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THE METHOD OF EXECUTING SIMULATION PROCEDURES ON ENGINE TEST BENCH IN TRAFFIC TESTS OF COMBUSTION ENGINES

In the paper, the Author presents the method of realisation of various scenarios of "test ride" on engine test bench. Research possibilities offered by semi-virtual system consisting of a real engine and a vehicle simulator are described. The previous article by the Author, "The Principles of Engine Operation Simulation in Test-bench Examination in the Conditions Equivalent to Traffic Exploitation of the Vehicle" [7] was devoted to the description of test requirements. Test accuracy, structure and equipment of the test stand were described there, as well as the characteristics of the software that controls the test and monitors its correctness.

1. Introduction

In the previous article, "The Principles of Engine Operation Simulation in Test-bench Examination in the Conditions Equivalent to Traffic Exploitation of the Vehicle" (Archive of Mechanical Engineering Vol. 48, 2, 2001), the Author demonstrated the usability of examinations carried out in a semi-virtual system consisting of an actual engine and a vehicle model. The method of modelling of vehicle characteristics and the "test ride" conditions was described. The present paper concentrates on the method of realisation of the tests, including description of the test stand and some selected typical test procedures. The intent of the Author is to carry out more extensive investigations on the subject, for example by applying neural network software. This tool could make it possible to perform the examinations without intervention of a human operator ("the driver"), who normally supervises the tests.

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2. Realisation of velocity function (simulation)

2.1. Linearization of test accelerations

The cycles of some tests (ECE R83 or Japanese test, for example) consist solely of intervals of constant acceleration of the vehicle:

- in the period of increasing speed at k^{th} interval of the test, $a_k = const. > 0$,
- in the period of constant speed, $a_k = 0$,
- during the slow-down period, $a_k = const < 0$.

In the cases of more complicated test ride scenarios, irregular "speed profile" functions can be divided into a series of short intervals that are characterised by a specific acceleration, constant within the interval, $a_k = const.$

The principle of test linearization, proposed by the Author, is illustrated with the graph in Fig 1. If the velocity assumed by the test specifications takes the value V_k at the instant t_k, and V_{k+1} at t_{k+1}, then the equivalent acceleration in the interval equals

$$\overline{a}_{k,k+1} = \frac{V_{k+1} - V_k}{t_{k+1} - t_k} \tag{1}$$

According to what is needed, one can assume time intervals of equal length (when the test specifications determine only allowable speed errors), or variable intervals in the case when an additional criterion of test accuracy is imposed, for example one concerning allowable error of instantaneous acceleration.

2.2. Bringing vehicle up to speed

During the phase when the vehicle accelerates, the required engine moment is given by Equation (9) in [7]. Similarly, the moment of resistance of ride, reduced to the flying wheel, is described by function (6) in the same Reference.

When the test stand is provided with a transmission box, it is purposeful to apply an inertial load of mass moment of inertia given by Eq. (4) in [7].

In the case when the engine and the brake are connected only through the clutch, the inertia of vehicle must be simulated by proper setting of brake's moment of resistance

$$M_H = M_{op}^{(s)} + M_{ob} - I_H \frac{a}{r_d} i_g i_{bi} \tag{2}$$

The value of M_{op} is determined by the right side of Eq. (9) in [7].

The settings of the degree of admission (eg. the position of accelerator lever) must ensure such a value of engine moment M_e that in the interval $t \in \langle t_k; t_{k+1} \rangle$ acceleration $a_{k,k+1}$ could be achieved – according to the cited Eq. (9).

One must also fulfill the control conditions, eg. of brake speed

$$\left| n_{Hrz} - n_{Ht} \right| \le \frac{30\Delta 0_{dop}}{\pi r_d i_g i_{bi}} \tag{3}$$

where $n_{HR}(t)$ – actual rotational speed of brake [RPM] at instant t,
$n_{Ht}(t)$ – rotational speed of brake given by "velocity profile" function V(t),

$$n_{Ht}(t) = \frac{30V(t)}{\pi r_d i_g i_{bi}} \tag{4}$$

ΔV_{dop} – allowable error of test speed realization.

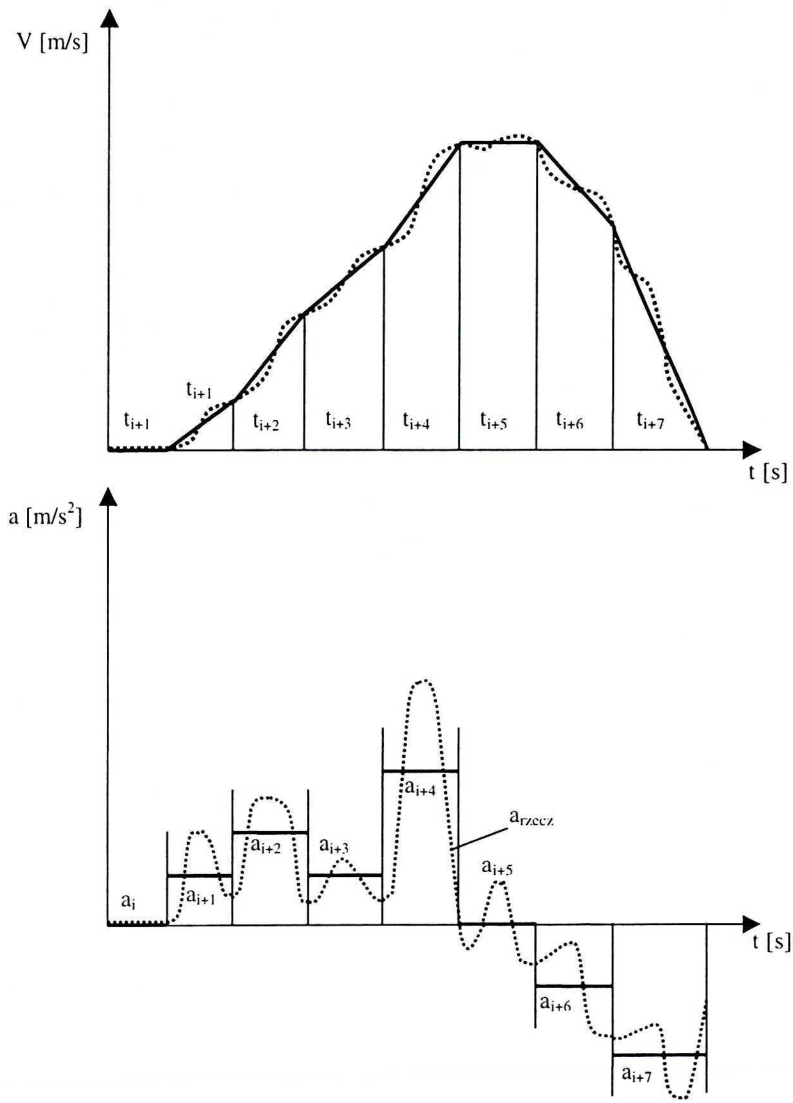

Fig. 1. Linerization of "speed profile" function

2.3. Simulation of gear switching

In the case when the test is carried out with a transmission box mounted in the test stand, switching the gears from the i^{th} to the i+1 takes place at engine rotational speed equal to

$$n_{s1}^{i,i+1} = \frac{30V_{i,i+1}}{\pi r_d i_g i_{bi}} \qquad 1 \le i \le b-1 \tag{5}$$

where b – number of transmission ratios of the box,

$V_{i,\,i+1}$ – velocity at the moment of switching to a higher gear, from i^{th} to (i+1).

Similarly, switching to a lower gear, from the i^{th} to the (i–1), takes place at engine speed

$$n_{s1}^{i,i-1} = \frac{30V_{i,i-1}}{\pi r_d i_g i_{bi}} \qquad 2 \le i \le b \tag{6}$$

Gear switching is performed in the same way as in an actual vehicle, so it is preceded by a simultaneous action of declutching and releasing the accelerator lever. One changes the gear when the engine is declutched. After that, by means of the accelerator, one brings the engine up to the speed

$$n_{s2}^{i,i+1} = n_{s1}^{i,i+1} \frac{i_{i+1}}{i_i} \kappa \qquad 1 \le i \le b-1 \tag{7}$$

when switching to a higher gear, or

$$n_{s2}^{i,i-1} = n_{s1}^{i,i-1} \frac{i_i}{i_{i+1}} \kappa \qquad 2 \le i \le b \tag{8}$$

when reducing the gear.

The coefficient $\kappa \in (1{,}05;1{,}1)$ is applied here [4] because of a speed drop occurring when the engine is declutched after the gear change.

When the test stand is not equipped with transmission box, the "gear switching" operation is simulated at speeds given by equations (5) – (8). On the other hand, the change of equivalent mass moment of inertia of the vehicle appearing in effect of gear change is simulated by the change of brake resistance setting, as described by Eqs. (6) and (7) in [7].

In the case when the course of gear switching process assumed in the "ride scenario" is left to the discretion of the "driver", gear switching to both higher gear and lower gear should be done at engine speed

$$n_{s1}^{i,i+1} = n_H \lambda \qquad \lambda \in (1{,}05;1{,}15) \tag{9}$$

$$n_{s1}^{i,i-1} = n_H \lambda$$

so that it must remain in the range of stable operation of the engine. Consequently, the beginning of engine-to-brake clutching after a gear change should take place at speeds given by Eq. (7) or Eq. (8).

Clutching should be performed smoothly, that means kinematic coupling of clutch plates should ensure, during time interval $\Delta t_{sp} \in (1,2)$ s, a linear increase of moment transmitted by the clutch.

2.4. Riding at constant speed

The engine moment necessary to counterbalance riding resistance in constant speed riding is given by Eq. (6) in [7]. If the speed of wind $V_w \neq 0$ is to be taken into account in the simulation, one must introduce a correction to vehicle velocity, according to Eq. (8) in [7].

In monitoring the speed of engine, one can tolerate an acceptable relative error δ_v, therefore the following condition must be fulfilled at each moment

$$\left| \frac{\omega_{rz} - \omega_x}{\omega_x} \right| \leq \delta_V \tag{10}$$

where ω_{rz} – actual speed of engine,
ω_x – angular speed of engine,

while the speed of vehicle is determined (at i^th^ gear) by the "velocity profile" function

$$\omega_x = \frac{V_x}{r_d} i_g i_{bi} \tag{11}$$

When condition (10) is not fulfilled, the monitoring software must intervene, giving engine controller a command to make an adequate change of degree of admission, ΔQ.

When in evaluating the adequacy of the test one assumes an acceptable error of speed ΔV_{dop}, the control condition is determined by Eq. (2).

2.5. Braking the vehicle

Specifications of the test usually determine the time limits and decelerations of the vehicle during its slow-down phases. For example, in the ECE R83 test (see [7] Fig. 1) action No 4 is a speed change from 15km/h to 10km/h in the time of 2s that is equivalent to a deceleration of

$$\begin{gathered} a_{h4} = \frac{\Delta V_4}{\Delta t_4} = \frac{10-15}{3{,}6 \cdot 2} = -0{,}69\, {}^{m}\!/_{s^2} \\ \varepsilon_{hs4} = \frac{a_h}{r_d} i_g i_{bi} \end{gathered} \tag{12}$$

Deceleration of vehicle can be obtained by engine braking, according to Eq. (13)

$$M_{op} + M_{Sh} = \varepsilon_{hS}(I_p^{(S)} + I_s) \tag{13}$$

where M_{Sh} – engine braking moment,
e_{hS} – angular deceleration of engine in the phase of braking.

If the moment of engine braking M_{Sh}, limited by engine braking characteristic $M_{Sh}(n_s)$ in "idle run" position of the accelerator, is not sufficient to ensure the desired deceleration ε_{hS}, then braking must be aided by applying vehicle brakes.

In the tests on engine test bench, brake action is represented by an additional brake resistance moment M_{Hdod}

$$M_{Hdod} = -\varepsilon_{hS}\,(I_p^S + I_s) - M_{op} - M_{Sh} \tag{14}$$

Vehicle braking can also take place with declutched engine, and then the brake moment must fulfill the equation

$$M_{Hdod} = -\varepsilon_{hS} \cdot I_p^S - M_{op} \tag{15}$$

2.6. Starting and stopping the engine. Warming-up

Starting, and warming the engine up, must be performed according to the tests conditions, at idle run, during a specific time. In the course of the ECE test, the engine should not be stopped after being started, till the end of the test. Usually, engine stall during examinations means that the whole test must be repeated.

2.7. Simulation of vehicle start

Starting the vehicle moving can be done in different ways. On a flat road with hardened surface course, the driver usually [4] brings the engine up to the speed n_f at idle run

$$n_r = \Psi \cdot n_M; \qquad \Psi \in (0{,}4;0{,}6) \tag{16}$$

then, gradually releasing the clutch, couples the engine with power transmission system, and simultaneously increases the degree of admission [6] in order to maintain constant engine speed during the whole clutching process.

When acceleration Q_r of the vehicle that starts moving is determined by the "velocity profile" function, then the time of clutching during the start at first gear is

$$t_{sr} = \frac{\pi}{30}\frac{n_r r_d}{i_g i_{bI} a_r} = \frac{V_r}{a_r} \tag{17}$$

Obviously, clutching effect will take place after rotational speeds of clutch plates are equalised. At the beginning of clutching, the moment of resistance M_r of vehicle starting to move, reduced to engine shaft, should be equal

$$M_r\begin{pmatrix} V=0 \\ a=a_r \end{pmatrix} = C_0 + I_{bI}\frac{a_r}{r_d} i_g i_{bI} \tag{18}$$

where I_{bi} is the equivalent mass moment of inertia of the vehicle (at first gear)

$$I_{bI} = \frac{m_c r_d^2 + I_{pI}}{\left(i_g i_{bI}\right)^2} + I_s \tag{19}$$

When simulating the vehicle "start moving" with applied brake, one must set the moment of resistance

$$M_{Hr} = M_r\begin{pmatrix} V=0 \\ a=a_r \end{pmatrix} - I_H \frac{a_r}{r_d} i_g i_{bI} \tag{20}$$

This moment may remain constant during the start, because the increase of velocity is so small that it does not cause any significant changes in riding resistance.

For example, in the test ECE R83, acceleration of the vehicle that starts moving should be n_r=1.04m/s$^{2\cdot}$ Assuming engine speed n_r=0.5n_M=1500RPM, one gets vehicle speed at the moment of clutching

$$V_r = \frac{\pi n_r r_d}{30 i_g i_{bI}} \tag{21}$$

when r_d = 0.34m, and $i_g \cdot i_b$ = 15, V_r = 3.5m/s = 12.6km/h, the time of clutching is then $t_{sr} = \frac{V_r}{a_r} = 3.37s$

When motion resistances are high, for example when the vehicle starts moving uphill, on unpaved road, etc., the engine must be brought up to a high speed

$n_r = \kappa\, n_M$; $\kappa > 1$

so that the process of clutching takes place in the area of stable operation[1]) of the engine $\left(\frac{\partial M_c}{\partial n_s} < 0\right)$.

Applying such a method of starting the vehicle to motion, one can also utilise kinetic energy of the flying wheel.

3. The test stand

The riding scenario of the vehicle, simulated on engine test bench, creates a number of requirements concerning the equipment of the stand. Besides of common standards of test bench examinations, the following requirements must be met in order to effectively carry out the tests:

1. The brake must be equipped with a programmer allowing for accurate setting of brake resistance, in accordance with the values determined by the control software.

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[1]) The condition $\frac{\partial M_c}{\partial n_s} < 0$ is used only to determine "the area of stability" and pertains to an interval of velocity on quasi-static velocity characteristic of the moment. In dynamic conditions, the partial derivative $\frac{\partial M_c}{\partial n_s}$ does not have unique interpretation.

2. Engine programmer must ensure setting of the position of accelerator lever according to the assumed "velocity profile" function, with adequate accuracy monitored by the control software.
3. The clutch programmer must be controlled according to the commands of the control software. The programmer must ensure that operations of clutching and declutching are performed smoothly.
4. In the case when transmission box is incorporated into the test stand structure, it must be equipped with a device allowing for automatic gear switching. The programmer of this device must work in concurrence with that of the clutch.
5. In some cases, it is purposeful to couple the engine with the brake by means of a transmission. It is necessary in the situation when, for example, maximum rotational speed of the engine, $n_{s\,max}$, is greater that the allowable speed for the brake, n_{dop}. The application of a gearbox of transmission ratio $i_z > \frac{n_{smax}}{n_{Hdop}}$ and efficiency η_z must be taken into account in the algorithms of the test control software.

Schematic diagram of information flow in the test stand is shown in Fig. 2.

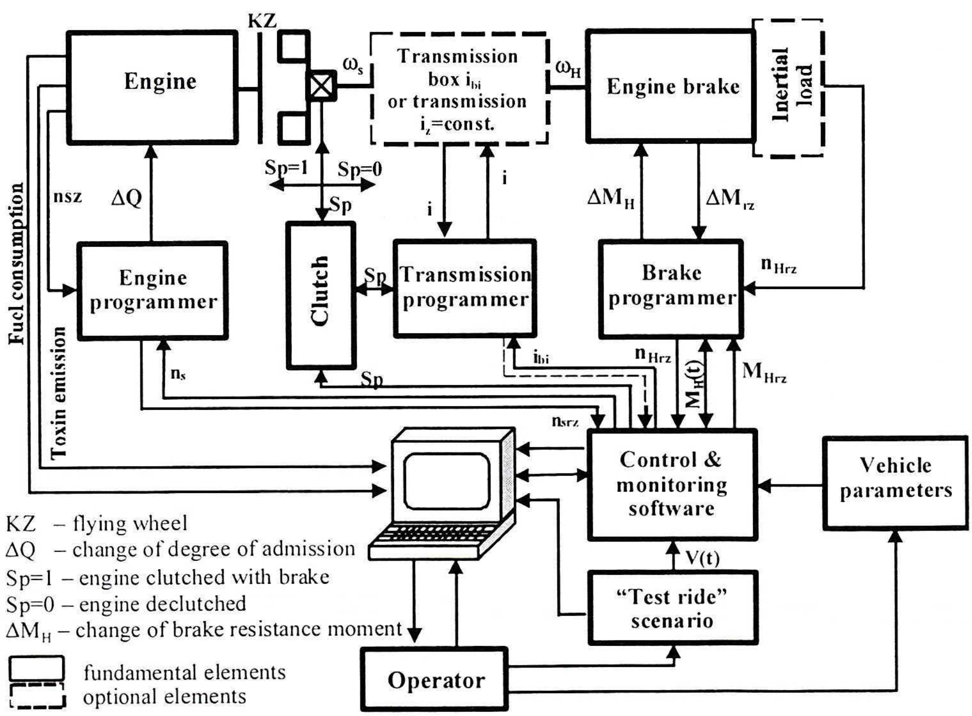

Fig. 2. Scheme of information exchange during traffic test simulation on engine tests bench

4. Control and monitoring software

The necessary prerequisite of successful test performance is an appropriate, well designed software that controls the engine, the clutch, gear switching in the transmission box (optionally), and monitors the correctness of realisation of the simulated "test ride" scenario.

The diagram in Fig. 2 illustrates the tasks of the software. The software algorithms must allow for calculation of the following quantities in consecutive time intervals:

- rotational speed and acceleration of the engine and the brake, according to the vehicle "velocity profile" function,
- current clutch operation status, $S_p=0$ or $S_p=1$, or engine-brake clutching status, $0<S_p<1$,
- current position of transmission box,
- current value of brake resistance moment.

The instrumentation of the test bench must also allow for measurement and registration of current values of rotational speed for the engine and the brake.

All these values of operation status of the engine, brake, clutch, and (optionally) transmission box must be stored in memory, and compared with the expected values, according to the simulation accuracy criteria.

Exceeding tolerance limits by any of the quantities must, in any case, evoke quick intervention of the monitoring program that prompts the system to make a correction. Usually, the correction consists in a change of degree of admission of the engine (by changing the position of accelerator lever), or a change of brake moment setting, ΔM_H.

The operator who supervises the system must have a possibility to intervene in program algorithms from the computer console. He must also be able to send commands directly to final control elements of the system.

The software must be provided with security functions that prevent the parameters of operation state of system elements to exceed allowable values, and generate alarm signals indicating erroneous functioning of the devices, for example vanishing of some of the control signals, etc.

It should be also noticed that some of the events simulated in the "test ride" scenario can be programmed in many different ways, according to preferences or intuition of the software's author.

The Author is convinced that it would be advantageous to introduce artificial intelligence software, like neural networks, in order to improve the performance of the tests.

5. Conclusion

In the paper, the Author presented the method of simulation of some most important phases of "test ride" scenario of a vehicle tested on an engine test bench. Some measurements associated with actual traffic tests, like those concerning fuel consumption, toxic gases emission, noise level, etc., were beyond the scope of this study.

The system consisting of an actual engine and computer-simulated vehicle, presented in this work, exemplifies the enhancement of research possibilities offered by computer-aided systems, in contrast to those obtainable in "purely" experimental examinations.

It is apparent that the vehicle and the "test ride" scenario can easily be modelled, while engine modelling is much more difficult. Then, the described system composed of a real object (engine) and a simulator of co-operating element (vehicle) proves very convenient.

Examinations of this kind are much less expensive, easier to realise, and create universal possibilities of examinations in extreme situations, even such that are impossible to be carried out in a fully real system. One can also apply these tests to verify the characteristics of a modelled object (vehicle) even at the stage of its conceptual design.

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Sposób realizacji procesu symulacji na hamowni badań trakcyjnych silników spalinowych

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

W artykule przedstawiono sposób symulacji różnych scenariuszy „jazdy" samochodu na hamowni silnikowej. Wskazano na możliwości badawcze półwirtualnego układu silnik rzeczywisty – symulator jazdy samochodu.

W artykule poprzedzającym, pt. „Zasady symulacji pracy silnika na hamowni silnikowej w warunkach odpowiadających trakcyjnej eksploatacji pojazdu" omówiono sposób realizacji podstawowych faz testowania pojazdu. W pracy niniejszej przedstawiono wymagania dotyczące dokładności testu, budowy i wyposażenia stanowiska badawczego oraz cech programu sterującego badaniami i nadzorującego jego prawidłowość.