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COMPARATIVE ANALYSIS OF THE OPERATING INDEXES OF MANUALLY AND AUTOMATICALLY CONTROLLED PASSENGER CAR POWERTRAIN SYSTEM AT VARIABLE LOAD STATES

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Abstract

This article reports the results of a study into operating parameters of a system consisting of an SI engine and a powertrain in a Fiat Panda passenger car in the conditions of a variable load. The analysis was primarily concerned with the variability of fuel consumption resulting of the changing load applied to the driving wheels in the conditions of a test performed on chassis dynamometer for manual and automatic controlled transmission gear change The test bench included a dedicated driving cycle, which was developed as cycle with periodically changed constant linear speed of the car every 10 km/h. According to the vehicle set speed, the load on its wheels was determined by the basic resistance as rolling resistance, air resistance and resistance corresponding to road inclination. Each period of a drive cycle corresponding to steady state driving gave the average instantaneous values of drive system performance indicators. The waveforms of these indicators were recorded and then averaged and presented as representative points of the powertrain system that were analysed. The focus of the study involved the identification of the points characterized with the minimum specific fuel consumption and impact of type of powertrain control on emission of CO_2 from passenger car SI engines.

Keywords: *fuel consumption, spark ignition engine, variable load, engine efficiency, motion resistance*

1. Introduction

The driving force developed at the vehicle wheels depends on many variables that the driver should take into account during manual gear changing. Both manual and automatic shift control should take into account many properties: dynamic, economic and also ecological [1-3, 5]. In recent times, very much attention is paid to ecological aspects [4, 9]. All this aspects is related to the interaction in the driver-car-surroundings. The driver, acting on the shift lever and the accelerator pedal, selects the momentary operating point of the drivetrain system that responds to the desired vehicle speed and decides about the output power in accordance with equation (1) [6-8]:

$$N = N_s \cdot \eta_P , \tag{1}$$

where:
N – powertrain output Power, W,
η_p – efficiency of transmission system,
N_s – engine output power, W.

The engine power and engine speed in the drive system is determined by the selected gear, and selecting the throttle position determining the torque of the internal combustion engine. This dependence can be written with equation (2) [6-8]:

$$N_s = M_o \cdot 2\pi n_s , \qquad (2)$$

where:
M_o – engine torque, N·m,
n_s – engine rotational speed, rpm.

At the same time the driver is interested in the direct control such parameter in the powertrain system, as the vehicle speed, in accordance with equation (3) [6-8]:

$$N = F_n \cdot V , \qquad (3)$$

where:
F_n – driving force, N,
V – vehicle speed, $m \cdot s^{-1}$.

Hence the interdependence of several variables, on the values of which also affect the environment. Hence, this article presents an analysis of the powertrain system parameters in response to the variable load both for manual and automatic controlled transmission. The work has verified the assumption that control of the powertrain system depends on its load. The variable load of powertrain system refers to the increase of percentage road inclination for the particular selected transmission ratios.

2. Measurement methodology

The analysis of fuel consumption of the conditions of the variable engine load was performed on the basis of the research conducted on a MAHA MSR 500 chassis dynamometer installed at the Department of Road and Agricultural Vehicles, Opole University of Technology. The testing applied Fiat Panda passenger car with the engine capacity 1242 cm^3 and a maximum power of 44 kW (Fig. 1).

Fig. 1. Test object and chassis dynamometer test stand

A dedicated driving cycle was defined for the purposes of the research with a section involving a constant linear car velocity for each of the gearbox ratios. The range of the linear vehicle velocity was selected individually for each of the gears so that the rotational speed can be changed in the range from 1000 rpm to 5500 rpm. The linear velocity was increased stepwise by 10 km/h and the velocity profile followed in the driving cycle is presented in Fig. 2.

Throughout the duration of the test, the car was in motion at a constant linear car velocity and the gearbox ratio was given in accordance with the cycle described above. In addition, the scope of the study involved the change of the additional load of the powertrain associated with the simulated variation in the road inclination. The basic study was conducted for the car rolling on a horizontal surface and, subsequently, simulation tests were repeated for the 3%, 5%, 7% and 10% road inclinations.

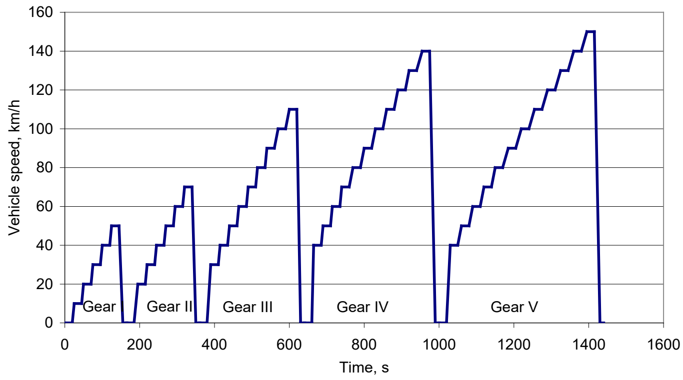

Fig. 2. Course of the driving cycle

The testing procedure was accompanied by the measurements of fuel consumption undertaken with Flowtronic 215 fuel measuring system accompanied by pollutant emission measurement by means of MGT 5 analyser.

3. Fuel consumption during constant car velocity

The literature in the area of vehicle dynamics fundamentals [7, 8] shows that driving force acting on a car in the conditions of its acceleration or rolling at a constant speed, we have to do with an equilibrium resulting from the resistance to motion, consisting of rolling resistance, drag forces, climbing resistance and inertia forces resulting from the car acceleration.

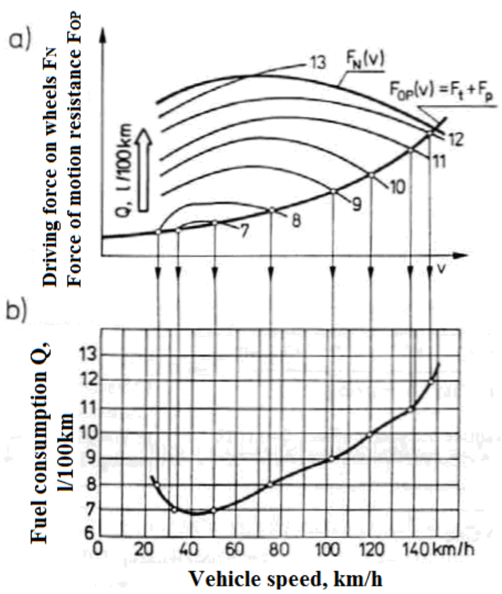

Fig. 3. Fuel consumption for a constant car velocity [8]

The figure above represents the theoretical description of the characteristic of fuel consumption for a constant car velocity. The points in Fig. 3a define the characteristics of the instantaneous equilibrium of the transmission system, where the driving force is balanced by the forces acting on the car. Given the simplifications above, for a constant linear car velocity, we can perform an analysis of the course of the driving force in a car powertrain in an experimental manner by following adequate procedures during road test. However, we need to bear in mind that it is beneficial to perform all these activities during a single road test, whose course should be similar to the standard driving manoeuvres performed by a driver throughout an actual road drive.

4. Variable load of the powertrain

The variable load of the transmission in a car is realized by application of an electrodynamic brake to the drive axle. The registered driving force acting on the dynamometer rollers is formed by the product of the driving force output and the linear car velocity. On the basis of the conducted studies, we have undertaken an analysis of the course of the power generated by the engine, and an exemplary power curve for a given constant load (for 3% road inclination) and variable linear car velocity corresponding to the particular gearbox ratios. However, within the range of the constant ratio in the 3rd gear, the variability of the engine power is already considerable during the changing road inclination (Fig. 4).

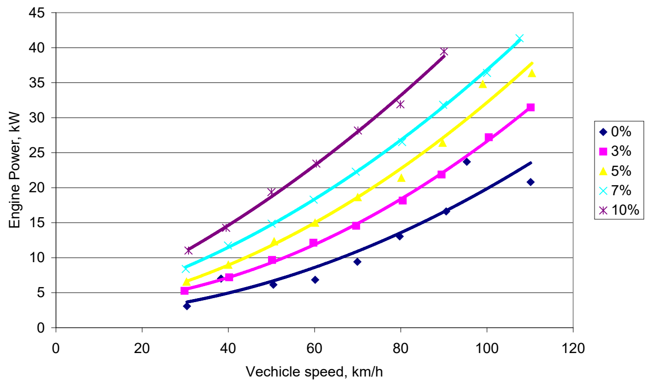

Fig. 4. Course of the engine power for 3rd gear corresponding to various road inclinations

The change in the road inclination from 0% to 10% leads to almost 2.5 times increase of the engine power. Concurrently, in the conditions of 10% road inclination, the car is not capable of developing an output adequate to accelerate the car to the demanded constant velocity specified in the driving cycle. This condition was registered for 3rd gear (partly), as well as 4th and 5th gears.

Such measurements for the manual controlled gearbox were compared, under the same conditions of varying load on the various road inclination angles, with the automatically controlled gearbox. For manual controlled gearboxes, minimum fuel consumption was determined for every cycle constant speed, for which the remaining powertrain system parameters were read. Particular attention was paid to the achieved engine torque and gear ratio selection. The results are shown in Fig. 5-8.

The analysis of research data (Fig. 5-8) shows that the increasing load in the powertrain system, the differences between the operating indexes of the powertrain system being controlled manually and automatically are more and more significant. In load conditions, for up to 10% road inclination, both the drive unit operates in a different operating area and the transmission system operates with a different gear ratio. Such operating conditions of the powertrain system result in a reduction in average fuel consumption by 1.25 dm^3 / 100 km. Taking into account the fuel consumption conversion factor for CO_2 emissions (1 dm^3 / 100 km to 24 g / km CO_2), reduction of emissions of more than 30 g / km can be achieved.

The reduction of CO_2 emissions in this case is the result of a change in the way the drive system is controlled. Despite the fact that for the manual controlled gearbox the least fuel consumption has been achieved, the change in engine speed when tested on a variable-duty engine dynamometer ultimately affects the engine's efficiency, which is close to its maximum value, as shown in the Fig. 9.

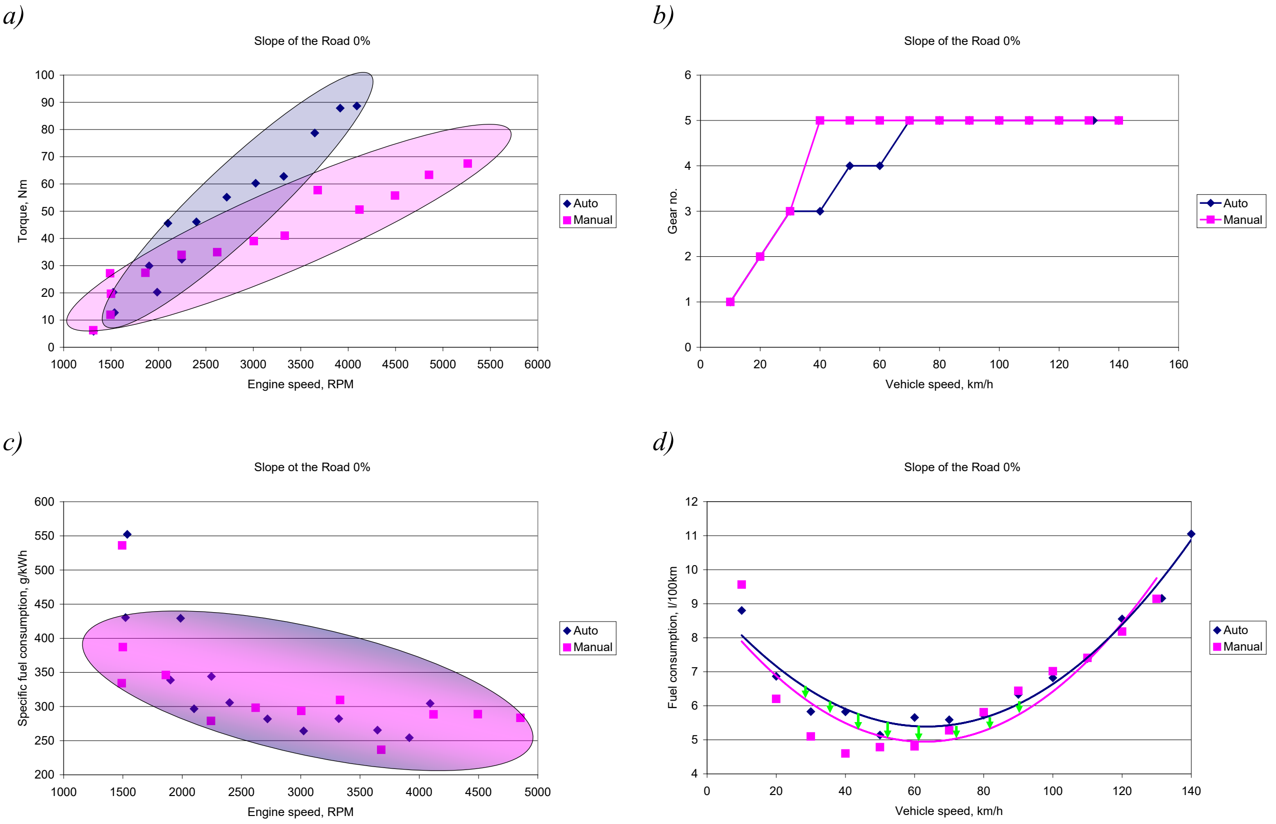

Fig. 5. Tests results for 0% road inclination; a) torque, b) gear number, c) specified fuel consumption, d) fuel consumption, for automatic and manual transmission

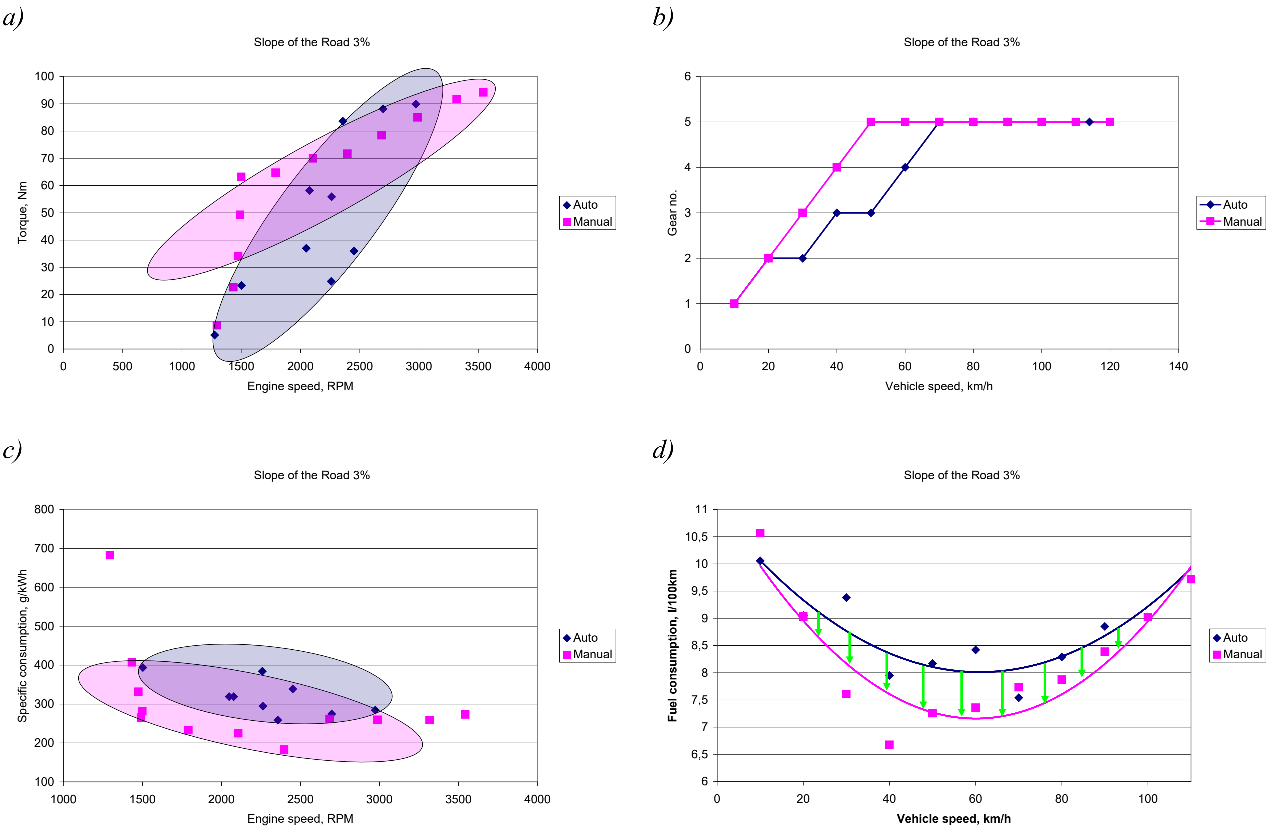

Fig. 6. Tests results for 3% road inclination; a) torque, b) gear number, c) specified fuel consumption, d) fuel consumption, for automatic and manual transmission

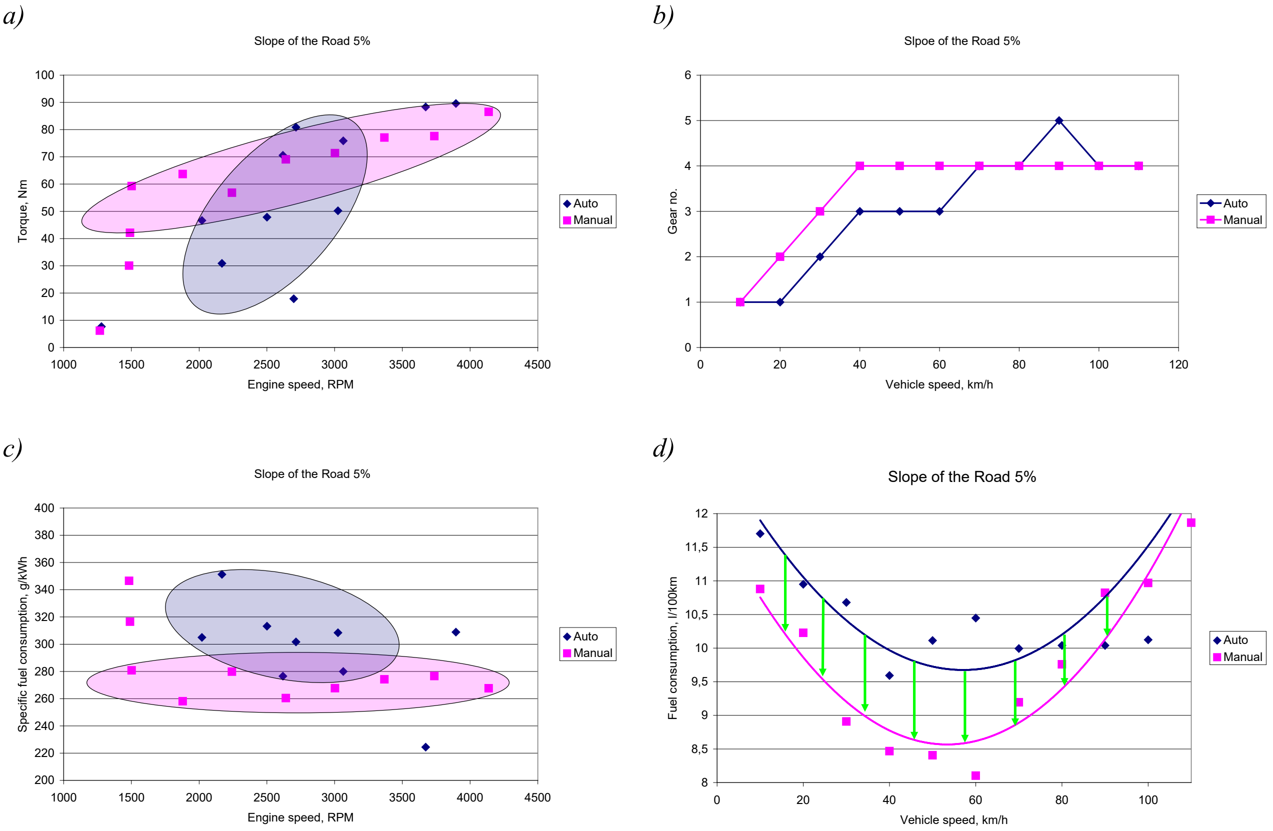

Fig. 7. Tests results for 5% road inclination; a) torque, b) gear number, c) specified fuel consumption, d) fuel consumption, for automatic and manual transmission

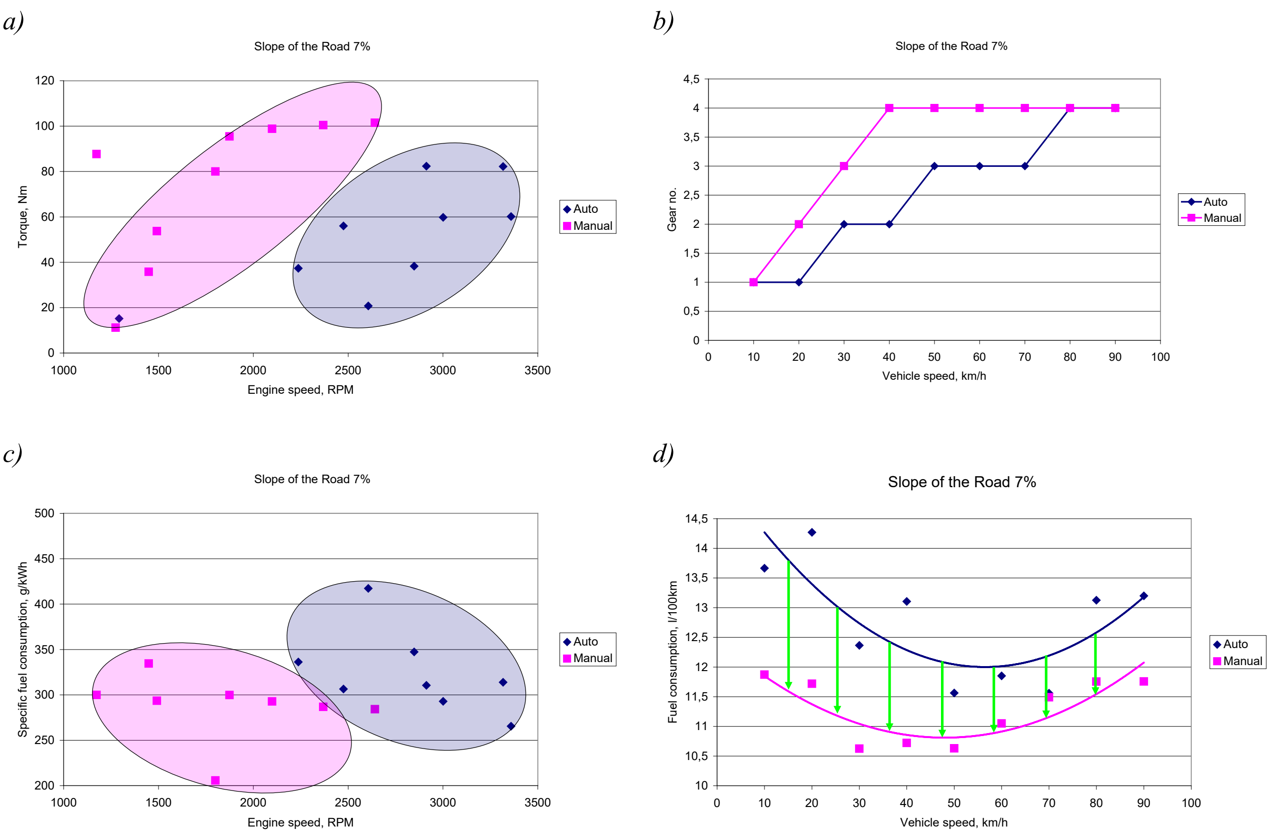

Fig. 8. Tests results for 7% road inclination; a) torque, b) gear number, c) specified fuel consumption, d) fuel consumption, for automatic and manual transmission

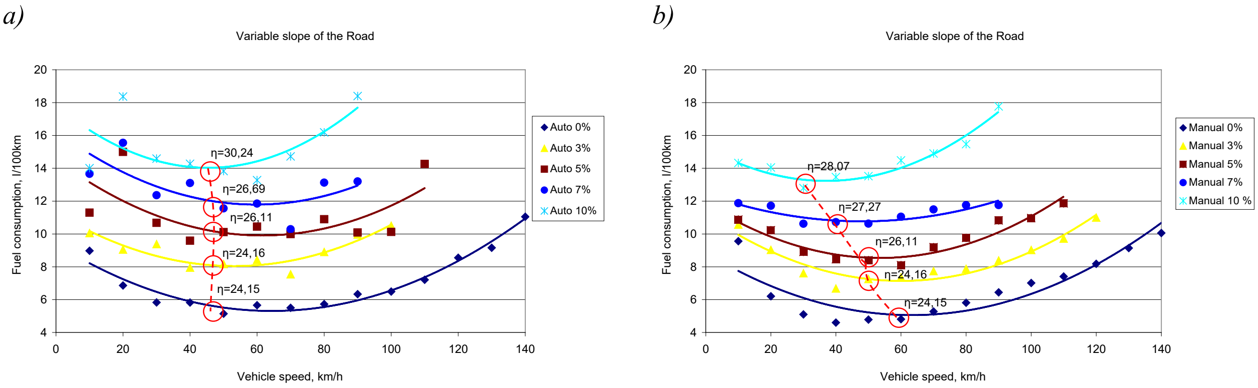

Fig. 9. Fuel consumption for variable road inclination; a) automatic transmission, b) manual transmission

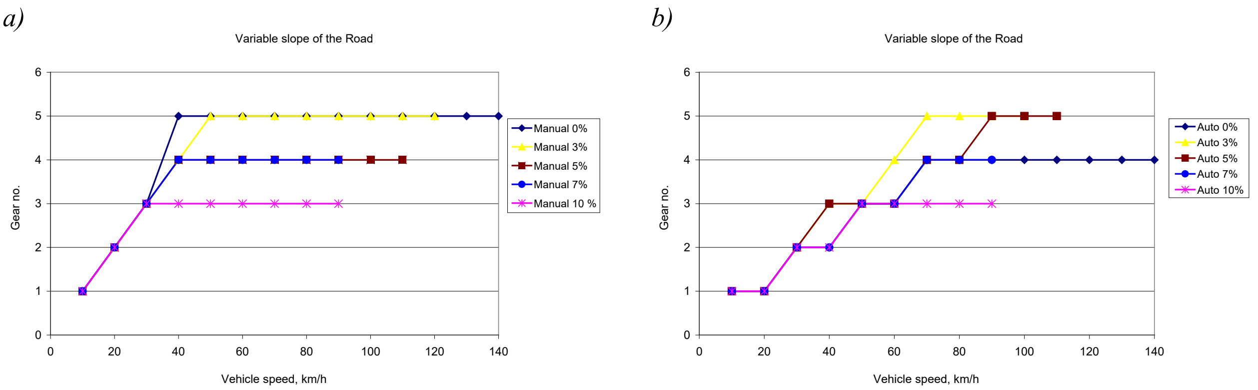

Fig. 10. Selected gear number for variable road inclination; a) automatic transmission, b) manual transmission

However, maximum performance values are achieved at other vehicle linear speeds. Fig. 10 a/b shows differences in gear selection. The automatic control system in a rather schematic way selects the gear ratio in comparison to the manual control of the drive system.

5. Conclusions

The results of the test of the passenger car's variable-load of powertrain system show the differences between the automatic transmission mode and the manual control. In the chassis dynamometer simulated variable vehicle resistance, it is possible to reduce fuel consumption and CO_2 emissions as a result of a change in control strategy. The powertrain system operating in automatic mode does not take into account changes in the load of the driveline as a result of variable loads resulting from the change of road inclination, which results in the appearance of temporary load fluctuations on the vehicle wheels. Under such conditions, it would be necessary to correct the gear ratio in the power transmission system that results in a change in the load on the power unit. Such changes cause that in the powertrain system we can achieve:

- with the same efficiency of the engine driving at higher vehicle speeds,
- driving at higher speeds and less mileage fuel consumption,
- in low speed conditions, adjust the gear ratio in the transmission system;
- contrary to popular opinion (ecodriving), not always the smallest gear ratio and low engine speed is beneficial.

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