ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/01.3001.0012.4783

COMPARATIVE ANALYSIS OF THE FUEL CONSUMPTION OF VEHICLES EQUIPPED WITH VARIOUS TYPES OF AUTOMATIC TRANSMISSIONS

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Abstract

The growing number of vehicles moving on Polish roads equipped with various types of automatic transmissions prompted the authors of this publication to carry out research to assess the impact of the use of this type of transmission on the fuel consumption of these vehicles. The presented article presents a comparative analysis of the fuel consumption of vehicles of different manufacturers equipped with automatic transmissions moving in specially prepared driving cycles for research purposes. In the developed driving cycle, the vehicle speed was gradually increased every 10 km/h, maintaining each speed for a period of at least 30 seconds in order to stabilize the measurement results. The tests were carried out for various load stages of the drive system. Load differentiation was made by simulating driving in the prepared cycle for simulated different slopes of the road. The tests were carried out on the MAHA MSR500 chassis dynamometer, and the obtained results for the vehicle moving in automatic mode, where the transmission controller selected the gear ratio according to the programmed algorithm, were compared with the vehicle's fuel consumption for the vehicle gear selected by the driver in the driving cycle. The control software used to test the chassis dynamometer allows taking into account the increasing resistance of traffic along with the increase of vehicle speed, which greatly approximates the simulated conditions in the laboratory to the conditions on the road. The main purpose of this publication is to check whether using automatic transmissions or other control algorithm of these gears can achieve a reduction in fuel consumption.

Keywords: *automatic transmission, fuel consumption, control algorithm, CVT, automotive powertrain, road slope*

1. Introduction

The first vehicles produced at the turn of the 19th and 20th century, could have three types of propulsion (three types of engines): combustion, steam, or electric engine. Today, cars are also powered by internal combustion engines or electric engines, but they are quite different in design and technology from those at the beginning of the history of motor vehicles. Electric and steam engines show very good compatibility with the drive's ideal characteristics. The undoubted advantage is that they have maximum torque at minimum (zero) rotational speed and the possibility of obtaining maximum power in various ranges of rotational speed. Due to the principle of operation, internal combustion engines do not have such a good drive characteristics as electric or steam units. Their biggest advantage is the type of fuel burned, i.e. diesel or petrol, which have a high-energy value at a low unit weight, which in turn translates into a significant range of the vehicle [6, 7]. Their undoubted advantage is also the short time and relatively simple and safe way of refuelling, which today is impossible to obtain by vehicles powered by electric motors.

Considering the above-mentioned vehicles powered by internal combustion engines, they will be produced and used on roads all over the world in the next decade or decades. However, more and more stringent emission standards force vehicle manufacturers to increasingly advanced systems to reduce fuel consumption and emissions of harmful substances emitted into the natural environment. Engines are constantly being modified in the vehicles, but also more and more attention is devoted to power transmission systems, and in particular to systems that allow for an automatic mode of operation. The share of automatic transmission systems in global terms shows a decisive upward trend, while the share of solutions offering manual mode of selection and shifting of the transmission ratio is decreasing [8]. Manual gear selection is often related to the driver's individual preferences and can result in a significantly different gear ratio selection than the optimal one, but also automatic transmission ratio algorithm could show not optimal operation [10]. Therefore, it was decided to conduct comparative tests of fuel consumption of vehicles equipped with automatic transmissions operating in automatic mode and manual gear selection. During the tests, additional loads of the drive system were made by simulating the vehicle's driving on the road with different degrees of inclination.

2. Research methodology

The tests needed to perform the analysis of fuel consumption under variable engine load conditions were carried out on a chassis dynamometer MAHA MSR 500 located in the Department of Vehicles of the Opole University of Technology. Three vehicles were used in the tests:

– Citroen C5 3.0 V6 with an engine capacity of 2946 cm^3 and a maximum power of 152 kW equipped with a 5-speed transmission with torque converter,
– Fiat Punto II with an engine capacity of 1242 cm^3 and a maximum power of 59 kW equipped with a CVT transmission and torque converter,
– Fiat Panda with an engine capacity of 1242 cm^3 and a maximum power of 44 kW equipped with friction clutch and automated gear transmission with 5 speed.

Fig. 1. Test vehicle Fiat Punto II on the measurement stand (chassis dynamometer MAHA MSR 500)

For the purpose of the study, dedicated driving cycles were defined (individually for each vehicle) with sections with constant linear velocities of the car for each gear ratio. Speed profiles for the tested vehicles are shown in Fig. 2.

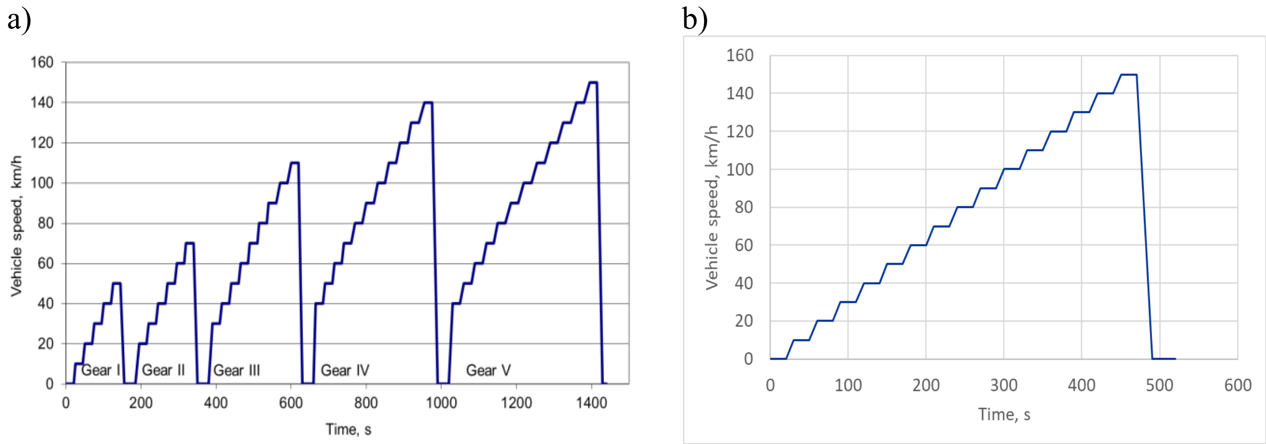

Fig. 2. The course of the driving cycle for: a) manual mode, b) automatic mode

During the tests, the vehicles drive at constant speeds according to the set driving cycle. The individual speeds were adapted to the gear ratios and the engine rotational speed range of the vehicle. The tests were carried out with a variable load on the vehicle's propulsion system, by simulating the load resulting from the inclination of the road. The basic measurement was carried out for a vehicle moving on a level surface, and then the tests for simulated slopes of 3%, 5%, 7.5% and 10% were repeated. Variable load on the drive system is implemented by applying an electrodynamic brake to the drive axle.

Fuel consumption values were measured using the Flowtronic 215 fuel flow meter and saved to a file.

In order to make a comparative assessment of the effects of the gearshift control algorithm in terms of fuel consumption, each driving cycle was carried out in automatic and manual mode. The measurement in manual mode consisted in examining the fuel consumption on each gear in the full range of engine speeds, previously individually matched to a particular vehicle, the limitation being the permissible range of engine speed. After receiving the results, gears were selected in which fuel consumption was the lowest for a given vehicle speed. The obtained results from both operating modes were compared and the analysis was created.

The gear ratio to vehicle speed charts are based on the calculated ratio of engine speed to the speed of the drive wheels. The calculations consisted in determining the wheel rotation speed at given speeds consistent with driving cycles, however, without taking into account changes in the tire dynamic radius and their deflection on the dynamometer rollers. Apart from the slight error resulting from the tire deformation of the tire on the roll, the total transmission ratio was estimated to identify a transmission gear.

3. Test results analysis

3.1. Fiat Panda

According to the driving cycles, the Fiat Panda drivetrain tests were carried out. The driving profile was implemented according to the automatic or manual gear selection algorithm (Fig. 3). As the graph shows, the manual method of gear selection gives more selection field. In the case of manual gear selection, it can be often choose between 3 gear ratios, and the automatic algorithm significantly narrows the selection field.

The result of consumption of mileage fuel consumption obtained for the automatic and manual selection of the transmission ratio is shown in Fig. 3 [9].

The comparison of the transmission ratio selection method for the automated gearbox shows that it is possible to achieve a reduction in fuel consumption in the case of manual selection of the transmission ratio (Fig. 4) especially for higher loads (5%, 7%, 10%). Savings in terms of mileage fuel consumption resulting from the change of the shift algorithm may in this case reach even more than 20% (e.g. for a road inclination of 5% and a speed of 60 km/h).

a) b)

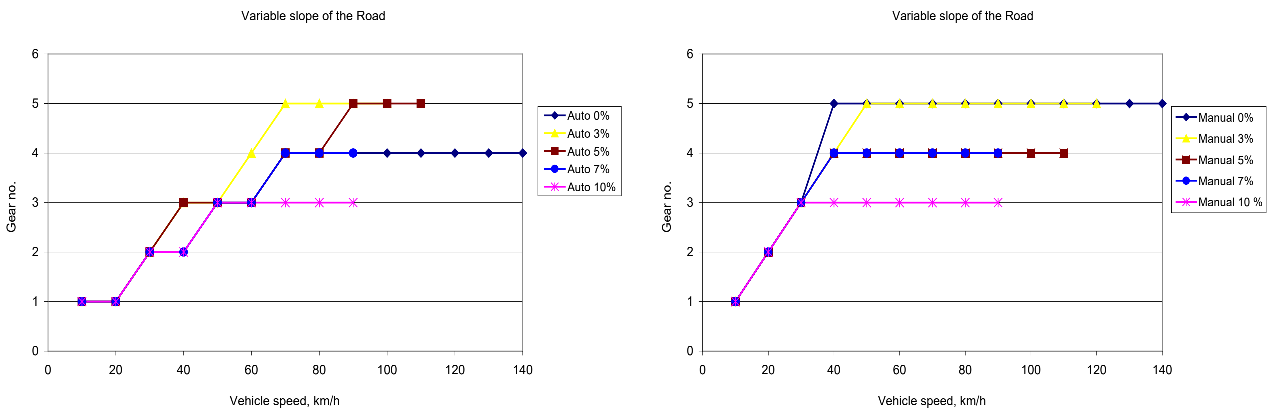

Fig. 3. Selected gear number for variable road inclination; a) automatic transmission ratio select, b) manual transmission ratio select [9]

a) b)

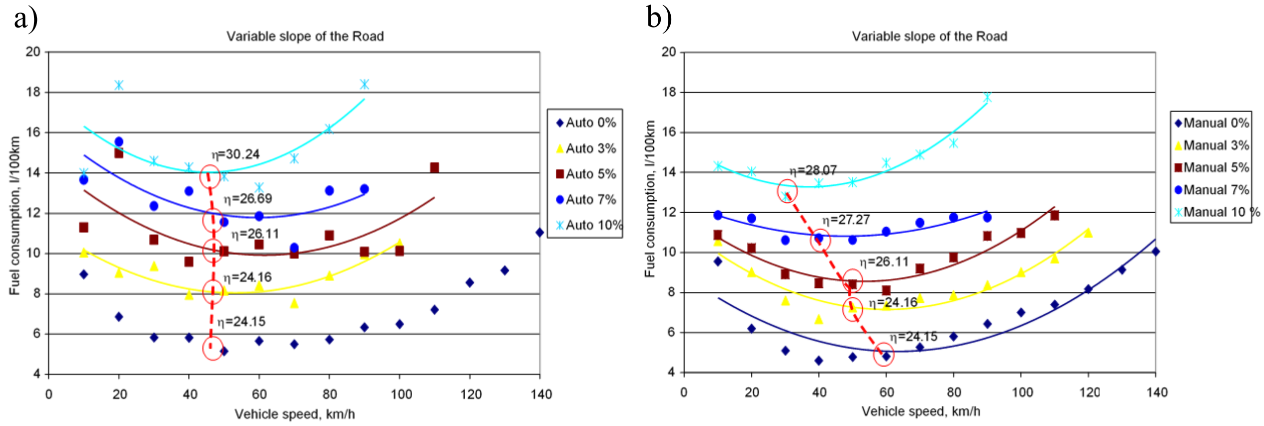

Fig. 4. Fuel consumption for variable road inclination; a) automatic transmission ratio select, b) manual transmission ratio select [9]

3.2. Citroen C5

Also in the case of the next test vehicle, the driving cycles presented in Fig. 2 were used. The change of vehicle wheel load was carried out by simulating the driving with different slope of the road from 0-10%. The results of the selection of the total drive transmission ratio realized in automatic and manual mode during tests in the test cycle are shown in Fig. 5. From the comparison of the graphs, you can clearly see the greater possibility of choosing a lower total gear ratio in manual mode.

The presented results (Fig. 6) of the results of mileage fuel consumption show that also in the case of high load on the propulsion system (simulated as a climb of 7%, 10%) it is possible to achieve a fuel consumption reduction by several percent to approx. 5%). At the same time, as the test results show, some of the measuring points with the automatic selection mode show a slight reduction in fuel consumption compared to the manual mode. This situation, despite choosing the same transmission ratio value, may be caused by a slightly different algorithm for controlling the torque converter between the manual and automatic gear selection modes.

a) b)

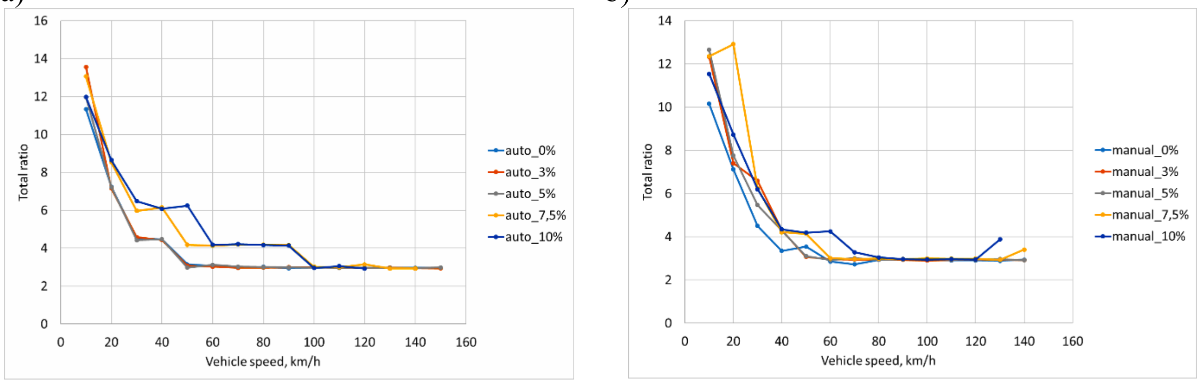

Fig. 5. Selected gear number for variable road inclination; a) automatic transmission ratio select, b) manual transmission ratio select

a) b)

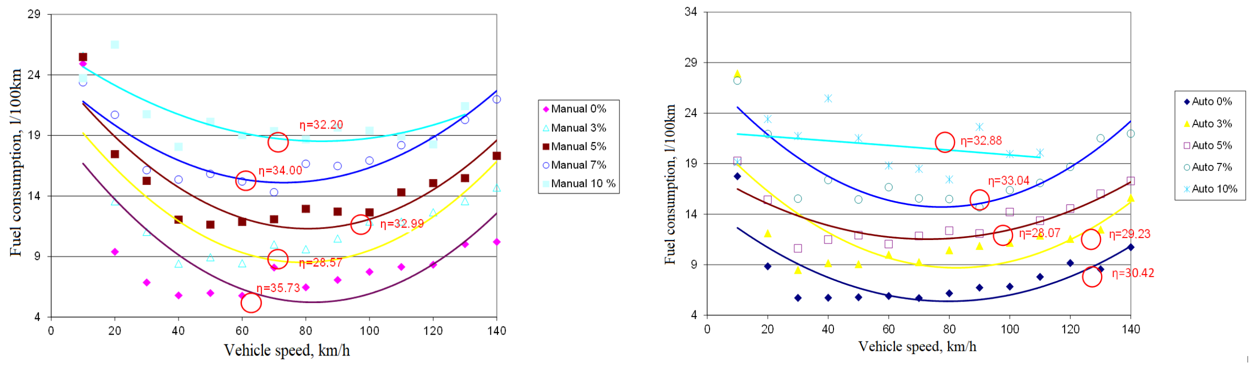

Fig. 6. Fuel consumption for variable road inclination; a) automatic transmission ratio select, b) manual transmission ratio select

3.3. Fiat Punto

In the case of the third test vehicle, the drive system is equipped with a continuously variable transmission interacting with the hydrokinetic torque converter. The infinitely variable gear ratio with a wide shift range allows for great flexibility in gear ratio selection. The application of manual selection of the ratio from among several selected software values limits the transmission selection field to a significant extent, only to the determined values. As shown by the results of the research (Fig. 7), the automatic selection of the ratio from a wide range allows achieving satisfactory results.

a) b)

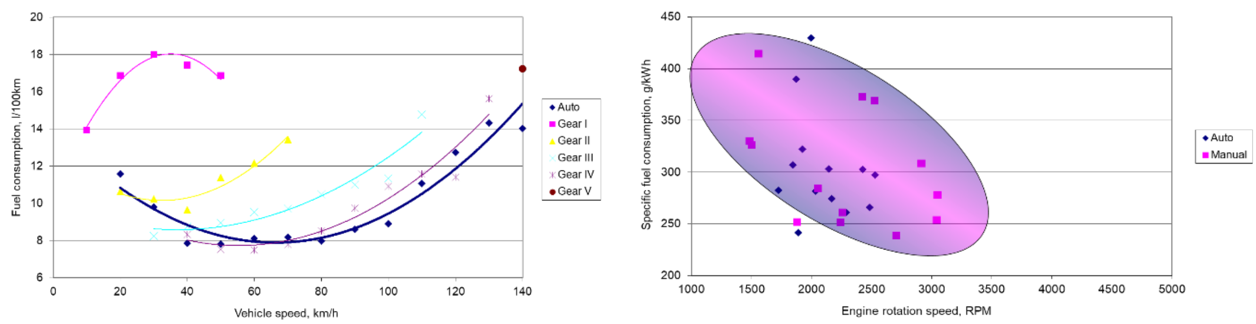

Fig. 7. Fuel consumption for 3% road inclination a) mileage fuel consumption, b) unit fuel consumption

The application of manual selection of the transmission value does not significantly affect the measured minimal values of fuel consumption, but there is a 3 – 4 operating point with a slack lower fuel consumption. Analysing the results of unit fuel consumption it can be noticed that the automatic steeples selection of the gear ratio results in narrowing the range of used engine speeds in relation to the manual mode. Thus, it can be concluded that for the load under test (driving simulation at an elevation of 3%); the gear selection algorithm is close to the optimal one in terms of fuel consumption. This does not mean, however, that the solution used has no potential to further reduce fuel consumption due to structural changes (e.g. replacement of the torque converter with an automatic friction clutch assembly) or a change in the control method of the clamping force of the variable transmission belt.

4. Summary

The article analyses the fuel consumption in variable engine load conditions and an assessment of the correctness of the operation of the transmission control algorithms in the tested vehicles was made. After analysis, it was found that in the case of the tested vehicles it is possible to optimize the control algorithms to reduce fuel consumption.

The development of an optimal automatic transmission control algorithm is troublesome due to the large number of variables such as the drive system load, the best engine efficiency range and the difficulty to perform the test under ideal conditions, but on the basis of the results it can be noticed how important the appropriate control algorithm plays. It allows reducing fuel consumption at given speeds by even more than 2 dm3/100 km (over 20%). Based on the analyses made, it can be concluded that the propulsion systems of tested vehicles operating in automatic mode often do not take into account the variable load resulting from changes in the road gradient, which is a direct reason for differences in fuel consumption. Summing up it should be noted that there is a considerable potential to improve the transmission control algorithms [6]. One of the important factors that can be used to improve the shift control algorithms is, among other things, to consider the transmission system load.

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Manuscript received 23 July 2018; approved for printing 24 September 2018