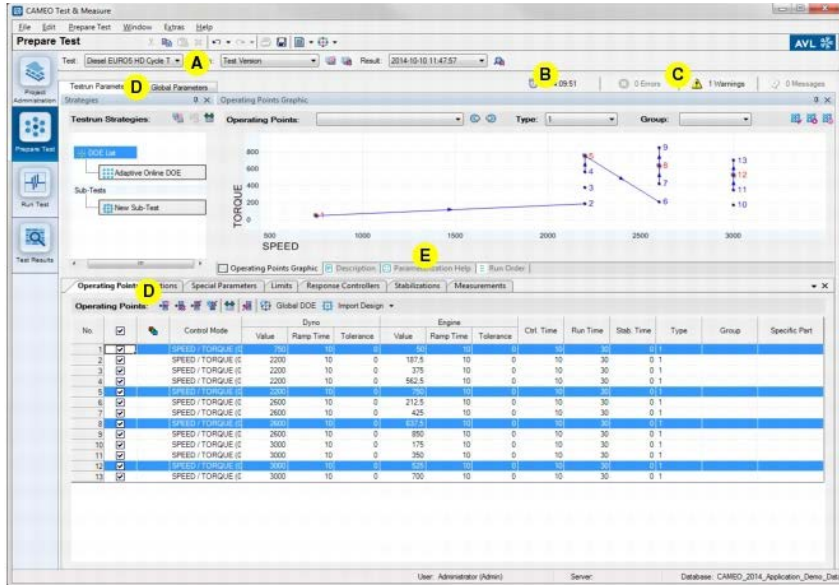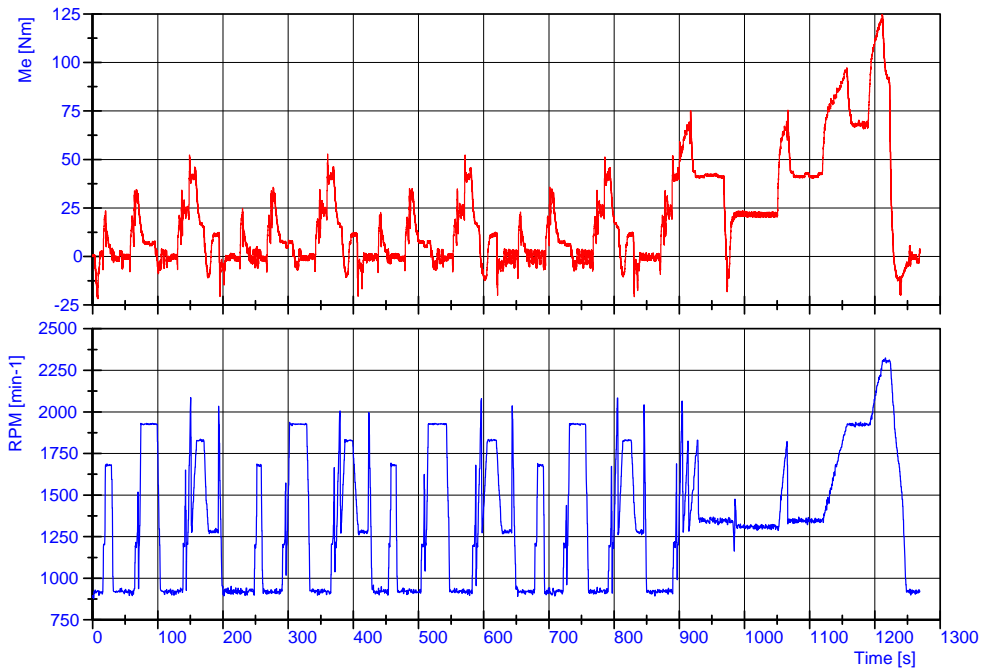
Figure 2.2.1. CAMEO working environment

Figure 2.2.2. Realized dynamic testing of the PSA DV4TD engine on the ICED engine test-bed.
(Virtual testing of the Citroen C1 1.4 hdi vehicle through the NEDC driving cycle)

3. Conclusion

In the past twenty years, the internal combustion engines and controlling of their parameters became very complex and it is impossible to make any further improvement in this field of engineering without a DOE method of engine testing and especially optimization. Hence, it is obvious that without fully operational and automated engine test bed, not a single engine cannot be optimized to meet more and more strict exhaust gas emission and fuel consumption regulations prescribed by European institutions.

Nomenclature

Latin symbols

m_v – Mass of vehicle in [kg].

$\dfrac{dv_v}{dt}$ – Acceleration of vehicle in [m/s^2].

F_t – Tractive force in [N].

F_a – Wind drag force in [N].

F_g – Inclined road force in [N].

F_r – Rolling resistance force in [N].

F_d – Other losses in [N].

Acknowledgements

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