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THE PRINCIPLES OF ENGINE OPERATION SIMULATION IN TEST-BENCH EXAMINATION IN THE CONDITIONS EQUIVALENT TO TRAFFIC EXPLOITATION OF THE VEHICLE

In this paper, the Author presents a method of simulating various "test ride" scenarios for an automobile tested on engine test bench. The research possibilities offered by the semi-virtual system consisting of a real engine and vehicle motion simulator are underlined. The Author also describes the method of performing tasks in basic phases of vehicle testing. The following article by the Author, "The method of executing simulation procedures on engine test bench in traffic tests of combustion engines", will present requirements concerning test accuracy, structure and equipment of the test stand, and the characteristics of software that controls the tests and supervises its outcome.

1. Introduction

1.1. Steady state engine tests versus examinations of transient processes

Traditional examinations performed on engine test bench have been uses, almost exclusively, to determine various quasi-static characteristics of the engine. This kind of tests has been carried out due to the standards specified by State Norms [1]. The principle of such tests is that each point of a characteristic is defined only after the "steady state" of engine operation is reached. It means [6] that the parameters of the state of action[1)] are as follows:

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1) The parameters of engine operation state are defined as multi-cycle mean values of the variables T_s, n_s, Q, M_s. In dynamic conditions, the values of these parameters obtained by measurement are not unique, as they depend on time constants of measuring devices. Then, there still is a need for a more precise specifications, especially in the case of multicylinder engines.

– engine temperature T_s=const.,
– moment generated by engine M_s and the degree of admission Q that directly determines it, Q=const. $\Rightarrow$ M_s=const.,
– loading moment M_{ob}=const.,
– engine rotational speed n_s=const.

Obviously, according to d'Alembert equation, the following relation holds

$$M_s - M_{sw} - M_{ob} = 0 \quad (1)$$

where M_{sw} – moment of resistance (of self losses) of the engine.

Denoting

$$M_e = M_s - M_{sw} \quad (2)$$

as the usable moment (formerly known as the effective one), that is the moment measured on flying wheel, we get the following general equation of motion of the engine-receiver system

$$M_e - M_{ob.} = I_z \cdot \varepsilon_s \quad (3)$$

where: I_z – equivalent mass moment of inertia of the system, reduced to flying wheel

ε_s – angular acceleration of crankshaft.

With the condition $\varepsilon = 0$, it reduces to equation (1).

Present and future regulations concerning certification and licencing of vehicles – that decide of allowing the car to ride on public roads – involve more and more rigorous ecological and economical requirements.

The fulfilment of these requirements is verified in special examination tests that are occasionally mandatory in certain countries (for example in the European Union, in the USA), and are updated after a certain period of time (each 5 years in the USA, for instance).

The State Norms specify requirements that are binding at that moment, and prognosticate the changes that might be introduced in future.

The tests are carried out on engine test bench in order to measure the so-called "speed profile", during which the engine runs with the speed changing according to a specified function.

$V=V(t) \neq$ const.

The tests consists then of a series of transient states of vehicle engine operation. Even in the intervals when engine speed is constant one can hardly assume steady state of engine operation, because temperature of the engine T_s still changes due to a short duration of the test.

This reasons, and other motivations related to eg. engine life, have induced an increasing interest in testing the engines in dynamic states, conventionally called the "unsteady" ones, that means examining the transient processes. In these states, one can not only determine a number of dynamic properties of the engine, but also find the differences in engine performance in reference to the "steady state" conditions.

1.2. Advantages of certification tests on engine test bench

Various road tests, such as these shown in Figs 1-3, are generally performed on standard, well-equipped chassis-based engine test benches, with high level of automation.

Road tests consist of standard processes of constant sped ride, acceleration, slow-down, braking the vehicle, and idle run of the engine. All phases of the test are defined by the Norm. The best illustration of the test is the "speed profile" [5], a diagram of time function of vehicle velocity. The diagram of gear switching in the transmission system during the test is also included.

Example speed profiles are presented in the Figures below.

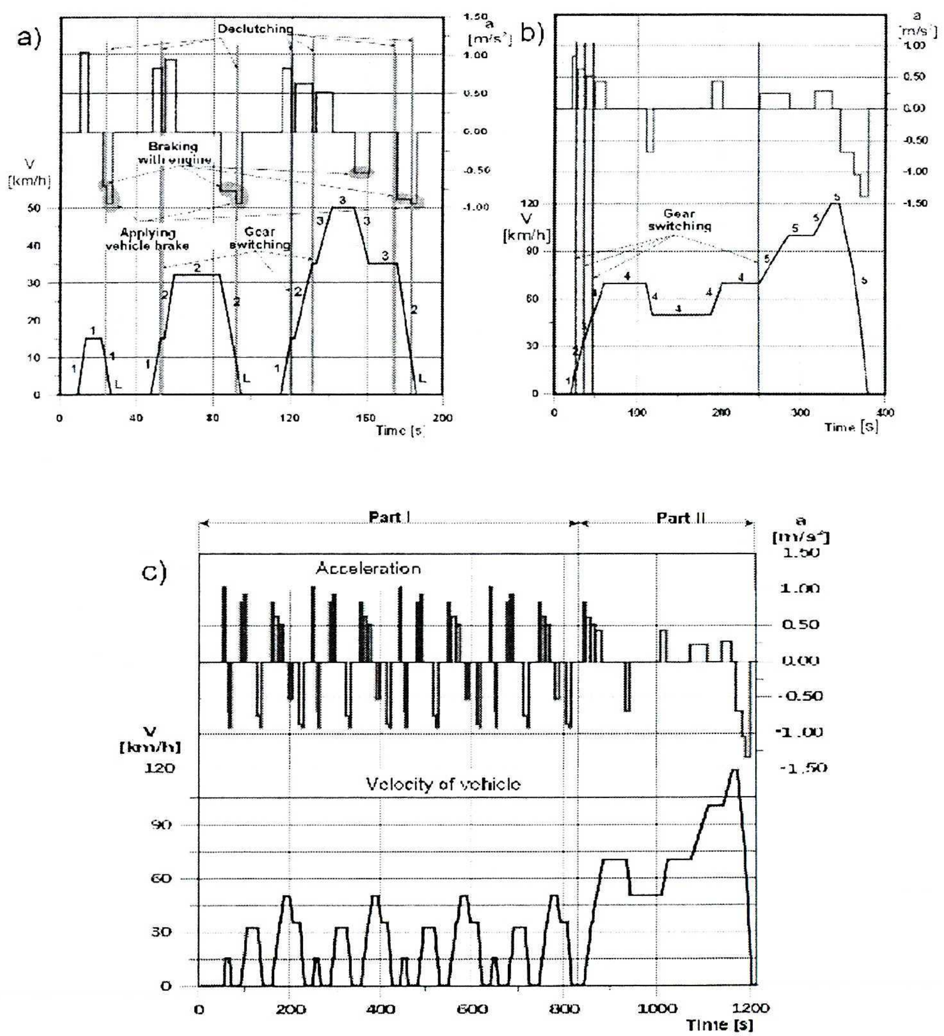

Fig. 1. The ECE R83 test (a – first part, b– second part, c – all test)

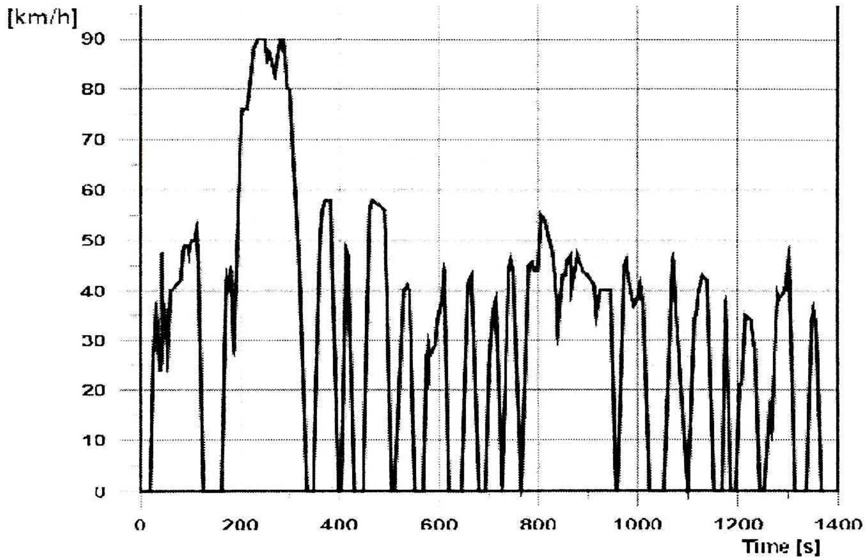

Fig. 2. The US Federal test

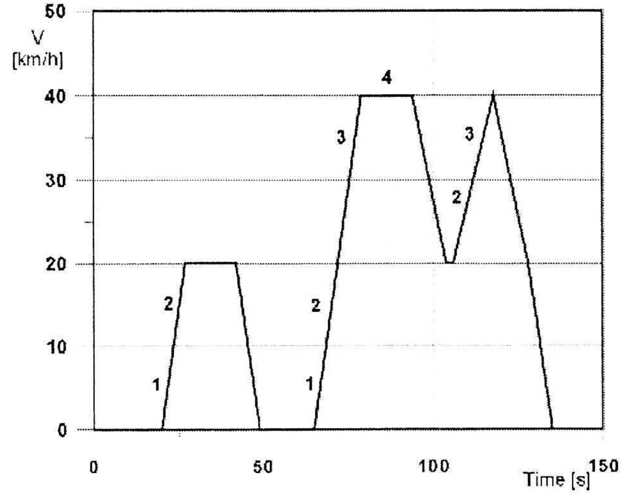

Fig. 3. The Japanese test (single run)

The aim of the examination is to determine whether, in the conditions of the "velocity profile" specified by the Norm, the vehicle fulfils certain requirements. These concern environment protection (ie. emission of toxin in exhaust gases and/or noise level), and take into account economical factors – namely limitations of fuel consumption.

When the opportunity occurs, in a way, one examines the ability of the vehicle to meet the "traditional" requirements of the test, such as the ability to develop assumed acceleration and speed.

All these requirements concern primarily the engine, and secondarily the power transmission system of the vehicle.

Schematic diagram of the test set-up is presented in Fig. 4. The elements denoted with broken lines are optional, the solid lines denote necessary parts of the set-up.

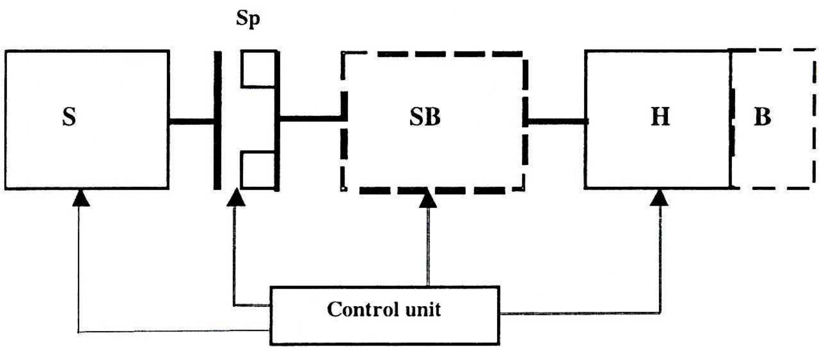

Fig. 4. Scheme of the structure of test set-up. S – engine, Sp – clutch, SB – gear box, H – brake, B – inertial load

Test simulation on the test bench is undeniably purposeful. It is very advantageous in every aspect, if one takes into account both testing costs and ease of performing the examination. In this semi-virtual system, the engine is a real object, the vehicle is replaced by its model, and the process of driving is simulated by controlling the settings of engine brake moment, according to the model of vehicle motion resistance. The structure of such a system is implicitly logical, as the modelling of vehicle motion is definitely much easier than the modelling of engine processes.

2. Purpose of examinations on engine test bench

In order to perform the tests on engine test bench in a proper way, one must have an engine brake with programmable control system. Nowadays, the dominating types of automotive engines are the microprocessor controlled ones. The problem of tests can then be reduced to proper modelling of "test ride" processes, that means applying software providing a real-time control of the settings of engine steering gears and the engine brake.

If the test set-up is equipped with a gearbox, and the test procedure includes switching the gears whose transmission ratios are identical to those in the actual vehicle, the influence of vehicle mass can be simulated by an inertial load coupled kinematically with the brake. The constant mass moment of inertia of the inertial load can in such a case be determined from the relation

$$I_b = \frac{m_c r_d^2 + I_p}{i_g^2} - I_H \tag{4}$$

where m_c – total mass of vehicle,
r_d – dynamic radius of vehicle tyre
i_g – equivalent mass moment of inertia reduced to vehicle drive wheels and rotating elements in power transmission system,
I_H – mass moment of inertia of brake.

Application of the gearbox in the test stand requires a transmission controller to be installed, with software that executes gear switching in accordance with the specifications of the test.

The gearbox is not a necessary element of the measuring set-up, because the software that controls the test can perform simulation of the changes of transmission ratio. In such a case, it is only necessary that the program controls operations of clutching and declutching.

An extraordinary feature of examinations performed on a test bench is the possibility of simulating the test even in the case when there is no real vehicle available, for example when it is still in the phase of design. The possibilities of test bench examinations are not limited to certification tests; one can also

– determine the limits of traction abilities of the system consisting of the examined engine and a vehicle being designed,
– rationalise transmission ratios in the power transmission system of the vehicle according to specific assessment criteria,
– examine usability of the tested engine to application in various vehicles, and determine functional qualities of the system engine – modelled vehicle,
– realise arbitrary scenarios of test drive simulation within the limits of traction abilities of the system engine – vehicle.

The range of examinations that can be performed in a computer-controlled measuring position is much wider than that of the conventional chassis-based engine test benches. Moreover, actual traffic tests would never be so easy to perform as the tests of semi-virtual type.

The universality of tests in a semi-virtual system Environment-Driver-Engine-Receiver (EDER) is not to be compared to that of tests performed on actual vehicles. At the same time, the costs of examination are much lower, because once the engine test bench is assembled, the main task is to develop control software.

3. Modelling the EDER system

3.1 Model of vehicle and environment

The fundamental equation of the EDER system [2, 3] is the equation of moments of vehicle motion resistances. The moment of resistance, reduced to the axis of driving wheels, is the sum

$$M_{op}=M_t+ M_w+M_p+M_u+M_{sk}+M_h \tag{5}$$

then, it is the sum of moments of rolling resistance M_t, grade resistance M_w, air resistance M_p, towing resistance M_u, turning resistance M_{sk} and breaking resistance M_h, respectively.

The sum of first three components is called the moment of ride resistance M_{oj}.

The moment of engine counterbalancing the resistance of ride equals (without taking inertial resistance into account)

$$M_{oj}= C_o+C_1V^2 + C_2V^2 \tag{6}$$

while

$$C_0 = m_c g \frac{r_d}{i_g i_{bi} \eta_{bi} \eta_g}\left[f_t \cos\alpha_w + \sin\alpha_w\right]$$

$$C_1=0 \tag{7}$$

$$C_2 = m_c g \frac{r_d}{i_g i_{bi} \eta_{bi} \eta_g}\left[k\cos\alpha_w + \frac{1}{2} A c_x \rho\right].$$

Equations (7) include the parameters of the vehicle model,

m_c – vehicle total mass,
r_d – dynamic radius of driving wheel,
i_g – transmission ratio of main transmission,
i_{bi} – transmission ratio of transmission box at i^{th} gear,
η_g – mechanical efficiency of power drive on the way from transmission box main shaft at i^{th} gear,
A – front surface of car,
C_x – coefficient of air head resistance,

as well as the following "environmental" parameters:

α_w – angle of longitudinal inclination, characterising profile of roadway,
ρ – air density.

The coefficients of rolling resistance f_t and k characterise both the vehicle and the quality of roadway. The speed of wind can be taken into account in the simulation by taking

$$V = V' - V_w \tag{8}$$

where V' – speed of vehicle,
V_w – speed of wind.

When the ride scenario includes uphill and downhill segments, $\alpha \neq 0$, and longitudinal profile of the roadway is known

$\alpha_w = \alpha_w(l)$

the program that controls the test must calculate the "covered" distance, l(t).

Modelling of towing resistance M_u is similar to ride resistance modelling in the case when a trailer of known parameters is towed. However, braking resistance M_h, and turning resistance M_{sk}, the latter appearing on curvilinear trail, need a different kind of modelling.

3.2. "Model" of the driver

The vehicle equation of motion is

$$M_c - M_{op}^{(s)} = am_c \frac{r_d}{i_g i_{bi} \eta_{bi} \eta_g} + \left(I_p^{(s)} + I_s\right)\varepsilon_s \tag{9}$$

In this version of the equation, all the moments are reduced to the axis of flying wheel, and the following denotations are used:

I_s – mass moment of inertia of crank-piston system and flying wheel,

$I_{pi}^{(s)}$ – equivalent mass moment of inertia of masses rotating in the power transmission system at i^{th} gear, reduced to flying wheel,

$$I_p^{(s)} = I_p \cdot \left(\frac{1}{i_g i_{bi}}\right)^2 \tag{10}$$

a – vehicle acceleration at i^{th} ear, given by

$$a = \frac{\varepsilon_s r_d}{i_{bi} i_g} \tag{11}$$

The role of vehicle's driver in performing the tests of velocity profile consists in:

- clutching and declutching the receiver, according to the requirements of the test,
- switching gears at appropriate moments due to test conditions,
- setting the position of accelerator pedal in order to achieve the assumed velocity and acceleration of the vehicle,
- using engine for braking or, additionally, applying vehicle brakes in order to precisely follow the slow-down scheme prescribed in the test.

In the case of tests carried out on an engine test bench, the role of driver is, partly or completely, simulated by the control software.

In the case of partially automated tests, the test-stand operator must, at appropriate moments, manipulate the clutch, and possibly switch the gears – provided the stand is equipped wit a transmission box. In fully automated test stands, the operations of clutching, declutching, and/or gear switching are performed by programmer units controlled by the software.

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Zasady symulacji pracy silnika na hamowni silnikowej w warunkach odpowiadających trakcyjnej eksploatacji pojazdu

S t r e s z c z e n i e

W pracy przedstawiono możliwości badawcze układu silnik rzeczywisty-symulator jazdy samochodu. Omówiono przygotowanie danych do programu sterującego testami, strukturę stanowiska badawczego oraz zasady obliczania nastawów hamulca silnikowego w dwu wariantach stanowiska badawczego:

- układ ze skrzynią przekładniową współpracującą z silnikiem, pozwalający na zastosowanie stałego bezwładnika,
- układ bez skrzyni przekładniowej wymagający obliczania symulowanej hamulcem bezwładności pojazdu.

Kontynuacją artykułu jest praca "Sposób realizacji procedur symulacji na hamowni badań trakcyjnych silników spalinowych"