

THE EFFECTS OF GEAR SHIFT INDICATOR USAGE ON FUEL EFFICIENCY OF A MOTOR VEHICLE

by

Ivan A. BLAGOJEVIĆ*, **Goran S. VOROTOVIĆ**,
Dragan D. STAMENKOVIĆ, **Nebojša B. PETROVIĆ**,
and Branislav B. RAKIĆEVIĆ

Faculty of Mechanical Engineering, University of Belgrade, Belgrade, Serbia

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The manner of gear shifting is one of the main factors affecting the fuel efficiency of motor vehicles. Potential savings resulted from optimized gear shifting led to introduction of gear shift indicators in passenger vehicles as an obligation from year 2012. The effects of gear shift indicators usage are still not studied enough. That was the motive for the authors to conduct the experiments to justify their usage, both from the economic and ecological standpoint. The presented results come from the tests conducted on FIAT 500L vehicle to determine the fuel consumption using the new European driving cycle, but for three different gear shift patterns: (1) as defined in UNECE Regulation No. 83, (2) as indicated by vehicle's gear shift indicator, and (3) based on the average vehicle speed values collected from gear shift indicators of 35 passenger vehicles of different makes, types, and characteristics. Maximum difference in fuel consumption recorded in tests done using three different gear shift patterns is 18.7%.

Key words: *gear shifting, gear shift indicator, fuel consumption, fuel saving, driving cycle, gear shift points*

Introduction

Limited oil reserves and growing pollution caused by ever-increasing number of vehicles, together with legislation dealing with the area, force the manufacturers to constantly reduce fuel consumption, and engine emission in their vehicles. One of the complementary measures is the fitment of gear shift indicator (GSI) on all M₁ category vehicles fitted with manual gearbox. The aim of GSI is to provide a visual indication, advising the driver when to change gear to reduce the fuel consumption. Beside the definitive effects of driver behavior in terms of gear shifting on fuel consumption, there are no exact data in the literature on the effect of GSI on fuel efficiency of motor vehicles equipped with it. That postponed the mandatory installation of GSI in relation to initial proposals [1, 2] to 2012, when Regulation (EU) No. 65/2012 [3] set out the specific procedure, tests and requirements for the type-approval of GSI. Regardless the fact that mentioned regulation defined the procedure to determine relative fuel saving when following the advice of GSI, the real benefits are still not known [4]. In that sense, the authors conducted the tests that led to conclusions that are very affirmative to GSI, but have also raised some new questions.

* Corresponding author, e-mail: iblagojevic@mas.bg.ac.rs

Gear shifting and fuel consumption

Previous studies [5, 6] point out, with arguments, that manual gear shifting may be considered as an automatic process performed routinely, but only for experienced drivers. On the other hand, for drivers who have just been granted driving license this process requires a mental effort. Automation is therefore achieved through experience, which is mostly independently acquired by a driver.

In addition, by a detailed analysis of the relation between a driver's behavior and fuel consumption [7-10], it was proved that those elements of driver's behavior, related to gear selection, vehicle speed and acceleration and/or deceleration have the largest influence on fuel consumption. The fuel consumption at the same average driving speed can be increased up to 20% only due to difference in the manner of gear shifting.

Very picturesque overview of the effect of gear selection on the fuel consumption at some driving speeds is shown in fig. 1, as the result of investigations carried out by Volkswagen with a passenger car [11]. The increase of fuel consumption in percentages when driving in third and fourth gear is shown relative to the fuel consumption when driving in fifth gear

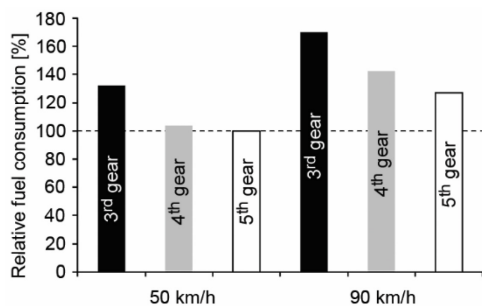


Figure 1. Fuel consumption related to 50 km/h in 5th gear [11]

at speed of 50 km/h and 90 km/h (fuel consumption in fifth gear at speed of 50 km/h was accepted as the reference value – 100%). When differences in fuel consumption in different gears under the same conditions are perceived, it can be concluded that significant fuel savings can be achieved by adequate gear selection, which has both large economic and environmental impact.

Beside the test's conducted by the manufacturers, there were only a few studies that have tried to find a solution for resolving the problem [12-16]. Some manufacturers interested in fuel economy improvement using proper gear shift-

ing came up with a new device, which unequivocally indicates to driver when to shift gear up or down, to reduce the fuel consumption for the same driving conditions. Commission Regulation (EU) No. 65/2012, implementing Regulation (EC) No. 661/2009 of the European Parliament and of the Council regarding gear shift indicators, defines special requirements for vehicles equipped with GSI. It sets functional requirements for GSI (applicable to all manual modes):

- the GSI shall suggest changing the gear when the fuel consumption with the suggested gear is estimated to be lower than the current one giving consideration to emission and safe operation requirements, and
- the GSI shall be designed to encourage an optimized fuel efficient driving style under reasonably foreseeable driving conditions.

Its main purpose is to minimize the fuel consumption when the driver follows its indication. However, regulated tailpipe emissions shall not be disproportionately increased with respect to the initial state when following the indication of the GSI.

Basic experimental setting

For the purpose of the paper, a FIAT 500L was tested on roller test bench. Before that, the authors needed to define driving cycles and gear shift patterns.

Table 1. Three gear shifting patterns – vehicle speed* v at shift points and corresponding rpm

| Gear shift pattern | | 1 → 2 | 2 → 3 | 3 → 4 | 4 → 5 | 5 → 6 |
|--------------------|--------------------------|-------|-------|-------|-------|-------|
| 1 | v [kmh ⁻¹] | 15 | 35 | 50 | 70 | 90 |
| | rpm | 2606 | 3203 | 2839 | 2877 | 2936 |
| 2 | v [kmh ⁻¹] | 10 | 29 | 38 | 58 | 69 |
| | rpm | 1737 | 2654 | 2158 | 2384 | 2251 |
| 3 | v [kmh ⁻¹] | 16.2 | 30 | 45.1 | 62.2 | 87.2 |
| | rpm | 2814 | 2746 | 2561 | 2556 | 2845 |

* When accelerating, gears are shifted up as soon as vehicle speed exceeds the value shown and when decelerating, gears are shifted down when vehicle speed reaches the value shown

ment, all equipped with a manual gearbox, done in a previous study [17]. The authors consider that these values could be some kind of compromise between the standard gear shift points defined in Regulation No. 83 and those declared individually for every vehicle, and that they can substitute the two decades old standard gear shift points in the future. This can provide a more exact way to measure the emission and fuel consumption, taking into account more realistic gear shift points. This coincides with the request from the manufacturers to use gear shift points indicated by GSI in these tests. This pattern can also be used to study the shift points that are between the standard ones used in the first pattern and those indicated by FIAT 500L in the second pattern (this is not the case only for the shift from the first to the second gear – tab. 1).

Gear shift points for all three patterns are also shown in figs. 2 and 3, with the corresponding symbol (circle for pattern 1, square for pattern 2, and triangle for pattern 3) accompanied with the number indicating the gear before the shift and an arrow to mark the shift-up or shift-down.

Testing

Three gear shift patterns used in two cycles (UC and EUC), three times repeated to check the repeatability, make a total of 18 tests. The vehicle used for the test was FIAT 500L with positive ignition engine (displacement: 1368 cm³, rated power: 70 kW), equipped with six-speed manual gearbox (gear ratios: 1st 4.1, 2nd 2.16, 3rd 1.34, 4th 0.97, 5th 0.77, 6th 0.65, and final drive 4.92) and with 195/65R15 tires (rolling radius 308 mm). All tests were done on roller test bench developed by the CIAH Laboratory at the Faculty of Mechanical Engineering at the University of Belgrade, Belgrade [18], which is able to simulate the resistance forces acting on the vehicle and to give the instructions to the driver when to accelerate, decelerate, or change a gear, fig. 4. Average fuel consumption was measured through controller area network (CAN) Bus (it is actually estimated based on the injectors' duty time, which is still good enough for the purpose of the paper, since the goal is to find a relative differences in whole-cycle cumulative fuel consumption). All tests were conducted with working temperature of the engine being achieved (GSI is not working when the engine is cold).

The analysis of the results

As mentioned before, the main parameter observed in the study was the fuel consumption. Average fuel consumption measured with the first pattern in UC was 8.87 L per

100 km, 7.47 L per 100 km with the second pattern and 7.87 L per 100 km with the third (as shown in fig. 5). An 18.7% higher fuel consumption can be spotted in the first pattern, where gears are shifted at standard speed values, compared to the second pattern where gears are shifted according to GSI. Fuel consumption with the third pattern is between the first two, being closer to the second. Fuel consumption recorded with the first pattern is 12.7% higher than that measured with the third.

It was expected that GSI indication provides the lowest fuel consumption because the algorithm behind it is tailored to the tested vehicle. The obtained results prove the efficiency of GSI in lowering the fuel consumption. Large differences in fuel consumption between the first (the worst) pattern and the other two may indicate the need to revise the standard gear shift points to make the test results more realistic. In that sense, the third pattern may be a good compromise.

It is important to explore how drivers obey the instructions given by GSI to consider the human factor when creating the future gear shift points. The obtained results prove the manufacturers' need to affirm the usage of GSI. This can be done through drivers' training or by the introduction of a signal in the cockpit to warn the driver that the gear shift points he uses deviate too much from the recommended ones.

In the tests conducted in EUC, average fuel consumption recorded with three patterns is: 5.7, 5.0, and 5.4 L per 100 km, respectively, fig. 6. As expected, values are lower than those recorded in UC. Again, differences in fuel consumption for the three patterns are more than noticeable. Compared to the lowest consumption obtained with the second pattern (5.0 L per 100 km), the first pattern gave 14% higher consumption, while the third gave 8% higher consumption. One of the factors leading to this are the higher differences in 6th gear shift speed values (90 km/h for the first, 69 km/h for the second, and 87 km/h for the third). That is why the same statements as for the UC apply. However, extra-urban driving conditions give the best opportunity to save the fuel because of the longer distances travelled. For example, at a constant speed of 70 km/h, FIAT 500L will indicate the 6th gear, while in most cases the drivers will use the 5th after the subjective feeling, thus making the consumption higher.



Figure 4. FIAT 500L on roller test bench

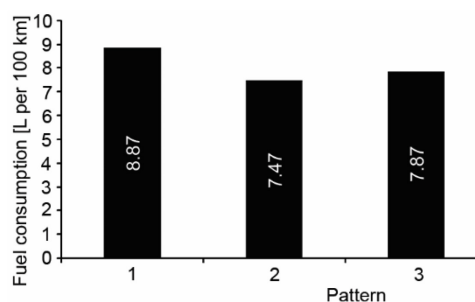


Figure 5. Average consumption in UC for all three patterns

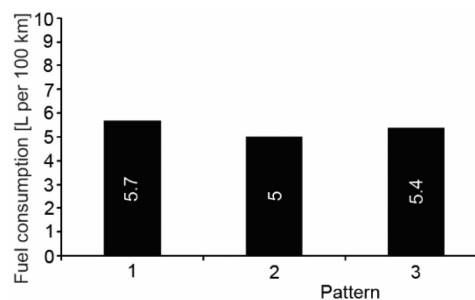


Figure 6. Average consumption in EUC for all three patterns

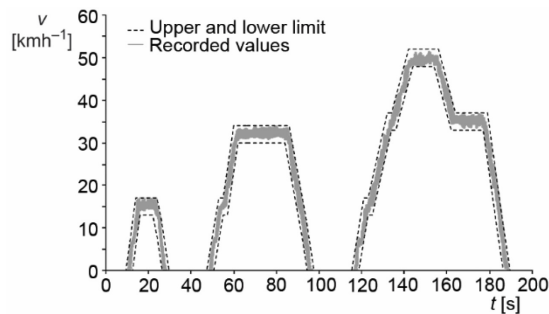


Figure 7. Recorded speed values in nine UC

point out the impact of gear shift pattern on fuel efficiency. It is proved that the use of GSI significantly lowers the consumption. Also, a need to revise the standard gear shift points, used for many years for the measurement of fuel consumption and emission, is noted, with the authors offering the points obtained from conducted statistical analysis as a possible choice. The request of the manufacturers to use GSI indicated gear shift points when measuring the fuel efficiency and gas emission is supported by the presented results. The major question, yet to be studied, is how to make the drivers obey the instructions given by GSI in order to make the savings possible in real conditions. One of the possible paths is the education of drivers, as within the mandatory training, as through additional energy efficiency courses. Manufacturers spend millions to reduce the fuel consumption only by 1%, so the driver must be instructed not to increase it by tenth of percent just by driving in a non-economical manner.

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To check the validity of data obtained through tests on roller test bench, a locus of recorded speed values is constructed. This is shown in fig. 7 for nine UC. As can be seen, it is set between the lower and the upper limit defined for NEDC (± 2 km/h, ± 1 second) for every time point. Average value of Pearson's cumulative test statistic χ^2 for nine UC is 214.37 km/h.

Conclusions

The obtained results unequivocally

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