

# EFFECTIVE EFFICIENCY IN CAR ENGINE AS A FUNCTION OF REDUCTION RATIO DURING ENERGY-SAVING SPEED CONTROL

Aleksander Ubysz

Silesian Technical University, Faculty of Transport, Department of Vehicle Construction  
Krasińskiego Street 8, 40-019 Katowice, Poland  
tel.: +48 32 6034146  
e-mail: aleksander.ubysz@polsl.pl

## Abstract

The study examines the effect of transformation ratio in power transmission system on engine efficiency as a function of passenger vehicle velocity ( $m = 1400$  kg) with energy-saving vehicle drive. The study also presents working range in driving phases for energy-saving speed control up to 120 km/h for a simplified overall engine performance map for SI engine.

Understanding of the presented considerations can be facilitated through relating with advantages of application of non-driving phases in low engine load phases (field 4 in overall engine performance map). Working points of SI engines in engine performance maps were divided in terms of energy-saving vehicle speed control into 4 ranges. Zone 1 is the most economic whereas zones 3 and 4 are the least energy-saving, which was also discussed by the author in other works. The study presents the location of engine working points in overall engine performance map during energy-saving vehicle speed control within the range of 30-120 km/h using two different 6-gear gearboxes. Working range for CI engine in simplified overall characteristics in truck, the impact of speed control upon fuel consumption in real traffic conditions, sum and difference characteristics of components of drive engine unitary power, area of maximal rise in overall engine efficiency after reduction of rotational speed, simplified SI engine performance maps, covering with economic zone of working point in energy-saving drive of vehicles are presented in the paper.

**Keywords:** power efficiency, driving cycle, effective engine efficiency, B.S.F.C., load torque

## 1. Introduction

In recent years, the factors connected with energy-saving drive of the given passenger vehicles started to play an increasingly essential role during purchase of a car. The initiatives of vehicle manufactures towards stimulation of car users' awareness of these issues cover wide range of solutions: from detailed characteristics of engine's and vehicle's parameters to installation of instruction software focused on energy-saving driving [1-5]. To car users, familiarizing with the principles of energy-saving use of vehicles so that they can be applied to each car, either big or small, with SI or CI engine, seems to be the best solution.

The author of this study presented the effect of the number of gears in most popular cars with manual gearbox on overall engine efficiency [6, 7]. The energy-saving principles of vehicle speed control were also presented [4, 8].

## 2. Energy-saving vehicle speed control

Best index of energy-saving vehicle control is a synthetic vehicle energy-saving index (SWEP) [9, 10]. It expresses the amount of energy contained in a fuel necessary to cover a set distance (100 km) by a mass unit (Mg). Among vehicles, best results are obtained for tractor units with fully loaded trailer. Calculated per fuel, these vehicles move a mass of 1Mg for a distance of 100 km at the cost of 0.8 dm. In passenger vehicles, these indexes are several times higher, especially in SI engines. As shown in Fig. 1, this is possible through application of 10- or 16- gears in the gearbox [11]. In road and motorway traffic, it is possible to drive at the speed of 90 km/h within the range of higher overall efficiency over 43%.

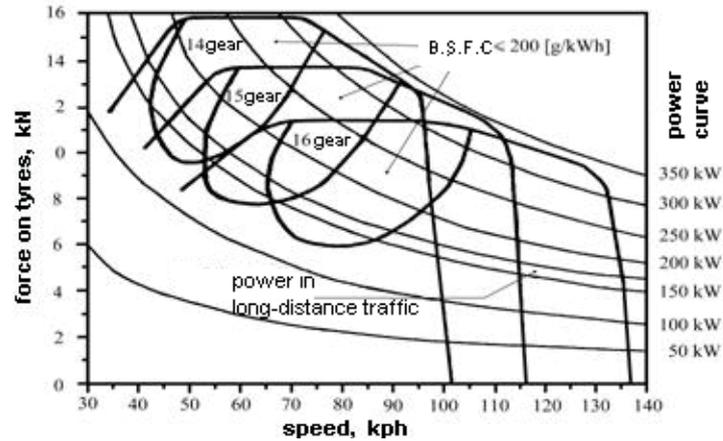


Fig. 1. Working range for CI engine in simplified overall characteristics in truck with 16-speed gearbox [18]

Searching for optimal range of engine work in each gear in 5-speed and 6-speed gearbox, one can employ the same method of analysis to the speed of 120 km/h.

There have been a lot of studies which explained what actually energy-saving speed control in passenger cars is; more or less comprehensible controllers and energy-saving programs of speed control and programs for post-factum analysis of speed profile have also been developed [3, 4]. Fig. 2 presents the effect of speed controller used in Ford Fiesta 1.25 SI on distribution of unit power derived from additional tractive resistance ( $a \cdot v$ ) [4]. Value of ( $a \cdot v$ ) from the range of 4-6 W per 1kg of vehicle mass is of universal meaning: energy saving is reached through minimization of the stream of fuel demand in the vehicle  $G$  (g/s). The control is characterized by low dynamics of acceleration since loss resulting from acceleration of the vehicle, comparable at flat road in terms of scalar value with delay in neutral is recoverable (the thesis not confirmed by the author yet). ' $a$ ' means a total of acceleration ' $a$ ' and road slope ' $p$ ' multiplied by gravitational acceleration ' $g$ ', and ' $v$ ' means car speed.

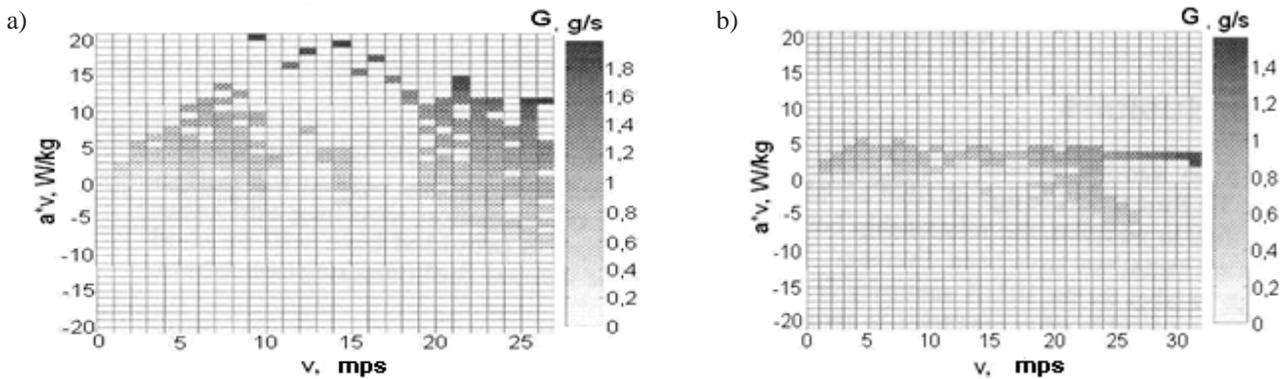


Fig. 2. The impact of speed control upon fuel consumption in real traffic conditions for Ford Fiesta SI 1.25, a) without a controller, b) with speed controller [19]

Based on [4], Fig. 3 presents a method of calculation of demand for engine effective power  $N_e$  in the car driven in an energy-saving manner. Dot line is a total of irrecoverable  $N_{m,op}$  and recoverable  $N_{m,a^*}$  unit power of tractive resistance. Its value multiplied by actual vehicle's mass gives the value of necessary effective power developed by the engine in the car driven in an energy-saving manner. By means of the technique presented in Fig. 3, engine working range as a function of driving speed (30-120 km/h) and the used total reduction ratio in power transmission system will be determined. Calculations were made for a car of B/C class with 1.6 SI engine with narrowly- and widely-stepped 5-speed gearbox with additional 6th overdrive [6]. The data for the considered reduction ratios are presented in Tab. 1.

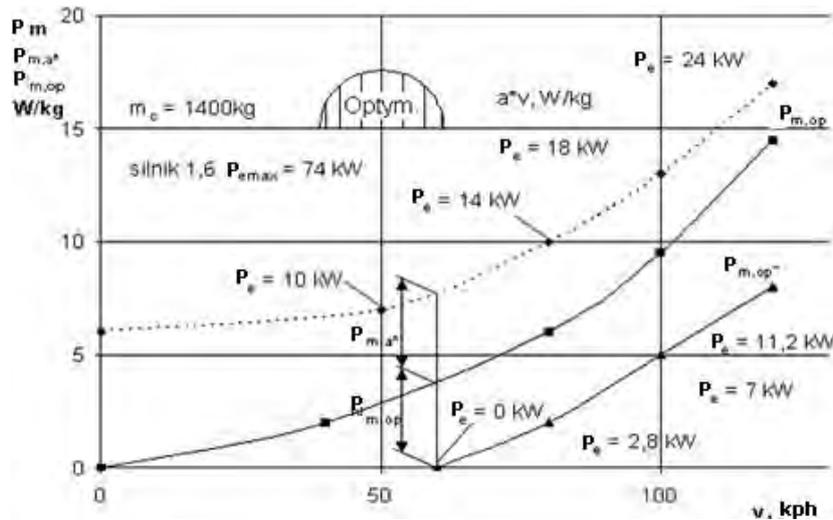


Fig. 3. Sum and difference characteristics of components of drive engine unitary power depending on velocity of B/K class car with SI o  $V_{ss} = 1.6dm^3$  engine [16]

Tab. 1. Total ratios in the two gearboxes adopted for calculations

Type and 6-speed gearbox	1.	2.	3.	4.	5.	6.
Dynamic gearbox CR 6/3.74	13.94	8.00	5.29	4.19	3.33	2.77
Dynamic gearbox WR 6/3.74	13.94	7.32	4.87	3.54	2.85	2.28

### 3. Simplified engine performance map

Figure 3 presents the diagram of calculations of demand for engine power in passenger cars during energy-saving vehicle speed control up to 120 km/h. One of the most important means of reduction of energy consumption to be used in vehicles is to change gear into higher one, which results in reduction of rotational engine speed and limitation of unsteady conditions of engine work [12]. Fig. 4a presents engine performance map for 1.6 SI map with economic drive line E [13] and grey zone of maximal ( $\geq 1\%$ ) rise in overall engine efficiency after changing into higher gear.

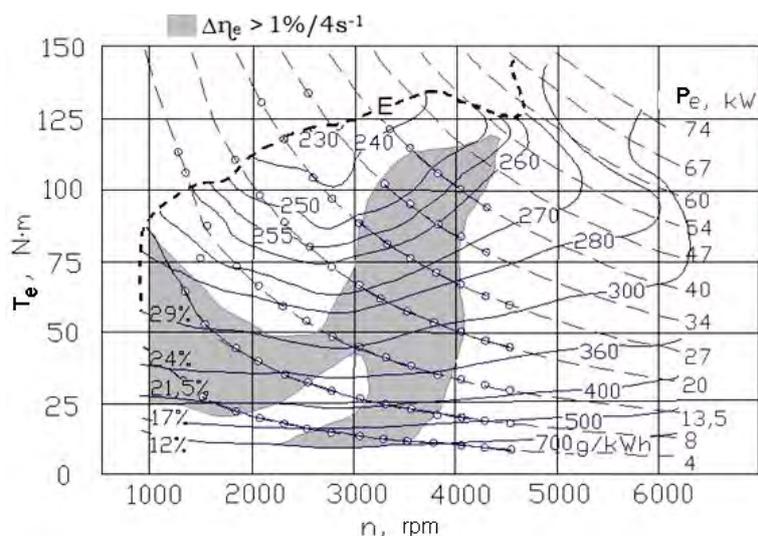


Fig. 4. Area of maximal rise in overall engine efficiency after reduction of rotational speed by  $4.1 s^{-2}$  by means of gearbox

In order to provide a more transparent presentation of the benefits which result from application of economic 6-speed gearbox, simplified engine performance maps were developed for the analysis

(Fig. 5). Contrary to [1], the author was interested in 4 zones of engine performance map, determined by means of three lines: economic E [13] and two contours lines: efficiency with  $g_e = 270 \text{ g/(kW}\cdot\text{h)}$  ( $\eta_o \geq 32\%$ ) divided with line E into two zones (1 and 2) and minimal efficiency  $g_e \leq 500 \text{ g/(kW}\cdot\text{h)}$  ( $\eta_o \leq 17\%$ ), below which it is recommended to use an alternative technique of car speed control (non-driving phases: neutral or engine braking) [8, 12]. The fields were marked in Fig. 5. Energy-saving car driving style requires different division of engine performance map compared to [1]. From the effective power installed in the car (1.6 SI), the demand for 1/3 of maximal power (24 kW instead of 74 kW) is predicted during energy-saving speed control (Fig. 3), which limits the area of use of performance map to lower left quarter, analogously to less dynamic NEDC driving cycle [c]. In consequence, in energy-saving control, engine working range in engine performance map is located in 3rd and 4th zone marked in Fig. 5. In the zone 1 to line E, where overall efficiency is high ( $\eta_o \geq 32\%$ ), engine should work sporadically, e.g. during overtaking.

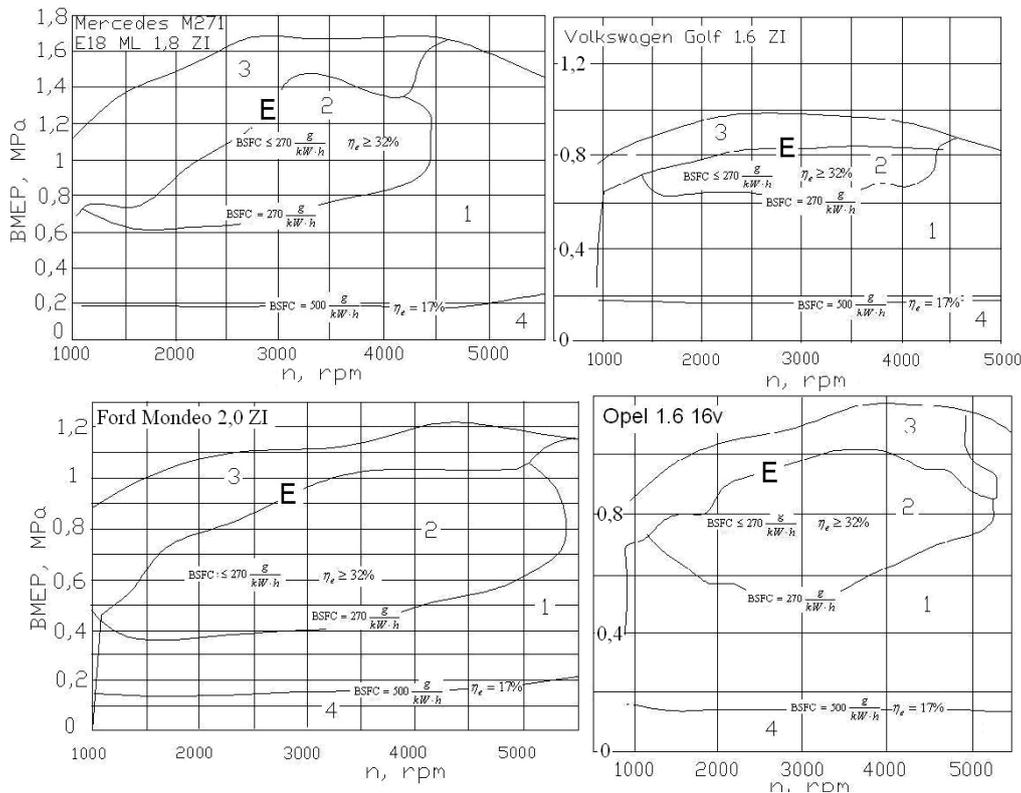


Fig. 5. Simplified SI engine performance maps in passenger vehicles

In the zone 2, despite very high efficiency, engine work is uneconomical because of big stream of fuel demand (g/s), which is presented in Fig. 2 [3]. Division of engine performance map into 4 zones provides answer to the question of which engine is more energy-efficient: one- or two-litre engine [3]. One-litre engine allows for more frequent use of the zone 1 but it has lower reserve for fast increase in power to the line E. In engines with lower capacity, lack of dynamics is compensated by means of a more dynamic selection of reduction ratio in power transmission system [6].

#### 4. Determination of engine working range in individual gears vs. speed

Figure 6 and 7, based on the chart in Fig. 3, present determination of location of engine working points as a function of energy-efficient speed control in relation to 4 zones from engine performance map for individual gearbox reduction ratio: economic and dynamic with very popular ‘overdrive’ (6th gear) [6]. The chart was plotted up to the maximal speed of 140 km/h (according to the author, energy-saving car driving should be limited to 120 km/h).

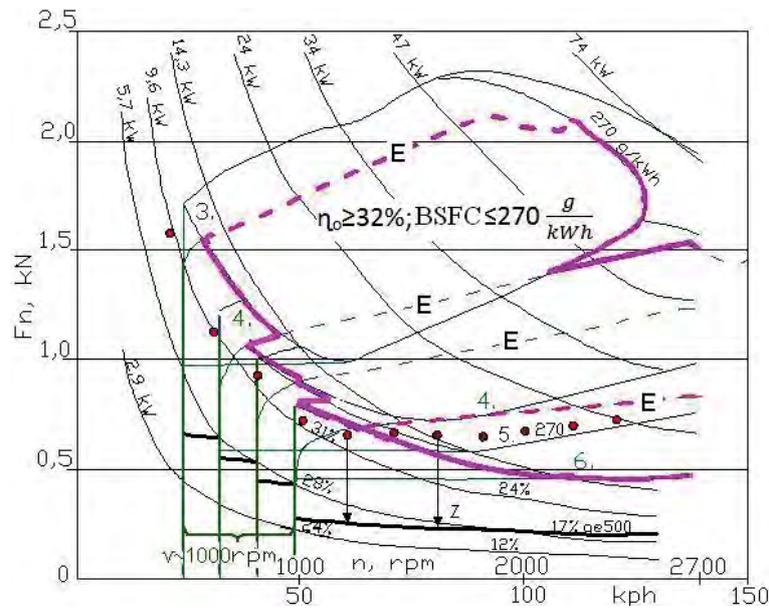


Fig. 6. Covering with economic zone of working point in energy-saving drive of a vehicle class B/K with  $m = 1400$  kg with economic 6-speed gearbox (WR+6)

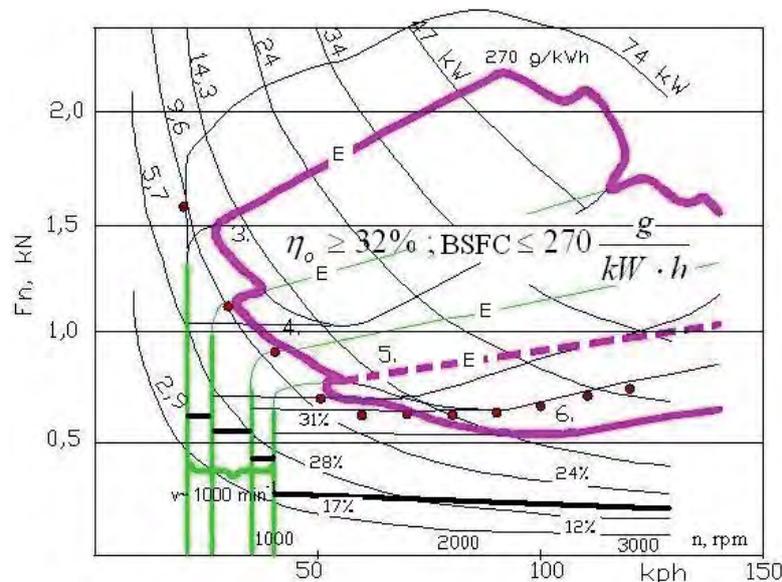


Fig. 7. Covering with economic zone of working point in energy-saving drive of a vehicle class B/K with  $m = 1400$  kg with dynamic 6-speed gearbox (CR+6)

In order to increase the transparency of the charts, analysis was limited to gears from third up (in energy-saving drive, it is recommended from the speed of  $v \geq 30$  km/h to use 3rd gear).

From the standpoint of location of the zone 1, engine performance map for 1.6 SI engine is unfavourable since working points corresponding to maximal load up to the speed of 60 km/h for each reduction ratio 'avoid' the area of  $g \geq 270$  g/(kW·h). It is as late as for the range of speed of 70-140 km/h where working points are included into the area of efficiency over 32%, although for economic gearbox (Tab. 1) this case occurs for 5th and 6th gear (in 6th gear working point are located deep in the zone 2, which means that overall efficiency is closer to maximal (38%).

In the car with dynamic gearbox, zone 1 shows the above-mentioned working points for 6th reduction ratio ( $i = 2.77$ ). Working points for individual speeds can adopt any lower value, marked along vertical arrows for the zone 4. Overall engine efficiency in this area is so small that it is economical to frequently switch into non-driving phase of engine work: engine braking or drives in neutral ( $\eta_o \leq 17\%$ ) [12].

## 5. Conclusions

Based on the presented material, one can conclude that:

1. Prior (at the engine rotational speed of 1500-2200 min<sup>-1</sup>) shifting into higher gear improves overall engine efficiency, which, for higher driving speed, is facilitated with adequately stepped (wide-stepped) 5- or 6-speed gearbox.
2. Energy-saving engine speed control limits the use of the zones of higher efficiency in engines with high power surplus (zone 1), but it allows for considerable reduction in the stream of consumed fuel (g/s).
3. It is recommended for energy-saving car speed control to use very low engine load (zone 4), elimination of driving phases with low engine efficiency and exchanging them with non-driving phases, which considerably limits fuel efficiency to zero value (engine-braking) or fuel consumption in neutral (calculated per vehicle speed).

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