Problems of introducing capacitive fuel level sensors on city buses

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Abstract. This paper substantiates the need for a procedure for warming up buses in motor transport enterprises engaged in passenger transportation, and the procedure for its implementation. The necessity of regulation of fuel consumption for heating is determined. A comparative analysis of existing methods and means of measuring fuel consumption for use in the regulation of fuel consumption for heating in motor transport enterprises engaged in passenger transportation is carried out. A schematic diagram of a device of its own design based on a fuel level sensor for measuring fuel consumption for heating is proposed. Methodical recommendations on the regulation of fuel consumption for heating with the help of the device are given. The procedure for processing statistical data is described in detail. The process of standardizing fuel consumption for warming up the LiAZ-429260 bus at the State Unitary Enterprise "Mosgortrans" is described. The results of standardization of fuel consumption for heating are shown.

1. Introduction

Warming up the vehicle engine consists in starting the internal combustion engine and then waiting for it to warm up to operating temperature. When carrying out transport work immediately after starting the engine, the wear of some of its parts can significantly increase. The use of heating allows to ensure the gentlest transition from the moment of starting the engine to the beginning of the transport work [1,7].

Despite the fact that the manufacturers of most modern vehicles have ceased to recommend mandatory warm-up of the internal combustion engine before driving for a moderate climatic region of operation, this procedure is still relevant in many cases. In particular, this applies to road transport enterprises in the territory of the Russian Federation engaged in urban passenger transportation.

The main factors that make it necessary to warm up city buses in MTE are:

1. Natural and climatic conditions. In the middle zone of the Russian Federation, the average monthly temperature in winter can drop to -10 °C, which is much lower than in Germany (0 °C), France (+5 °C), Great Britain (+4 °C) and other European countries ... At negative temperatures, operating fluids are not immediately able to reveal their properties [3, 8], working gaps between structural elements are violated, their relative position, shape, etc. change.

2. While the engine is warming up, the interior of the bus is also warmed up and its individual systems (air suspension, pneumatic brake drive, etc.) are brought up to operating condition, which ensures environmental and transport safety and passenger comfort when working on the line [2].
3. Additional control of the technical condition of the bus by the driver and mechanic due to the
detection of extraneous noise, leaks, leakage of the pneumatic systems of the bus, etc. during engine
warm-up.

4. Injection of working pressure in the pneumatic systems of the bus for their reliable and safe
functioning.

The start of the bus engine is usually carried out after pre-heating with a pre-heater to the minimum
temperature for accepting the load (+ 40 °C). Temperature control is carried out from the driver's
workplace using a standard temperature sensor [4,5].

After the temperature arrow of the internal combustion engine cooling system deviates from the
lower mark according to the standard sensor on the instrument scale corresponding to a temperature of
+ 40 °C, the bus engine is started. In the process of joint operation of the preheater and the bus engine,
the bus interior is heated, as well as the working pressure in the bus pneumatic systems is pressurized.
When the arrow of the standard temperature sensor reaches 80 °C, the heating stops and the bus moves
to the line [2].

At the same time, in the conditions of motor transport enterprises, the issues of fuel economy occupy
a leading position, therefore, it is necessary to pay special attention to instruments and methods for
measuring fuel consumption for heating the rolling stock at low temperatures for the subsequent
development of fuel consumption rates for heating at the enterprise.

2. Review of existing approaches to measuring fuel consumption by car
To select a device and / or method that is optimal for use in measuring fuel consumption for heating, a
comparative analysis of existing solutions in this area was carried out [6].

2.1. Measurement by injector pulses
On vehicles equipped with engines with electronically controlled injectors in the fuel injection system,
fuel consumption can be measured from injector pulses using a proximity reader. This method involves
the removal of information from the internal measuring instruments of the standard information and
diagnostic system of the vehicle about the operation of the fuel equipment. Signals are read without
electrical contact with the injector wires and without interfering with the vehicle’s electronic systems.

The advantages of the method:
- high accuracy;
- the ability to timely identify malfunctions of the vehicle fuel system;
- no need to use additional sensors.

Disadvantages of the method:
- the need for complex and time-consuming calibration of fuel equipment for each vehicle and
determination of the dependence of the unit volume of injected fuel by the injector on the engine
operating mode [2];
- high requirements for manufacturability and design perfection of standard fuel equipment and
means of diagnosing and taking indicators of its work.

This method of measuring fuel consumption is the cheapest from the point of view of the required
equipment, but extremely laborious, especially in the conditions of large motor transport enterprises
with a diverse fleet of vehicles. The cost of using this method also needs to add fleet downtime during
the equipment calibration process.

This method is not suitable for measuring fuel consumption for heating for large motor transport
enterprises.

2.2. Measurement according to the data of the vehicle’s on-board information buses
There are many sophisticated electronic devices aboard a modern car. For data exchange, they are united
into a single network through onboard information buses - CAN (SAE J1939 standard) or J1708 (SAE
J1587 standard). On-board data buses transmit information about the parameters of the transport,
including data on fuel consumption.
The data that can be obtained from on-board information systems contains information about the level and amount of fuel consumed, as well as hourly and track fuel consumption.

The advantages of the method:
- no need to use additional sensors.

Disadvantages of the method:
- the accuracy of data on fuel consumption is lower than that of other measurement methods and differs depending on the standard sensors for measuring the fuel level in the fuel tank of the bus.

The measurement accuracy of this method differs depending on the measured vehicle. Increasing the measurement accuracy by calibrating standard sensors is impossible.

This method is also not suitable for rationing fuel consumption for heating due to the low accuracy of the results obtained.

2.3. Measurement of the fuel level in the fuel tank using fuel level sensors.
Electronic fuel level sensors (FLS) can be used as a tool for measuring the fuel level in the tanks of any vehicles.

The use of such devices allows:
- receive reliable information about the current volume of fuel in the car’s tank;
- to determine the volume of refueled fuel;
- detection and prevention of fuel theft;
- control fuel consumption.

The advantages of the method:
- low cost;
- no interference with the fuel system of the car, installation on warranty vehicles is possible;
- measuring the level of various types of liquid fuel;

Disadvantages of the method:
- the measurement accuracy depends on the operating conditions of the vehicle, the shape and volume of the fuel tank;
- when installing the fuel level sensor, it is necessary to perform the tank calibration operation [2].

The use of such a device for measuring fuel consumption for heating when installed directly into the vehicle tank does not allow obtaining accurate data due to the large total volume of the tank. The use of the device with direct installation into the vehicle tank does not allow obtaining sufficiently accurate data on fuel consumption in the warm-up mode.

2.4. Measurement of fuel consumption in the fuel line of the engine
This measurement method measures the actual fuel consumption of the vehicle engine. Instantaneous fuel consumption can be accurately determined by direct measurement using a flow meter installed in the engine fuel line.

The use of flow meters allows the fleet owner to provide:
- accounting of actual fuel consumption;
- accounting of the time of equipment operation;
- testing of engines in terms of fuel consumption.

The advantages of the method:
- high measurement accuracy;
- fuel consumption is correctly determined in any engine operating modes, including short runs;
- it is possible to identify engine malfunctions, leading to increased fuel consumption, and violation by the driver of the optimal operating modes of the machine;

Disadvantages of the method:
- installation of a fuel flow meter is a complex procedure that requires appropriate qualifications and intervention in the design of the vehicle fuel system;
- on some machines the installation of a flow meter may change the operating conditions of the engine;
- volumes and time of refueling (draining) of fuel are not controlled [2].
- high cost of the device;

A more accurate determination of the fuel consumed in the transport mode of ATS operation in comparison with other devices and methods, however, the flow meter is not able to determine the fuel consumption for warming up small buses, due to the fact that such a device has a limitation in the form of a minimum volume of liquid passing through it (minimum spillage).

3. Description of the created installation

Due to the fact that none of the existing devices can fully meet all the accuracy requirements for measuring fuel consumption for heating city buses at the State Unitary Enterprise "Mosgortrans", the Research Centre has created its own solution based on the fuel level sensor R-7 for accurate automated measurement of fuel consumption for heating the bus.

The device consists of two high cylindrical interconnected containers of different volumes. The small tank contains the R-7 fuel level sensor, the large tank has an external marked glass tube, two holes at the bottom (for draining the fuel) and at the top (for connecting the fuel return line) (Fig. 1).

Figure 1. Schematic diagram of the installation:

1 - fuel level sensor; 2 - filler neck with a connector for connecting the return fuel line of the vehicle; 3 - drain neck with a connector for connecting the vehicle fuel supply; 4 - container for installing the fuel level sensor; 5 - main fuel tank; 6 - dimensional scale; 7 - openings for communication of containers with the external environment; 8 - the place of communication between the containers.

A device created according to this principle has the following advantages:
- low cost;
- measuring the level of various types of liquid fuel;
- high measurement accuracy due to the shape of the containers;
- low labor intensity when preparing the device for operation, due to the absence of the need for calibration before each measurement;
- automation of the measurement process.

Disadvantages of the method:
- the need to intervene in the vehicle's fuel system to connect the device.

The device, made according to the proposed schematic diagram, combines the advantages of using a fuel level sensor, as well as eliminating its main disadvantages - low accuracy and the need for individual calibration for use in each vehicle.

It should be noted that the degree of accuracy depends on the quality of the calibration procedure of the installation after assembly.
4. Guidelines for the regulation of fuel consumption for heating using the installation

Fuel consumption for warming up is the amount of fuel consumed from the moment the bus engine starts until it reaches the operating temperature.

To measure the consumed volume of fuel for heating using the installation, it is necessary to fill it with fuel through the filler neck (2) in Figure 1, connect it to the fuel system of the bus instead of the fuel tank (the fuel supply line of the bus is connected to the drain neck (3), and the fuel return line to the filler neck (2). It is important to install the device strictly vertically to exclude the influence of inclination on the measurement results.

After filling and connecting the unit, the heating procedure is carried out directly, consisting of:

1. Starting the engine preheater and its operation until the temperature reaches 40 °C according to the standard temperature sensor;
2. Starting the bus engine and running it together with the heater for 10 minutes or more until the operating temperature is reached.

The volume of consumed fuel is measured in automatic mode by the model R-7 fuel level sensor and recorded in its memory. During the measurement process, it is necessary to keep track of the time to determine both the total warm-up time and its components.

After the end of the warm-up procedure, the bus is shut down, the fuel is drained from the installation and dismantled from the vehicle.

The next step in determining the norms is the processing of the results obtained. For this, data is extracted from the installation using specialized software and presented in a tabular form for further processing.

Depending on climatic conditions, it is possible to adjust the fuel consumption rates for warming up over the temperature range to increase reliability. Calculation of norms should be made separately for each temperature range.

The most important factor affecting the reliability of the measurement data is the sample size (number of measurements required). Fuel consumption for heating obeys the law of normal distribution, so the following formula is used to determine the sample size:

\[ N \geq \frac{t^2 \nu^2}{\epsilon_0^2} \]  

where \( V \) is the coefficient of variation;
\( t \) is the value of the significance level, which at the five-one percent significance level is 1.96 at \( q = 0.05 \) and 2.58 at \( q = 0.01 \);
\( \nu \) is the level of significance;
\( \epsilon_0 \) is relative accuracy.

Depending on the required relative accuracy \( \epsilon_0 \) and the level of significance \( q \), as well as the coefficient of variation \( V \), calculated on the basis of the results of the measurements, it is possible to flexibly adjust the required number of them, which is an important economic factor for MTE.

| Table 1. Sample size for normal distribution |
|-------------------------------------------|
| Significance level \( q \) | Coefficient of variation \( V \) | Relative accuracy \( \epsilon_0 \) |
|                            | 0.05  | 0.10  | 0.15  | 0.20  |
|-----------------|-------|-------|-------|-------|
| 0.05            |       |       |       |       |
| 0.1             | 16    | 4     | 2     | 1     |
| 0.2             | 62    | 16    | 7     | 4     |
| 0.3             | 138   | 36    | 16    | 9     |
| 0.4             | 245   | 62    | 28    | 16    |
| 0.01            |       |       |       |       |
| 0.1             | 27    | 7     | 3     | 2     |
| 0.2             | 107   | 27    | 12    | 7     |
| 0.3             | 240   | 60    | 27    | 15    |
| 0.4             | 697   | 174   | 78    | 27    |
The heating time of individual rolling stock models may differ, therefore, the most convenient value for accounting for fuel consumption within the MTE is the hourly fuel consumption for heating (l/h).

The hourly fuel consumption of the preheater is calculated using the following formula:

\[ Q_{ph} = Q_{p10} \times 6 \]  

(2)

where \( Q_{ph} \) is the hourly fuel consumption of the pre-heater, \( Q_{p10} \) is the fuel consumption of the pre-heater for 10 minutes of operation.

The hourly fuel consumption of the engine in both modes is calculated using the following formula:

\[ Q_{eh} = (Q_{eh10} + Q_{p10}) \times 6 \]  

(3)

where \( Q_{eh} \) is the hourly fuel consumption of the engine, \( Q_{eh10} \) is the fuel consumption of the engine and the pre-heater during 10 minutes of joint work, \( Q_{p10} \) is the fuel consumption of the pre-heater for 10 minutes of operation.

Further, on the basis of the hourly rates of fuel consumption by the engine and pre-heater, as well as the time of their operation during engine warm-up, the calculation of the fuel consumption rate for warm-up is made.

5. Implementation of methodological recommendations and main results of fuel consumption data processing

In the autumn-winter period of 2019/2020, at the Research Centre of the State Unitary Enterprise "Mosgortrans", fuel consumption standards for heating buses were developed and, in particular, for the modification of LiAZ-429260 in the temperature range from -10 to 5 °C according to the described method with using the described setting. Data from each measurement of fuel consumption for heating using the installation were recorded in Excel tables (electronic protocols). For each protocol, the hourly fuel consumption by the pre-heater and the engine was calculated according to formulas 2 and 3. In total, 11 measurements of the fuel consumption for warming up were made for this bus model. Table 2 presents the data collected.

Further processing of the data was carried out in the Statistica 10 program. When processing the data on the hourly fuel consumption, the calculations were performed on the upper limit of the mathematical expectation with a confidence level of 95%. Table 3 summarizes the post-processing data.

The hourly fuel consumption of the preheater is 1.7 l/h. The time of its operation when the engine warms up to the starting temperature is 20 minutes, and the total time of its operation during the warm-up until the engine reaches the operating temperature is 30 minutes.

### Table 2. The results of measurements of fuel consumption on the LiAZ-429260 bus

| № | Bus modification | Garage № | Fuel consumption by the engine, l/h | Fuel consumption by pre-heater, l/h | Warm-up time before starting the engine, min. | Ambient temperature °C |
|---|-----------------|----------|------------------------------------|-----------------------------------|---------------------------------------------|------------------------|
| 1 | LiAZ-429260     | 11181    | 4.06                               | 1.54                              | 17                                          | 0                      |
| 2 | LiAZ-429260     | 11275    | 3.7                                | 1.4                               | 13                                          | -1                     |
| 3 | LiAZ-429260     | 11285    | 3.16                               | 1.32                              | 19                                          | -9                     |
| 4 | LiAZ-429260     | 11275    | 4.6                                | 1.6                               | 19                                          | -7                     |
| 5 | LiAZ-429260     | 10981    | 3.8                                | 1.1                               | 17                                          | 5                      |
| 6 | LiAZ-429260     | 11091    | 2.7                                | *                                 | *                                           | 5                      |
| 7 | LiAZ-429260     | 11175    | 2.8                                | 1.9                               | 10                                          | 4                      |
| 8 | LiAZ-429260     | 11281    | 3.5                                | 1.02                              | 17                                          | 4                      |
| 9 | LiAZ-429260     | 11284    | 3.6                                | 1.6                               | 19                                          | 3.1                    |
| 10| LiAZ-429260     | 11276    | 3.5                                | 1.6                               | 12                                          | 3.1                    |
| 11| LiAZ-429260     | 11093    | 2.6                                | *                                 | *                                           | 5                      |

* fuel consumption and heater warm-up time were not measured.
Table 3. The results of the post-processing data of hourly fuel consumption on the LiAZ-429260 bus

| Bus modification | Preheater operation time, min | Fuel consumption by pre-heater, l/h | Engine running time, min | Engine fuel consumption, l/h | Total warm-up time, min |
|------------------|------------------------------|-----------------------------------|--------------------------|-----------------------------|--------------------------|
| LiAZ-429260      | 30                           | 1.7                               | 10                       | 3.9                         | 30                       |

Respectively:

\[(1.7 \div 60) \times 30 = 0.85 \, \text{l}\]

The hourly fuel consumption of the engine for warming up is 3.9 liters, and the total operating time until the operating temperature is reached is 10 minutes, respectively

\[(3.9 \div 60) \times 10 = 0.65 \, \text{l}\]

The total consumption of diesel fuel for heating is:

\[0.85 + 0.65 = 1.5 \, \text{l}\]

Table 4 shows the obtained fuel consumption rates for heating the LiAZ-429260 bus in the temperature range from -10 to 5 °C.

Table 4. Rates of fuel consumption for warming up the engine of the LiAZ-429260 bus

| Bus modification | Preheater | Engine | Total  |
|------------------|----------|--------|--------|
| LiAZ-429260      | 0.85     | 0.65   | 1.5    |

6. Conclusion

The research shows the necessity of carrying out the procedure for warming up the buses engine was substantiated in connection with the necessity to warm up the interior of buses to ensure the comfort of passengers, to build up working pressure in the pneumatic systems of the bus for their reliable and safe operation and to additionally monitor the technical condition of buses in motor transport enterprises engaged in passenger transportation. The necessity of regulation of fuel consumption for heating has been substantiated.

In the course of a comparative analysis of existing methods and means of measuring fuel consumption for use in standardizing fuel consumption for heating, it was revealed that there are no ready-made solutions for use at MTE during the operation of modern low-floor buses performing passenger transportation.

A schematic diagram and design of a home-made installation based on a fuel level sensor for measuring fuel consumption for heating, suitable for use in standardizing fuel consumption, was proposed. The key advantages of this device are the ability to measure fuel consumption for warming up without additional setup and calibration on any vehicle, automation of measurement, low labor intensity and high accuracy of results. The disadvantage of the device is the need to change the fuel system of the vehicle by connecting the device instead of the fuel tank.

Methodological guidelines have been developed for standardizing fuel consumption for heating city buses using a specially designed installation, which consists in measuring fuel consumption for heating based on a fuel level sensor, the procedure for obtaining data, calculating the required number of measurements, statistical data processing and calculating the final fuel consumption rate for warming up for the vehicle.

The practical result of the research carried out at the Research Centre of the State Unitary Enterprise "Mosgortrans" is to determine the rate of fuel consumption for warming up the LiAZ-429260 bus in the temperature range from -10 to 5 °C, equal to 1.5 liters.
A further area of research is the automation of the process of transferring, storing and statistical processing of data on fuel consumption for heating from the device in order to reduce labor costs and measurement time and improved usability.

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