Estimation of the accuracy of fuel consumption measurement based on data from the on-board CAN-bus

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Abstract. The legal requirements for vehicle exhaust emissions are becoming increasingly stringent. Emissions are directly related to fuel consumption. Therefore, reducing fuel consumption is a very urgent task. To solve this problem, it is necessary to assess the influence of various factors on the actual fuel consumption. To determine the fuel consumption, there are a large number of different methods using external flow meters installed in the fuel line, installing additional level sensors in the fuel tank. A very simple and convenient method is based on the use of information from the electronic engine control unit. This method requires minimal financial investment and does not require significant structural changes. The question arises about the measurement accuracy according to this method, since the ECU calculates the fuel consumption according to a mathematical model, calibrated and programmed at the factory. To assess the accuracy of this method, a set of tests was carried out. The tests were performed at constant vehicle speed and according to the standard driving cycle. During the tests, the fuel consumption was recorded using a high-precision calibrated flow meter installed in the fuel line and on the basis of data from the engine ECU. Based on the test results, a conclusion was made about the size of the discrepancy in the methods for determining the fuel consumption.

1. Introduction

The most pressing issue that automotive industry faces has always been rational fuel consumption [1]. Apart from the efforts to reduce the environmental footprint, amid the soaring fuel prices, the OEMs strive to increase economic feasibility of the road carriages by cutting the fuel expenses, which constitute from 25% to 45% of the total expenditures [2, 3].

This problem is tackled in several stages: first during vehicle design and production, and then during its operation [4 - 6]. Engineering factors impacting fuel economy include power unit (ICE) properties, aerodynamic features, efficiency of powertrain units and assemblies, wheel tire parameters. Operating factors mainly imply driving behaviour, traffic conditions, and terrain features [1, 4]. To reach the lowest fuel consumption, it is necessary to ensure the most accurate measurement of the actual fuel use [7, 8].

Today OEMs practise several options to obtain actual fuel consumption figures [9]:

1. The flow meter (pulse, rotameter, ultrasound or piston type) allows one to obtain quite accurate measurements if correctly connected; however it can also entail installation and...
configuration difficulties in modern vehicles, and compromise reliability of the whole fuel system [10].

2. The regular fuel level sensor in the fuel tank is easy to connect, non-invasive, but fails to ensure high accuracy, and has to be thoroughly calibrated [10].

3. The injector pulse counter issues a signal directly proportional to the injected fuel amount. It is easy to install, but even with accurate calibration of the pulse rate and the injected fuel amount, the error in measurement can be as high as 15% [10, 7].

4. The additional fuel level sensor in the fuel tank (capacitive type) ensures highly precise measurements, but requires drilling a hole in the tank, which constitutes a warranty breach. For a large vehicle fleet, it means substantial investment [7].

5. Devices that obtain data from the on-board CAN-bus are non-invasive and require no calibration. Moreover, all commercial vehicles have to be fitted with telemetry systems according to the regulations in force [11]. The owner has no issues with data interpretation, as the software includes basic parameters calculated by the electronic engine control system (EECS): instantaneous fuel consumption, engine speed, accelerator pedal engagement, vehicle speed, etc. [12].

Today OEMs around the world integrate vehicle monitoring systems due to the benefits specified in item 5 [12]. However, in some vehicles, there is no data on the fuel level in the on-board CAN-bus at all; in others, users have to search for location in the matrix, calibrate the values, and further calculate the proportionality factor. In such cases, it is best to calculate the actual fuel consumption via the instantaneous fuel consumption rate, and then evaluate a certain integral. The instantaneous fuel consumption rate is calculated by the EECS, can always be obtained from the CAN-bus communication network, and decrypted via the OBD-II diagnostic protocol [1]. The engine ECU determines the instantaneous fuel consumption rate basing on the calibration tables integrated by the manufacturer. The ECU developer tests the engine on the test bench comprised of the torque meter, lab flow meter, mixture analyzer, temperature recorder, and an indexing system. One obtains experimental data used to compile these calibration tables. This raises the issue of how to ensure accurate measurements of the combined fuel consumption rate in real driving conditions. NNSTU engineers have developed an approach to tackle this problem, which is described in this paper.

2. Test procedure development

Fuel consumption is currently measured at a constant speed and in the transient mode (the so-called driving cycle), which simulates real driving conditions. Measurements are performed either on the test track (dedicated proving ground), or on the chassis dynamometer in the lab, and after the dynamic vehicle simulation. Although the last two options are quite beneficial and convenient, some input parameters, such as engine characteristics, road resistance, efficiency factor, aerodynamic features, etc., can be obtained only through experimental tests [13]. Therefore, the engineering team decided to put a focus on the track tests, which can reflect actual fuel consumption, and to check the accuracy of this method.

To measure fuel consumption, two types of tests were performed in different loading conditions (full and curb weight):

1. driving at constant speeds of 60, 80, 100, 120 km/h. Test procedure according to GOST R 54810-2011;
2. driving cycle test. OEMs use a large number of driving cycles, such as NEDC, US06, HWFET, WLTC, FTP-75, JC08, ARDC etc. But this test was performed according to “New European Driving Cycle” (NEDC), as it is stipulated in UN Regulations No. 83, 101, which we apply in Russia. As seen from the curve (Figure 1), the test includes two different phases, and thus reflects real fuel consumption in urban, extra-urban and combined driving modes.
Since a driving cycle represents a set of vehicle speed points versus time, the driver performing the road tests has to be provided with visual data (speed tolerance is ±2 km/h). NNSTU engineers have developed a model in Matlab/Simulink to calculate driving cycle parameters in real time.

As part of the test procedure, special equipment has been designed to measure and record all relevant driving parameters and to establish data exchange between the components. Figure 2 illustrates the configuration of the equipment designed by NNSTU specialists in order to evaluate fuel economy of a light commercial vehicle.

Figure 1. NEDC curve

Figure 2. Fuel economy measuring equipment layout

1 – DFL.3x-5bar fuel flow meter; 2 – Vbox 3i 100 Hz data logger; 3 – GPS/GLONASS antenna with a gyroscope; 4 – user CAN-bus; 5 – cycle parameter computation system (PC+ Simulink SW + CAN adapter); 6 – Bluetooth-connection; 7 – Windows OS tablet and Vbox TestSuite SW; 8 – CAN-bus data reader.
Main components of the test set-up developed by NNSTU:

1. A high-precision fuel flow meter Kistler DFL3X-5bar (item 1) is connected to the vehicle fuel system. Measurements are transmitted to the user CAN-bus (item 4) to be further recorded by external data acquisition systems.

2. Racelogic Vbox3i 100Hz (item 2) measures the vehicle speed and acceleration via the antenna and the gyroscope (item 3) installed on the vehicle roof. This device can also be connected to the CAN-bus to record additional parameters.

3. CAN02 (item 8) is used to record the data from the on-board CAN-bus.

4. Driving parameters according to the driving cycle are calculated on PC. Getac S400 (item 5) with Simulink software transmits the calculated data to the user CAN-bus (item 4) via a special Peak-system adapter.

5. The human-machine interface is implemented via a rugged tablet with Vbox TestSuite software (item 7), which can establish connection to Vbox3i via Bluetooth. Figure 3 shows a screenshot of the interface, which displays the actual and target vehicle speed, as well as total and instantaneous fuel consumption in real time.

Figure 3. Human-machine interface of the measuring equipment

3. Preparation and testing
The GAZelle Next all-metal van powered by the UMZ Evotech 2.7 petrol engine was used as a test vehicle. Fuel consumption measurements were performed on the vehicle in curb and full weight. The tests were conducted on a dedicated proving ground “Berezovaya Poyma” with the assistance of LLC “United Engineering Center” specialists.

The measuring equipment mounted to the vehicle according to the layout (Figure 2) is presented in Figure 4.
Figure 4. Measuring equipment

\begin{itemize}
  \item[a)] DFL flow meter;
  \item[b)] cab equipment;
  \item[c)] Racelogic Vbox 3i and CAN02;
  \item[d)] GNSS antenna with gyroscope on the vehicle roof
\end{itemize}

The tests were performed according to the test procedure mentioned above: 1st stage – constant speed, 2nd stage – driving cycle. Figure 5 displays NEDC curve samples with post-processed and integrated values of instantaneous fuel consumption and the vehicle speed obtained from the ECU via CAN-bus.
As seen from the curves, the behaviour of the parameters measured with GNSS and the flow meter aligns with the data received from the engine ECU via CAN-bus; however, there are small discrepancies. These discrepancies in % are presented in Table 1.

Table 1. Discrepancies in experimental data

|                     | Average fuel consumption, l/100 km | Discrepancy, % |
|---------------------|-----------------------------------|----------------|
|                     | GNSS + flow meter | CAN-bus |                |
| Full weight         |                             |            |
| Constant speed:     |                             |            |
| - 60 km/h           | 10.98                        | 10.49      | 4.5            |
| - 80 km/h           | 13.37                        | 13.48      | 0.81           |
| - 100 km/h          | 16.58                        | 16.01      | 3.42           |
| - 120 km/h          | 22.69                        | 21.43      | 5.53           |
| NEDC:               |                             |            |
| - urban              | 20.49                        | 19.91      | 2.91           |
| - extra-urban        | 17.56                        | 17.03      | 3.15           |
| - combined           | 18.67                        | 18.11      | 3.08           |
| Curb weight         |                             |            |
| Constant speed:     |                             |            |
| - 60 km/h           | 9.97                         | 9.54       | 4.55           |
| - 80 km/h           | 12.45                        | 12.63      | 1.44           |
| - 100 km/h          | 15.56                        | 15.13      | 2.79           |
| - 120 km/h          | 21.11                        | 21.21      | 0.49           |
| NEDC:               |                             |            |
| - urban              | 18.31                        | 17.94      | 2.05           |
| - extra-urban        | 15.76                        | 15.44      | 2.07           |
| - combined           | 16.68                        | 16.37      | 1.9            |

As seen above, only in one case the discrepancy is over 5%, but it can be neglected. This means that the data obtained from the on-board CAN-bus accurately reflects real fuel consumption of a vehicle.
4. Conclusion
The test procedure for evaluation of fuel economy in a vehicle has been developed and verified on a dedicated proving ground.

The measuring equipment has been developed and verified; the viability of fuel consumption calculation using CAN data obtained from the engine ECU has been proved.

To align the vehicle speed with the NEDC driving cycle, NNSTU specialists have developed and patented special software which informs the test driver of the target and the actual parameters [14, 15].

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