EXAMINATIONS OF EFFECTIVE EFFICIENCY OF A CAR ENGINE IN NON-STATIONARY WORK CONDITIONS FROM TORQUE LOAD

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Abstract

Measuring method and calculations of the impact of non-stationary work conditions of car engine torque load upon its effective efficiency have been presented in the paper. The obtained results have been compared to the already achieved results. The applied method of calculation balance and the consumed fuel enabled the writer of the paper to calculate the value of the change of unitary fuel consumption at a work point on engine performance map.

The carried out examinations focus on measurements at one measuring length and so the rate of torque load at each of the four gear box ratio (2-5) can be controlled by constant final velocity of driving or by shifting or extending the measuring length against the lowest point (the measuring length is '◡'-shaped). Finding the right solution to this problem will allow elaborating the calculation algorithm of engine effective efficiency for the examined range of engine performance maps for changeable, non-stationary work conditions.

The results make it quite explicit that non-stationary work conditions from the engine speed and the engine load impair the effective efficiency of the engine at work in particular gears. Non-stationary mode of engine operation is essential for the higher values of gear box ratio whereas for lower values the engine load really matters.

Keywords: *engine performance maps, specific fuel consumption, effective efficiency*

1. Introduction

The problem which has not been solved so far is determining the effective efficiency of the engine which is of great importance. It allows defining with great precision the total energy consumption of a moving car [1-5]. Determining the effective efficiency of the engine at non-stationary work conditions with engine speed and torque load taken under consideration separately, regarding effective efficiency in stationary conditions (engine performance map) seems to be of great importance in practice [6, 7]. The carried out tests made it possible to determine the impact of engine speed changes (non-stationary work conditions from engine speed) upon the effective efficiency. The effective efficiency of the engine at non-stationary conditions can be calculated with great precision, using BSFC map (the so called quasi-stationary work conditions) [8, 9].

However, non-stationary work conditions are generally quite complex since they include both the engine speed changes and torque load changes (characteristics in Fig. 1). Thus it is important to define the impact of the rate of torque load change at constant engine speed upon the effective efficiency from engine performance maps (non-stationary work conditions from torque load).

The schedule of further examinations based on the writer's research work has been presented in the paper. Changeable driving cycle of a car in real traffic conditions on a suitably shaped measuring length of the road has been chosen for testing. It is also highly recommended to monitor the emission of toxic compounds in exhaust gas.

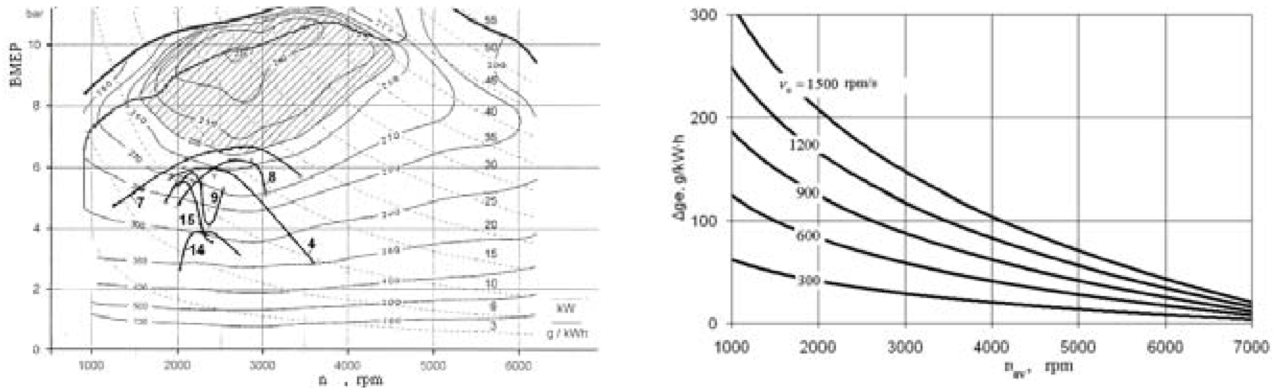

Fig. 1. Engine performance map and growth characteristic of g_e specific fuel consumption in ν_n and n_{av} function

2. Effective efficiency of SI engine at dynamic work conditions

2.1. Changeable engine speed – constant torque load

Total energy consumption of a moving car depends mainly on car's resistance to motion and the efficiency of power unit to generate driving force on road wheels which helps to overcome that kind of resistance. The efficiency of η_n drive system is simply a product of η_p power transmission efficiency system and η_e effective efficiency. Engine performance maps in conventional power transmission systems with manual gear box do not feature significant changes except for boundary driving conditions [1, 2, 9].

However in boundary conditions η_m efficiency can be even below 10-20% when the car is off the road or back again [11, 12].

On the contrary, η_e effective efficiency in SI and CI engines can have the value from 0 (at idle) up to 38-46%. Engine performance maps of the engine are very useful in calculating η_e values for the purposes of static work conditions (Fig. 1a). Unfortunately in real traffic the engine works in dynamic conditions, i.e. at least one value changes in time which is characteristic for engine operation (tangential velocity and torque load). Effective efficiency of the engine while taking into account general engine performance maps has been used so far in calculations for practical reasons.

A method for calculating the decrease of effective efficiency of the engine has been elaborated by the writer of the paper who designed a programme regarding fuel consumption in a B/K class car. The method took into account the drop of effective efficiency at the point of work on engine performance maps which results from dynamic work conditions depending on engine speed – ν_n. This value is based on a comparison of calculated and actually used fuel by a car in variable driving cycle (changeable acceleration). Such difference results from the impact of car acceleration dynamics upon the decrease of engine's effective efficiency in ν_n function at constant load. The element of constant load has been determined by the maximum accelerator pedal angle.

The introduced ν_n coefficient of non-stationary work conditions of the engine from engine speed expresses the velocity of engine speed in time (rpm/sec). In the examined engine operation ($\leq$ 70%) the proportional increase has been assumed, its impact upon g_e unitary fuel consumption from general characteristic was taken into account as well. Different ν_n coefficient causes diversified decrease of effective efficiency in the examined average engine speed for each gear. The examination results confirm the determined $\Delta\eta_e$ characteristic for two ranges of average engine speed (1800 and 2300 rpm) which were assigned in a variable driving cycle with acceleration at the first two stages of gear box ratio up to 25-45 kph (grey lines in Fig. 2) and at three stages of 25-43-56 kph. The method of interpolation was used to determine the probable decrease of effectiveness for the fourth and fifth gear (grey break line). There is a significant diversification in the decrease of effective efficiency for particular values of gear box ratio for n_{av} = 2300 rpm which has been presented in Fig. 2. If 2% is assumed as an acceptable error of effective efficiency calculations, then the characteristic for the third gear is within the boundary of stationary and non-stationary work conditions. For stationary conditions, the so called quasi-stationary, the characteristic is in the range of unitary power of additional motion resistance $(a*v) \leq 11$ W/kg [5, 10].

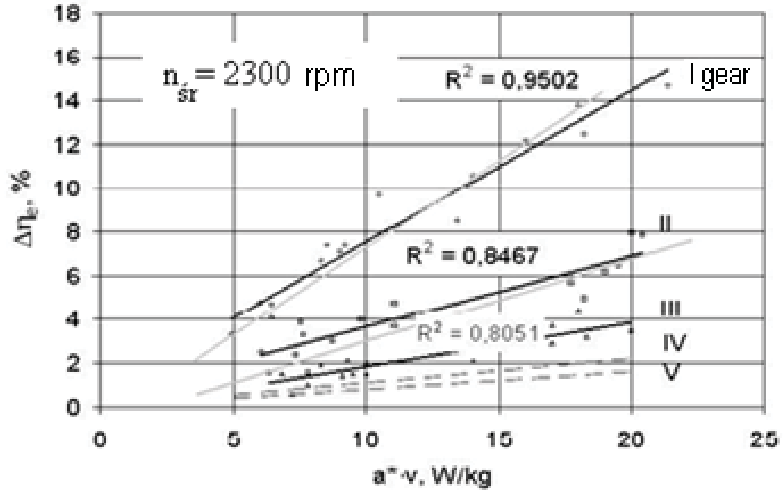

Fig. 2. Characteristics of effective efficiency drop based on BSFC map of 1,6 SI engine for each purchase of the gear box in B/K class car in function

Furthermore, the decrease of engine effective efficiency indicated by the increase of g_e unitary fuel consumption at a work point on the engine performance maps in SI engines (with the adaptable control of fuel injection) depends on the average engine speed which has been presented in Fig. 1b.

2.2. Changeable torque load– constant engine speed

The variable driving cycle in real road length of 400-500 m and of precisely characterized inclination (geodesic straight-edge) has been used by the writer of the paper in the carried out examinations as a novelty. Free choice in fixing the maximum accelerator pedal angle enables to establish the profile of car's speed in a variable driving cycle. It also makes it possible to place the measuring points in a given area on the engine performance maps of the engine. The second important aspect of the carried out examinations was that the tests could be done for going 'up the road' and 'down the road' mode of driving, thus the examinations are of complex and universal nature and they present the impact of road declination characteristic upon the areas discussed in details in this paper [12, 14].

Characteristic concave profile of the road can be used while testing 'variable engine load – constant engine speed' driving 'up the road' and 'down the road'.

Coefficient from the load can also be defined following the same principles as those used for defining the coefficient of non-stationary work conditions of the engine from engine speed [12].

$$v_M = \frac{d\,T_e}{d\,t}, \frac{\mathrm{N \cdot m}}{\mathrm{s}}. \tag{1}$$

Non-stationary work conditions of the engine from engine load have been defined by the growth of engine torque (or the average effective pressure) in the unit of time. It seems to be more precise to define the increase of load in a unit of time of a work cycle of the engine which in practice means two rotations of a crankshaft.

$$v_M = \frac{d\,T_e}{d\,n}, \frac{\mathrm{N \cdot m}}{\mathrm{rps}}. \tag{2}$$

The model profile of inclination of the measured distance on the road and of the predicted profiles of speed in a changeable driving cycle has been presented in Fig. 3. In such case the application of the method of fuel consumption balance presenting the driving and non-driving phases will be most appropriate as well in the following conditions:

1. The length of the measurement distance in relation to the starting up distance is quite considerable.
2. Energy consumption of the starting up phases in relation to the measurement phase is low enough to see its influence upon the calculated fuel consumption of non-stationary work conditions from the load. It also needs to be kept in mind that the calculated fuel consumption has been based on general characteristic in this case.
3. The increase of engine load at the measurement distance is big enough to notice the loss of calculation balance and the consumed fuel when ν_M is increased.

Such conditions can be fulfilled on the measurement distance of 200-300 m with growing longitudinal inclination, whereas the starting up distance of the vehicle up to the right speed and the desired gear should be of negative inclination (condition no 2 has to be fulfilled).

The length of measurement distance with a profile presented in Fig. 3. meets the above mentioned conditions. Concave profile provides reaching the required speed at low energy input on the starting up distance and the position of the beginning of measuring length near the lowest point of the road (point B) facilitates a considerable increase of load at constant engine speed for the chosen gear box ratio.

3. Analysis of non-stationary engine work conditions from load

The results of simulation calculations of a coefficient of non-stationary work conditions of the engine from ν_M load have been presented in Tab. 1 and they were based on Fig. 3 and equation (1) and (2). Contrary to the balance of consumed fuel in non-stationary work conditions of the engine from engine speed where there were two components: one with very high energy consumption of the drive phase acceleration with various acceleration dynamics and one at idle, three components of the balance can be distinguished (Fig. 3):

- drive phases of increasing speed up to the required value at each reduction ratio in order to obtain the constant average engine speed for each cycle,
- measuring drive phase of a constant driving speed and increasing engine load,
- idle phases of the engine in boundary conditions and while changing gears.

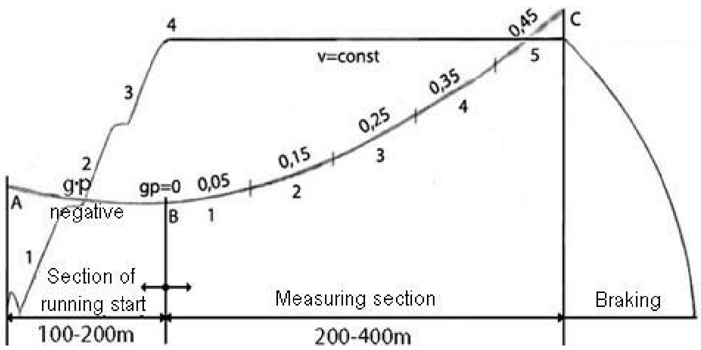

Fig. 3. The required geodesy profile of a road measuring length for examining the non-stationary work conditions from torque load

The first and the last balance components of the consumed fuel should be taken into account properly in calculations since it is of great importance for the final result. It is worth remembering that considerable non-stationary engine work conditions from engine speed occur when the engine accelerates at the highest reduction ratio. It influences the effective efficiency and it ought to be considered using the examination results.

Another important conclusion can also be drawn that the non-stationary work conditions from engine speed are characteristic for the highest reduction ratio, i.e. the first three gears and the lower engine speed (Fig. 1 and 2). However when the reduction ratio is really low (from the third gear up) the non-stationary work conditions of the engine from engine speed are of less significance and non-stationary conditions from the engine load become more important (Fig. 4). That is why the programme of the research works includes the variable driving cycle at a measurement distance for three types of the lowest reduction ratio.

Tab. 1. Calculated non-stationary engine work conditions from v_M load at the required measurement distance taken from Fig. 3 at particular types of i_c total gear box ratio

Lp.	v = const kph (mps)	Engine speed n = const. rpm; rps			Dla L = 200 m Δt_{200} s	Definition: $v_M = \Delta T_e/\Delta t$ (Nm/s)/ /$2\Delta T_e/\Delta n$ (Nm/rps) ($\Delta T_e = T_{e,max}/T_{e,min}$)		
Total ratio i_c =		3. 5.27	4. 4.53	5. 3.33		3.	4.	5.
1	2	3	4	5	6	7	8	9
1.	40 (11.1)	1880; 31.3	1613; 26.9	-	18.0	1.77/2.03 (2.84)	2.06/2.75 (2.84)	-
2.	45 (12.5)	2110; 35.2	1814; 30.2	-	16.0	-	-	-
3.	50 (13.9)	2345; 35.1	2016; 33.6	1482; 24.7	14.4	2.18/1.60 (2.64)	2.06/2.19 (2.66)	3.47/4.05 (2.65)
4.	55 (15.3)	2580; 43.0	2218; 37.0	1735; 28.9	13.1	-	-	-
5.	60 (16.7)	2815; 46.9	2420; 40.3	1893; 31.5	12.0	2.64/1.35[1)] (2.54)	3.08/1.83 (2.54)	4.19/3.40 (2.55)
6.	65 (18.1)	3245; 54.1	2621; 43.7	1927; 32.1	11.05	-	-	-

Figure 4 presents the marked range of engine load changes on the engine performance maps for separate types of gear box ratio at constant phase of driving speed for L = 200 m measurement distance in a changeable driving cycle. Simulation calculations of the engine load changes have been carried out the geodesy profile of measurement distance B-C as it is shown in Fig. 3.

Simulation calculations of the engine load have been carried out for three constant values of speed of a car. One example has been calculated for the second gear (B_2-C_2). A shift of the left starting point of B measuring length increases the rage of engine load changes. The shift of 'the start up length' to a bigger negative inclination reduces the total value of energy consumption of gaining speed and at the same time the position of point B is lowered on the characteristic. The second possibility of changing the range of measurements is to alter simultaneously the distance of B-C measuring length.

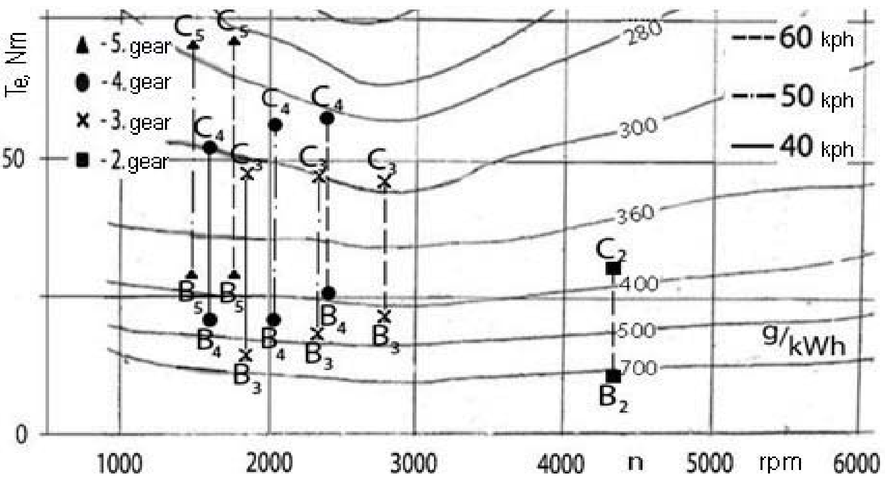

Fig. 4. The course of 1.6 SI ($T_{e,max}$ = 150 N·m) engine load changes (at a measurement distance B-C from Fig. 3) for three types of gear box ratio on general characteristic

Non-stationary operation conditions of the engine from load in the traffic result from increasing the car's speed. This can be done by pressing the accelerator pedal gradually or in a stroke-like manner to the new position which ensures the required acceleration of the car. From the energy consumption point of view in each of the cases the unitary power of the resistance to motion in the final effect should not exceed 4-6 W/kg [4] and in special cases 13 W/kg [13].

4. Conclusions

The above presented examination results make it quite explicit that non-stationary work conditions from the engine speed and the engine load impair the effective efficiency of the engine at work in particular gears. Non-stationary mode of engine operation from engine speed is essential for the higher values of gear box ratio whereas for lower values the engine load really matters.

Larger number of components of the consumed fuel balance generates some difficulties in determining the decrease of effective efficiency of 1.6 SI engine in non-stationary conditions from torque load. However finding the best solution to this problem seems be of great importance since the cars operate in traffic mainly at a lower gear box ratio (i.e. the top gears).

Despite the fact that the engine operates mainly in non-stationary work conditions both from engine speed and torque load, but for each gear box ratio only one of the values is of great significance which, in turn, has impact upon the decrease of engine's effective efficiency from the engine performance maps. The carried out examinations revealed that the considerable drop of effective efficiency for each type of non-stationary work conditions can be observed when the car is in the third gear (i_c = 4.53). That is why the third gear can be considered as the boundary one.

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