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INFLUENCE OF CONDITIONS OF VEHICLE MOTION ON ITS ECONOMY

In the past period, around the world there were signs of depletion of natural energy sources. This is manifested by rising fuel prices and a significant increase in commitment to the search for alternative sources of energy that can be used in vehicles. The said increase in fuel prices caused the operators of the vehicles attempted to reduce its consumption by introducing the principles of economic and efficient driving. These rules represent a compromise between the economy, security and pleasure. It combines a quiet, smooth ride under certain conditions with dynamic acceleration when possible. The paper presents the influence of selected traffic conditions on its economy. It is a development of the literature of this subject [1-13].

INTRODUCTION

Operating consumption depends on many factors. The user of the vehicle for some of them does not have a direct impact, and some of them do. These are precisely these relationships, for which has a direct impact, can be used to minimize the cost of everyday use of vehicles. The most important factors affecting fuel consumption are:
- construction of the entire vehicle,
- technical condition of the vehicle,
- individual personal driver characteristics,
- atmospheric conditions,
- characteristics of a route on which the vehicle is moving.

Cars with engines of large power are usually operated at low loads. In contrast to them, cars with engines of small power, they work predominantly in the range of maximum load. In these load ranges, at fixed operating conditions, modern motor construction solutions provide economical operation.

But in order to take advantage of these properties, the vehicle user must demonstrate the knowledge and skills to apply the relevant ratios of the gearbox. The dynamic properties of the car - especially the acceleration, require the user to the appropriate skills to operate the motor control devices and the car and certain personal characteristics affecting the riding technique.

At fixed and constant speed, a decisive influence on fuel consumption has structural solutions and external conditions. In contrast to this type of driving, in temporary states very important role plays the driver. The most energy-intensive processes here are acceleration processes of the car. In contrast, during deceleration is possible the partial use of the kinetic energy of the vehicle.

1. ECONOMICS OF DRIVING CAR

Fuel consumption is closely related to the power required to overcome the resistance to motion of the motor vehicle, that is, power passed on to the engine. So that the vehicle could move must overcome resistance associated with this movement. To make this happen, the drive motor must provide adequate power and torque. Perfect for the engine characteristics of the supply of power and torque are shown in Figure 1 and 2.

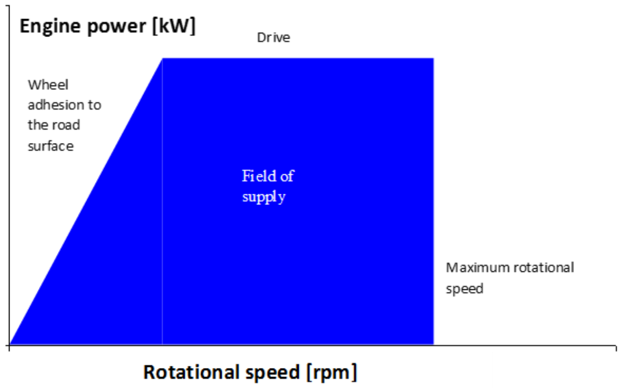

***Fig. 1.** The ideal characteristics of the power supply of the internal combustion engine*

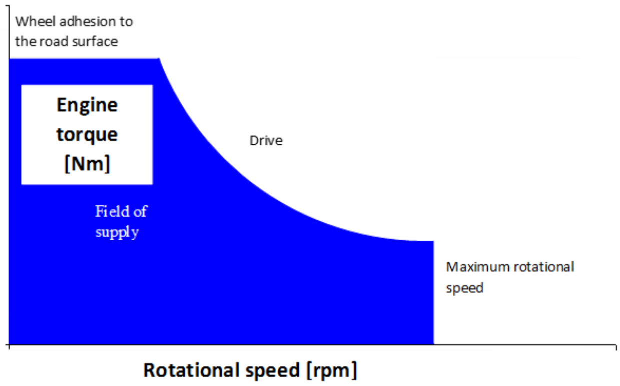

***Fig. 2.** The ideal characteristics of the torque supply of the internal combustion engine*

Possible field of supply to use during operation of the engine is limited. From the top the limit is the maximum possible power (N) and torque (M). It would be best if the car engine would produce a constant maximum power in the entire rotational speed range (n). The highest value of torque (the driving force) at the wheels of the car is limited by their adhesion to the road surface. Torque cannot be too large so that there has been no slippage of the drive wheels, especially when starting and at low rotational speeds. The power increase in this case ensures the growing speed (N = M * N / 9550 [kW]). When the power reaches its maximum value at a constant level, the torque begins to decrease with increasing rotational speed. This is advantageous because in opposite case, if the friction level rises and lowers the rotational speed, the torque (driving force to the wheels) allowing overcoming the resistance will increase. Supply area limit is also the maximum possible rotational speed. It results from the design features of the engine, as well as the speed capability of the vehicle.

Currently used structures of internal combustion engines are not possible to achieve the ideal characteristics. Real engine has a maximum power generally at only one rotational speed. Similarly, the torque, the value of which decreases with decreasing rotational speed in the low speed range, and with increasing speed of rotation at high speed. The internal combustion engine cannot also work with too little rotational speed, because the speed reduction below idle speed causes it to stop. For high engine speeds, decreasing significantly torque causes a significant decline in its power.

In order to ensure proper operation of the engine in terms of the useful rotational speed - comprised between speed corresponding to the maximum torque n_M and the maximum power n_N (Figure 3), is used the gear box in the drive system.

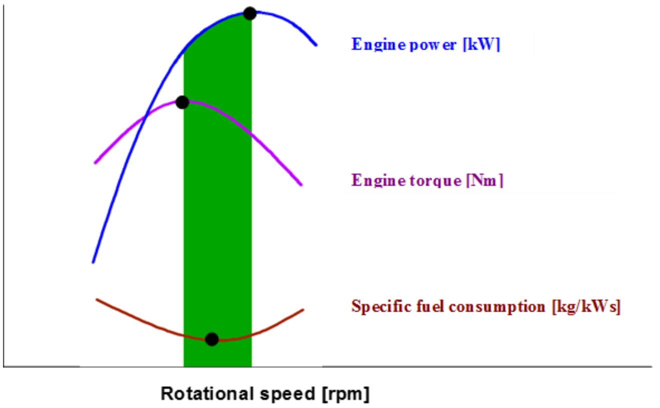

Fig. 3. *The range of useful rotational speed of the internal combustion engine*

Gearbox allows changing the speed and torque transmitted from the engine to the wheels of the car. The resultant torque on the driving wheels of the vehicle depends not only on the value of the engine torque, the selected gear ratio of the gearbox, but also the mechanical efficiency of the drive. It should be realized that the efficiency is always less than zero and takes smaller value for a lower gears. It follows that for the lower gear - due to the lower mechanical efficiency of the drive system, driving will be less economical.

The maximum useful efficiency of the internal combustion engine with its operation a constant rotational speed falls on its speed corresponding to the high speed of the car. This corresponds to speeds obtained with the highest gear. The efficiency of the engine depending on the vehicle speeds is shown in Figure 4.

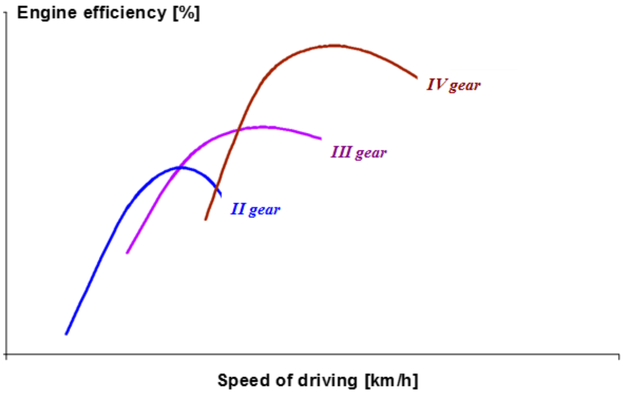

Fig. 4. *The dependence of the efficiency of the engine from the vehicle speed*

The efficiency for the engine of the car moving at variable speed takes a value significantly lower than the established traffic conditions - constant driving speed. The decisive influence on it has frequency of acceleration and deceleration phases and their intensity. In the case of city driving, engine efficiency is about two times lower than the maximum occurring at a constant driving speed. In the braking and stopping phases the engine operating at idle does not provide power to the wheels while consuming fuel. Its useful efficiency is therefore equal to zero.

Choosing the driving technique suitable for your needs, pay attention to characteristics showing the dependence of torque of wheels to the speed of movement of the vehicle (Figure 5).

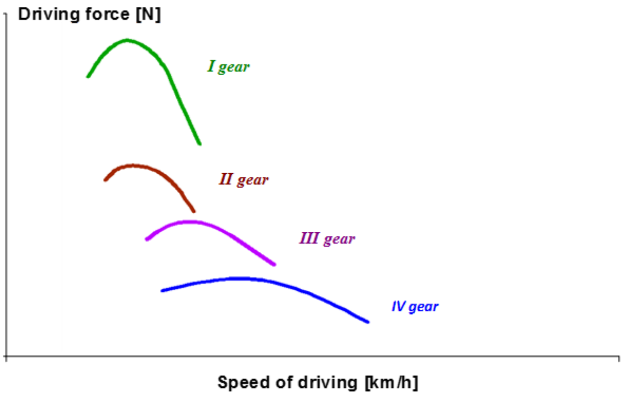

Fig. 5. *Dependence of torque of the car driving wheels to its driving speed*

The greatest value of the torque to the wheels driving of the car can be obtained for the lowest gear. Because the vehicle acceleration is proportional to that occurring torque, and therefore more possible values can be obtained at lower gears. At the same time, however, reduced by the transmission rotational speed engine do not allows for high driving car speed on the lower gears. The highest driving speed of the car is possible to achieve at the highest gears, where the ratios are the smallest. Obtained at the expense, however, significantly reduced the ability of the vehicle to accelerate. Also note that the acceleration of the vehicle strictly depends on its mass. The vehicle is loaded more heavily by the laden, the smaller the acceleration values will be able to generate. At the same time unnecessarily carried load in the car adversely affect the amount of fuel burned. Therefore, it is important to draw attention to transport loads in the car only needed in everyday work.

In order to make optimum use of the supply fields of torque, the gearbox should be properly controlled. The usage of the supply field of torque for economic and uneconomic driving is shown in Figure 6 and 7.

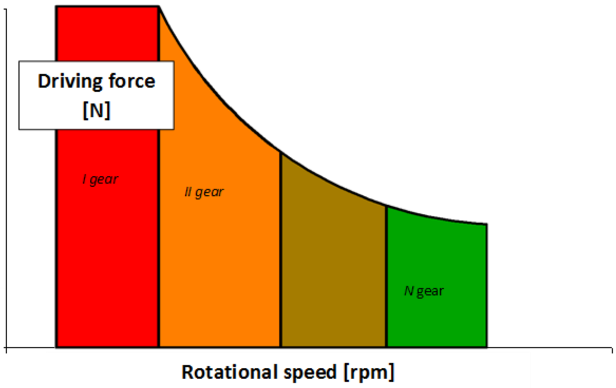

Fig. 6. *Ranges of the supply field use of torque for uneconomic driving*

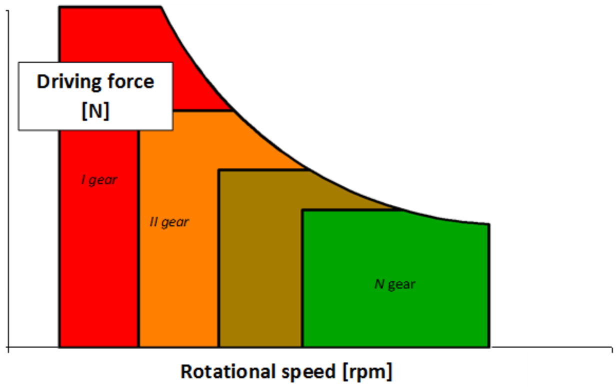

Fig. 7. *Ranges of the supply field use of torque for economic driving*

The most favourable driving technique is one that will allow keeping the engine speed in the range of usable rotational speed (between the speed corresponding to the maximum torque and maximum power). In the case of acceleration of the vehicle, when the motor reaches a rotational speed corresponding to the maximum torque, the gear should be changed to the next one. This will allow further acceleration. An example of the possibility of acceleration processes of the car through successive gears is shown in Figure 8.

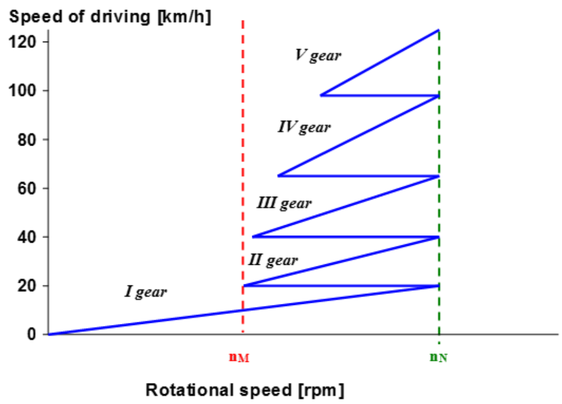

Fig. 8. *The possibility of car acceleration by another gear*

In the case of driving at a constant speed, it is best to keep the rotational speed at the maximum torque. This gives the best results in terms of economy driving. Effect of gear selection and constant movement speed on the fuel consumption is shown in Figure 9.

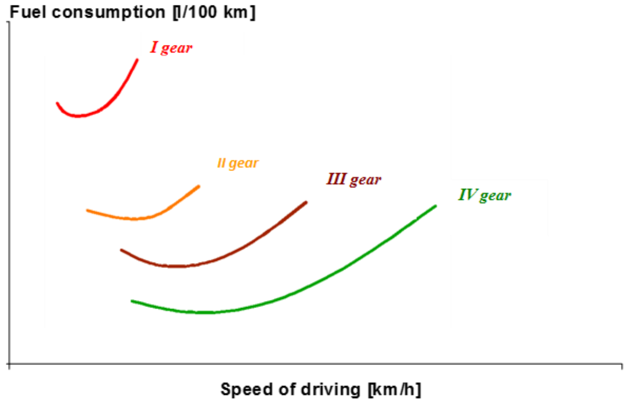

Fig. 9. *Fuel consumption as a function of speed selection and constant movement speed of the car*

Desired effects to reduce fuel consumption are also achieved by using the high-speed driving overdrives - also known as the economic gears. It is worth noting that the supply of power to the overdrive area is characterized by the lowest specific fuel consumption - which is the source of operating cost savings. However, depending on constructional factors of drive system, for some cars are being obtained less fuel consumption by using overdrives in the entire speed range, but only for a part of the vehicles after exceeding a certain speed. This relationship can be observed for two cars with different maximum driving speeds (V_{1max}, V_{2max}), Figure 10.

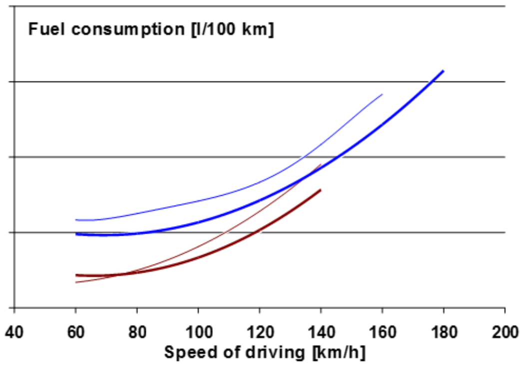

Fig. 10. *Fuel consumption on the economic gear (A) and direct (B) depending on the choice of a constant driving speed*

If there were no resistance to motion during travel, the vehicle accelerated to a certain speed would never be automatically slowed down and would not move at a constant speed without downloading for this purpose additional energy from the fuel. If there were no resistance to motion during travel, the vehicle accelerated to a certain speed would never be automatically slowed down and would not move at a constant speed without downloading for this purpose additional energy from the fuel. You could then talk about the ideal of economic driving. Such a situation does not occur, however, and it becomes necessary to provide energy from the fuel to overcome the resistance forces occurring during the movement of the vehicle.

The resistance to motion can include:

– rolling resistance,,
– grade resistance,

– air resistance,
– internal mechanisms resistance,
– inertia resistance,
– twist resistance,
– towed resistance.

Part of the resistance to motion is always present and some for only certain conditions of vehicle motion. Rolling resistance and air resistance is always present when the vehicle is moving. Grade resistance occurs only when the vehicle is moving uphill, the resistance of inertia occurs when there is a speed change (acceleration or deceleration of the car), while the twist resistance occurs when the vehicle moves on an arc. About the occurrence of towing resistance will be possible to speak for the movement of the vehicle with towed trailer or semi-trailer.

At the strength of the rolling resistance occurring during the car movement will be affected by car weight and the coefficient of rolling resistance. With the increase of these two parameters increases the resistance and thus to overcome them, it is necessary to provide more energy - that is, increase fuel consumption.

The coefficient of rolling resistance depends on many factors, inter alia:
– type and condition of the road surface on which the vehicle is moving,
– kind of used tires
– tire pressure
– car driving speed.

The use of too low tire pressure or too soft tires results in their increased deformation during driving, increased rolling resistance, and thus increased fuel consumption. The dependence of the relative rolling resistance coefficient of relative tire pressure is shown in Figure 11. The reference value was set at the pressure recommended by the vehicle manufacturer.

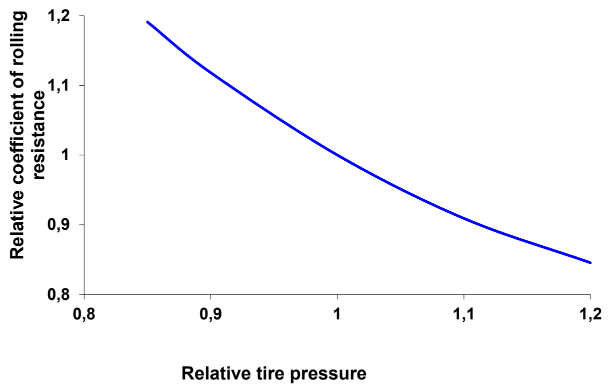

Fig. 11. The impact of the rolling resistance coefficient of the vehicle tire pressure

At present rolling resistance also affects the resistance of the convergence of the steered wheels due to their distinctive settings and the resistance caused by the friction elements of the suspension and damping in shock absorbers. Improper wheel alignment of the car increases the deformation of the tires, larger lateral slides of the tread on the road surface, increased friction and heating of tires, accelerated wear of the tread. Similar effects also causes friction of brake pads - brake drums or discs as a result of improper regulation Heating up the tires and tread wear while driving the vehicle, on which also affects condition of shock absorbers, requires the provision of additional power by the engine, and therefore increases fuel consumption

Regardless of the type of used tires and applied pressure values, with an increase in speed of the car increases the coefficient of rolling resistance. This relationship can be seen in Figure 12.

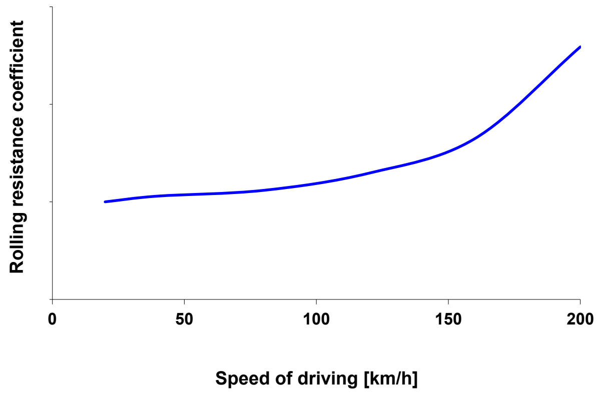

Fig. 12. The impact of driving speed of the car on the value of the rolling resistance coefficient

The movement of the car at every hill is associated automatically with the increase occurring resistance to motion. The driver to beat the hill must press the accelerator harder, which is associated with an increase in the amount of fuel supplied to the engine, or downshift to a lower, which also results in increased fuel consumption. In the case of small hills you can also do nothing, what allow automatically reduce the rotational speed and thus the driving speed of the car. This cause an increase in engine torque allowing overcoming the hill.

The influence of the road inclination on value of the fuel consumption of the vehicle traveling on the various gears is shown in Figure 13.

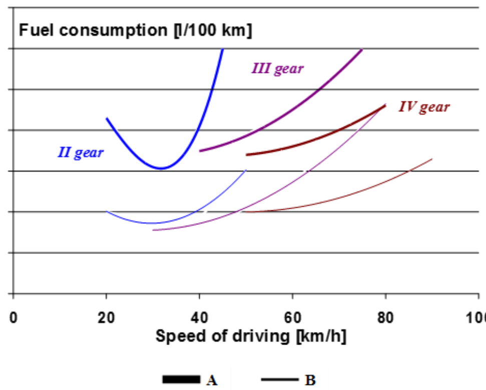

Fig. 13. The influence of the inclination of the road on the level of fuel consumption for the car moving at different gears: A - hills with a gradient of 5%, B - hills of inclination 0%

The force of air resistance depends on the shape and size of the bodywork and vehicle speed. Particular attention should be taken to the fact that air resistance increases with the square of the driving speed of the vehicle. Increasing the driving speed of 30 [km / h] to 120 [km / h] will result in up to sixteen fold increase in air resistance, and the related increase in fuel consumption. When driving a car with low speed, the force of air resistance is close to zero.

The shape of vehicle body is characterized by a coefficient of aerodynamic resistance c_x.

The total air resistance consists of the following factors:
– profile resistance dependent on the shape of the longitudinal section of the car body (share of approx. 58%),
– Inductive resistance caused by swirls of air on the sides of the car body (share of approx. 8%),

- resistance of air friction to the car body (share of approx. 10%),
- resistance of interference caused by the presence of handles, mirrors, ornaments, protruding elements under the floor (share of approx. 14%),
- resistance of the cooling and ventilation system (share of approx. 10%).

Use of additional covers - spoilers, improves air flow around the car body and can have a positive impact on fuel consumption. This is particularly evident in the case of cars with significant dimensions and disadvantageous shape of the body. By placing the spoiler on the roof of a truck, you can get a reduction in the coefficient of air by 10-15% and thus reducing fuel consumption by up to 15%. The influence of used roof and a front spoiler for the fuel consumption is shown in Figure 14.

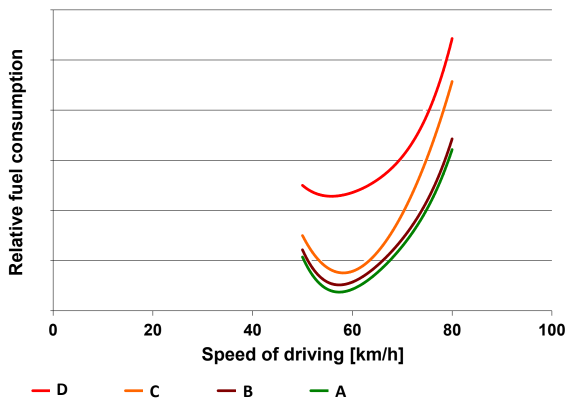

Fig. 14. The dependence of fuel consumption of the truck on driving speed and used spoiler: A - roof and front spoiler, B - roof spoiler, C - front spoiler, D - no spoilers

A significant impact on the level of fuel consumption in the car has a thermal state of the drive motor. Therefore, regardless of how the motor is cooled - air or liquid, it is equipped with regulators (thermostats), whose proper action is to ensure rapid heating after a cold start, and then keeping the temperature at a constant level regardless of the ambient conditions, load and rotational speed, road conditions and driving speed. Car user can observe lower fuel consumption during the summer compared to the winter and during operation over long distances than on short distances with frequent long stops. Dependence of relative fuel consumption of the distance travelled by the vehicle and the temperature is shown in Figure 15. The relative fuel consumption was related to the fuel consumption occurring at fully warmed up engine.

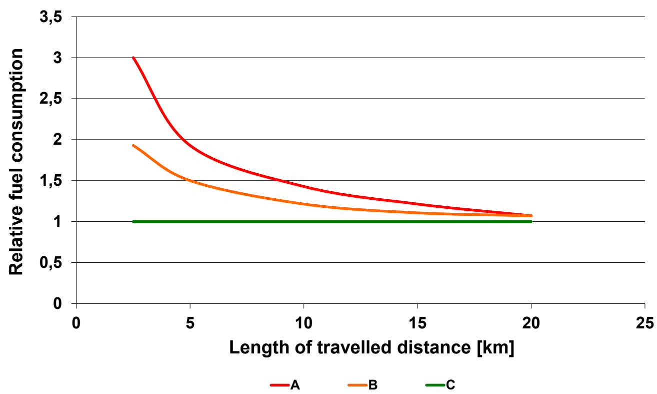

Fig. 15. Dependence of relative fuel consumption of the distance travelled for a complete heated engine - A state with an initial temperature of 20 [°C] - B, a state with an initial temperature of -10 [°C] - C

Significant impact on the car's fuel consumption has a length of route. The greatest amount of fuel the engine consumes in the first minutes after starting their work. This is particularly evident at start-up in fully cooled engine at low ambient temperatures. This is due to the fact that the time of thermal stability of the car - the time period until the engine oil reaches the predetermined temperature, strongly depends on the ambient temperature and it may exceed 10 minutes. On the length of the thermal stability time of the engine depends on the degree of cooling of, which is dependent on the parking time of the vehicle at a given temperature. Depending on the ambient temperature, engine cools by several hours. Figure 16 shows the effect of thermal stabilization time of engine for additional fuel requirements, while Figure 17 illustrates the effect of the parking time of the car on the degree of cooling of the engine.

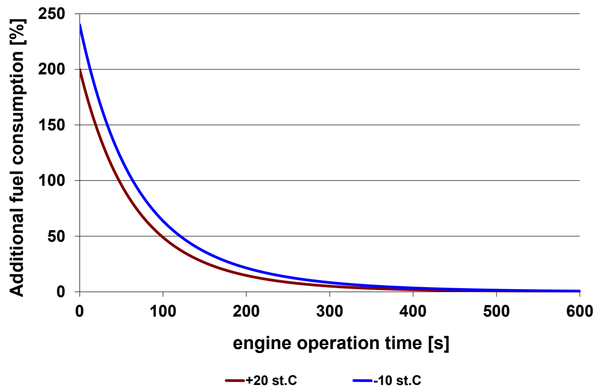

Fig. 16. Dependence of fuel consumption on the thermal stabilization of the engine.

Occurring during the drive resistance of all types, and energy losses must be compensated by an appropriate power of the drive unit. Sample demand for engine power while driving a car at a constant speed is shown in Figure 18, 19, 20, 21 and 22.

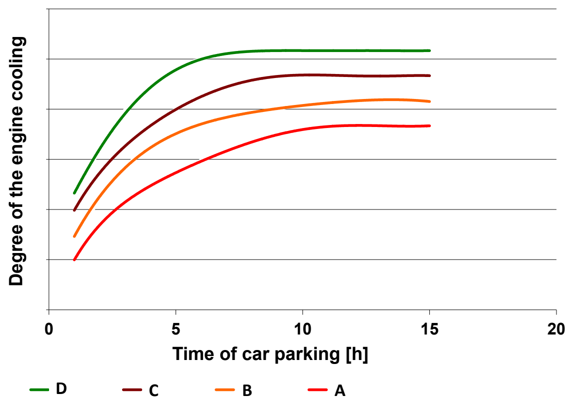

Fig. 17. The influence of the time of car parking and ambient temperature on the degree of the engine cooling for: A – -15 [°C], B – 0 [°C], C – 10 [°C], D – 20 [°C]

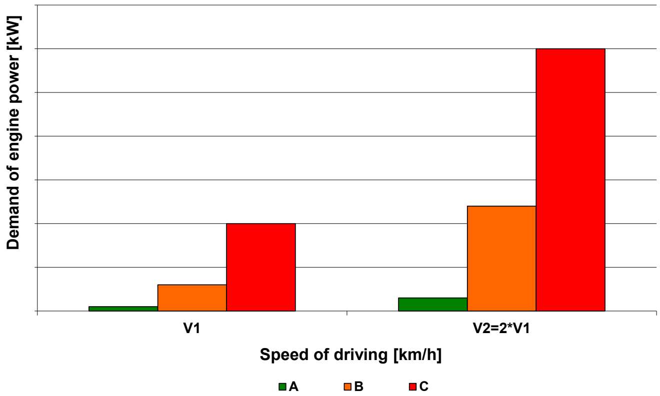

Fig. 18. *Demand of engine power on losses in the drive system: A - passenger car, B - truck, C - truck tractor with trailer*

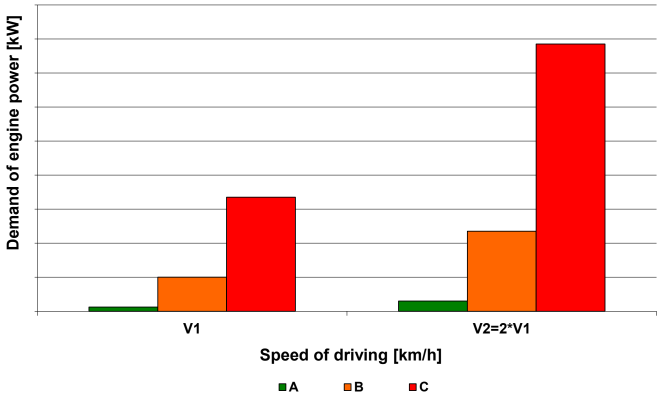

Fig. 19 *Demand of engine power to overcome rolling resistance for: A - passenger car, B - truck, C - truck tractor with trailer*

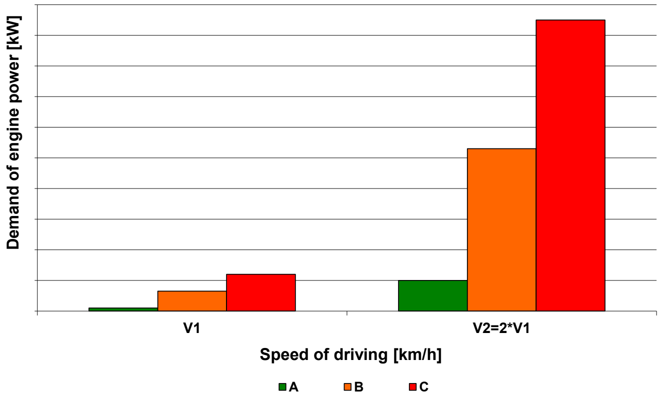

Fig. 20. *Demand of engine power to overcome air resistance for: A - passenger car, B - truck, C - truck tractor with trailer*

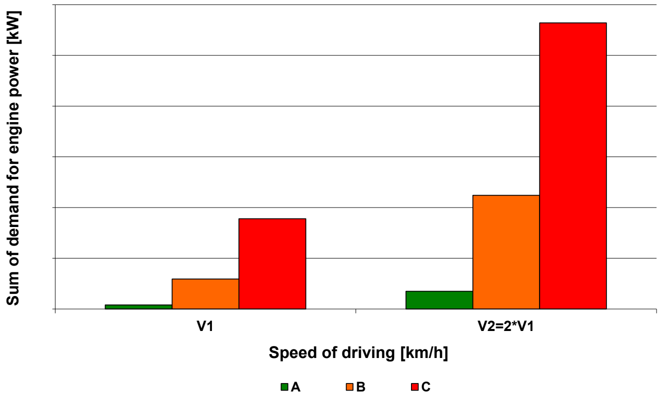

Fig. 21. *The sum of demand for engine power for: A - passenger car, B - truck, C - truck tractor with trailer*

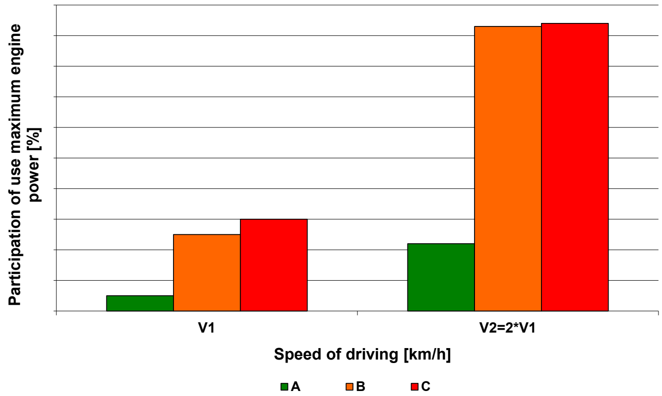

Fig. 22. *Participation of use maximum engine power for: A - passenger car, B - truck, C - truck tractor with trailer*

Effect of increasing the unit power, which is the ratio of maximum power to the total weight of the vehicle on the achieved fuel consumption, is shown in Figure 23.

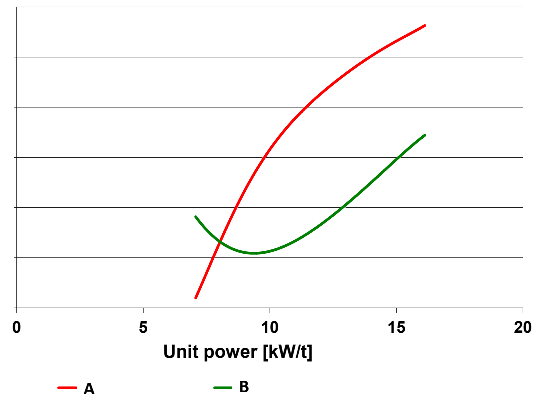

Fig. 23. *Dependence of fuel consumption (B) and the average speed of the car (A) on the unit power*

The increase in unit power, results in improved drivability of the car, increases the average speed, but it will happen at the expense of increase in fuel consumption. Also, excessive reduction of the power unit is disadvantageous due to appearing reduction in the average driving speed of the car with increased fuel consumption. Having, therefore, the choice of the drive unit when buying a car, you should in this respect proceed with caution.

SUMMARY

The energy intensity of vehicle motion expresses the energy demand for the driven wheels, which is essential to the movement of the assumed by the driver motion parameters (speed, acceleration). The total energy supplied to the engine in the form of fuel chemical energy is the sum of energy on the driven wheels - balancing resistance to motion, energy losses in the engine and drivetrain, and energy consumed by the drive motor when idling (no transfer of power to the wheels) - for example, during braking or layover.

The kinetic energy gained in the acceleration phases is somewhat dissipated by the brakes, and to some extent consumed to overcome the resistance to motion, when driving with the engine off - although to a much lesser degree.

The process of acceleration is the most energy-intensive phase of the vehicle. Even with the car accelerating at a moderate intensity, the increase in kinetic energy far exceeds the energy expenditure required to overcome the resistance to motion.

Also in case of braking process, the driver can influence the energy consumption. Of course, it should be noted that its formation is possible only under free braking - means that when the driver has freedom to choose the intensity and a method of reducing speed.

When analysing the factors affecting the level of fuel consumption by the vehicle, you should keep in mind the system: driver - car - an environment, the components of which are interrelated.

Please note that the malfunction of individual components of the vehicle system may contribute to the increased energy demand. Therefore, all over the world are conducted numerous studies related to increasing the reliability of the individual components as well as the entire systems [14-26]. Of course, there is no shortage among these studies those directly related to the issues concerning the issue of energy consumption of motion [1-13]. This study was based on this type of literature sources.

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Wpływ warunków ruchu pojazdu na jego ekonomiczność

W minionym okresie na całym świecie pojawiły się symptomy wyczerpywania się zapasów naturalnych źródeł energii. Przejawia się to poprzez rosnące ceny paliw oraz znaczne zwiększenie zaangażowania w poszukiwania alternatywnych źródeł energii, które mogą znaleźć zastosowanie w pojazdach samochodowych. Wspomniany wzrost ceny paliwa sprawił, że użytkownicy pojazdów podjęli próby zmniejszenia jego zużycia poprzez wprowadzenie zasad ekonomicznej i oszczędnej jazdy. Zasady te stanowią kompromis pomiędzy oszczędnością, bezpieczeństwem oraz przyjemnością. Łączy spokojną, płynną jazdę w określonych warunkach z dynamicznym przyspieszaniem wtedy, kiedy jest to możliwe. W artykule przedstawiono wpływ wybranych warunków ruchu na jego ekonomiczność. Stanowi on opracowanie literaturowe omawianej tematyki [1-13].

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