Diagnostics of fuel efficiency indicators of internal combustion engines in the logging industry

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Abstract. The article presents a methodology for assessing the fuel efficiency of diesel internal combustion engines, as well as the influence of fuel devices on the operational efficiency of timber tractors.

1. Introduction
Fuel efficiency of logging equipment is characterized by fuel consumption per unit of time per unit of engine power or per unit of work performed.

2. Methods and Materials
The most justified in the diagnostic system is the use of non-selective methods in assessing the technical condition of machines [1-4]. Many works in this direction have proved the effectiveness of using transient modes. It is noted that the introduction of non-selective diagnostic methods allows you to reduce the number of failures by 2 or more times, increase the inter-repair technical resource by 2 times, reduce the cost of technical maintenance by 40%, reduce fuel consumption by 20-25 % and increase the durability of parts by 16-26 % [5-8].

Unsatisfactory operation of fuel equipment increases the risk of diesel engine failures by 20 - 40 % [9-11]. According to a number of studies, every additional 3% of the unevenness of the supply causes an increase in fuel consumption by 2%. In 10-20% of engines, there is a decrease in the rated speed of the crankshaft [12-14].

In cylinders where the supply is increased, the maximum combustion pressure increases, which indirectly characterizes the reliability of the engine [15-18]. An increase in the cycle feed by 7% causes an increase in the maximum combustion pressure, by 0.4 MPa, and an increase in the feed advance angle - by 0.3 MPa. The power of an engine with an uneven power distribution across the cylinders is 3 to 5% lower than that of a regulated engine, and the specific fuel consumption is increased by 6-8%, respectively. This leads to uneven wear of parts and a reduction in engine life [6].

In addition to structural changes in the mated parts, wear has a negative impact on the efficiency of the working processes in the cylinders [19]. In the internal combustion engine, the thermodynamics of the combustion of the working mixture in the cylinders is disrupted due to a decrease in the compression ratio, changes in the ignition advance angle (injection), fuel supply and mixture formation, gas distribution phases; oil consumption for carbon monoxide, mechanical loss power, noise and vibration levels increase [17].
Fuel costs in the total cost of operating cars are 18 ... 20%. To assess fuel efficiency, two indicators are used: the value of the total fuel consumption $Q$ in litres per 100 km of the travelled path $S$ in kilometres and the value of the specific fuel consumption $Q$ per unit of transport work [4, 10].

The specific fuel consumption per 100 km of vehicle mileage is expressed by the formula:

$$ Q = \frac{G_{\text{sum}}}{L_{\text{sum}} \rho_m} \times 100, $$

(1)

Specific fuel consumption per 100 thousand km of transport work:

$$ Q = \frac{G_{\text{sum}}}{L_{\text{gr}} Q_{\text{gr}} \rho_m} \times 10^5, $$

(2)

where $G_{\text{sum}}$ - is the amount of fuel consumed by the car for a certain mileage, kg; $L_{\text{sum}}$ - total mileage of the car (with and without cargo), km; $L_{\text{gr}}$ - mileage of the car with the load, km; $G_{\text{gr}}$ - payload carried by vehicle, kg; $\rho_m$ - fuel density, g/cm$^3$.

The specific fuel consumption per 100 km of mileage when driving a car is related to the specific fuel consumption of the engine $g_e$ by the ratio:

$$ Q = \frac{G_{\text{sum}}}{L_{\text{sum}} \rho_m} \times 100 = \frac{g_e N_e}{V_a \rho_m} \times 0.1, $$

(3)

where, $N_e$ - effective engine power; $V_a$ - vehicle speed.

The dependence of the specific fuel consumption on the speed at steady motion on the road with a certain resistance is called the economic characteristic of the car [1, 4, 18].

Fuel consumption when driving a car, at any speed, depends on the total resistance to movement and on the efficiency of the engine when driving at this speed [5, 7]. At a low speed of movement, the power required to overcome the resistance to movement is small. The total amount of fuel consumed by the engine is relatively small [11]. When the speed of movement increases (in the same gear), the power spent on overcoming the resistance increases. Accordingly, fuel consumption also increases [1, 5].

Fuel consumption per mileage is used quite often because of the ease of definition, but it characterizes fuel efficiency in terms of the perfection of the car design [3, 13]. Cars that have the best indicators of fuel consumption per mileage are inferior to other cars in terms of specific fuel consumption per unit of transport work [6, 7].

Of the total amount of energy released from the combustion of fuel, only about 25% is used usefully, converted into the traction force of the driving wheels, the rest of the energy is irretrievably lost. Thus, of the 100 liters of fuel entering the combustion chamber, only about 25 liters are converted into useful work. The rest of the fuel is lost in the form of thermal and mechanical losses [2, 10].

The perfection of the working process in the engine can be judged by the specific fuel consumption:

$$ g_e = 1000 \times \frac{G_{\text{sum}}}{N_e}, $$

(4)

Recently, in the practice of the automotive industry, a lot of work has been done to improve engines, improve fuel quality, and increase fuel efficiency. But in the course of operation, the ways to save fuel must be sought in the choice of appropriate operating modes and maintaining the car in technically sound condition [16]. One of the main factors indicating the impact on fuel consumption during the operation of machines is the technical condition of the machines [12]. Thus, a malfunction or incorrect adjustment of one nozzle of a diesel engine increases fuel consumption by 15 ... 20% [15]. Lowering the coolant temperature by 30 ... 40°C leads to an increase in fuel consumption by 5 ... 10% due to the deterioration of the combustion process [2]. When the angle of the beginning of the fuel supply is deviated by 3 ... 5°, the specific consumption increases by 4 ... 8%.

The results of the work on determining the stability of fuel-power indicators of engines in real operation show that most engines operate with reduced power and increased fuel consumption [1].
Engine power is reduced by 5...15%. Unsatisfactory operation of the fuel equipment most often leads to a deterioration in the efficiency of the engine [8].

After about 300 hours of operation, the new injectors reduce the injection pressure by 2.5…4 MPa, and fuel atomization deteriorates due to the burn-in of the end interfaces and the loosening of the nozzle attachment to the body [3]. When operating for more than 700...800 hours, the end of the spray needle is covered with varnish deposits, the discharge valve wears out, fuel leaks through the gap between the holes of the housing and the needle, which causes coking of the inner and outer surfaces of the spray gun and, as a result, a decrease in power and an increase in fuel consumption [19]. To reduce the harmful effect of these reasons, it is necessary to check the setting of the fuel advance angle by the pump after 120 hours of operation, adjust the engine shaft speed to the maximum idle speed every 480 motorcycle hours of operation with the help of diagnostic tools or on the stand to monitor the operation and, if necessary, adjust the injectors. Replace the oil in the speed controller at the same time as changing the oil in the engine [8].

The fuel efficiency of the engines largely depends on the correct installation of the spray nozzles. The placement and number of holes of the sprayer at a given position of the nozzle is chosen so that with high fuel efficiency of the engine, its mechanical and thermal stress are moderate [4]. Therefore, before putting the nozzle on the engine, it is necessary to check the designation of the sprayer. In the presence of packaged sprayers, it is enough to look at the label on the package or directly the marking on the sprayer [1, 17]. It should be remembered that the throughput of each sprayer is additionally regulated and only one group of through put should be installed on the engine (usually only the 2nd group is applied to the sprayer). Each type of sprayer is designed for the engine, depending on the method of mixing and the shape of the combustion chamber. The reliability and technical and economic performance of the engines will decrease with the rearrangement of different types of sprayers [14].

The frequency of the air entering the engine significantly affects the fuel consumption [15]. Clogging of the air cleaner, reducing the intake of clean air into the engine cylinders increases fuel consumption by up to 6...8%. In order to save fuel during operation, it is necessary to maintain the engine systems in a technically sound condition, while it is necessary: to constantly monitor the stability of the engine's economic and power indicators by means of technical diagnostics; to maintain the necessary thermal regime of the engine and to carry out maintenance in a timely and complete manner [11].

The efficiency of logging equipment largely depends on the condition of the main components and units of the diesel fuel system [8]. These include: the booster pump, the filter elements of fine and coarse fuel purification, the bypass valve, the precision pairs of the fuel pump, the performance of the fuel pump and the unevenness of the fuel supply, the injection pressure, the quality of the fuel spray by the injectors, the tightness of the fuel system [13]. The nominal permissible and limit values of indicators for assessing the technical condition of the diesel engine power system are given in table 1. Signs of uneconomical operation of the fuel pump are associated with the fuel supply. The fuel pump, complete with injectors and high-pressure fuel lines, must ensure economical operation of the engine at rated mode, at overload mode, at idle and at start-up [1]. Indicators of the engine that characterize such work are: rated power, hourly fuel consumption.

The performance of the pump sections of the fuel pump, without removing it from the engine, the uniformity of the fuel supply between the pump sections and the engine crankshaft speed are determined by the KI – 4818 fuel gauge device, which consists of a housing in which glasses with defoamers, a beaker for measuring the volume of fuel, a stopwatch and an electric tachometer pointer [1] are installed. By the amount of fuel supplied by the sections, it determines the performance of the sections and the unevenness of the fuel supply. The performance of the fuel pump sections is measured at the rated speed of the engine crankshaft [6].

In six-cylinder engines, the fuel supply is measured simultaneously in 3 sections of the pump, in eight-cylinder engines - in 4 sections. If the unevenness of the fuel supply in individual sections exceeds 11%, then the pump must be removed from the engine and adjusted on the stand [11]. If it
does not exceed 11%, and the performance of individual sections exceeds the permissible values, the fuel supply should be adjusted on the machine [8].

Table 1. Nominal permissible and limit values of indicators.

|                         | SMD-14BN | A-01ML | YAMZ-236 | YAMZ-740 |
|-------------------------|----------|--------|----------|----------|
| Fuel pump cell capacity m³/h: | 84       | 98     | 108      | 120      |
| Nominal permissible load | 79.8/89.9| 93.4/110.2 | 100.5/108.7 | 115.3/127.4 |
| Fuel injection advance angle, deg: | 18…20   | 26…28  | 19…21   | 20…22   |
| Nominal permissible      | 17…21   | 25…29  | 18…20   | 19…20   |
| Fuel injection start pressure, MPa: | 18       | 15.5    | 18.5     | 19.5     |
| Nominal permissible value | 16.5     | 14.5    | 16.0     | 17.0     |

Fuel consumption is checked with the KI-8940 flow meter. To continuously determine the hourly fuel consumption of a diesel engine, the KI-11267 device is used, and to measure the mass fuel consumption – KI-8910A. To check the moment of the start of the fuel supply, you can use the device KI-13902, which includes a torque detector KP-4941 or a protractor KI-13926. If the difference in the starting angles of the fuel supply in the tested sections exceeds 4° in the angle of rotation of the crankshaft, the pump must be adjusted on the stand, if less than 4°, the advance angle must be adjusted by changing the position of the pump shaft relative to the engine crankshaft [4].

The condition of the precision pairs of the fuel pump is checked by the device KI-4802, which includes: a stopwatch, a pressure gauge with a scale of 0.40 MPa, a high-pressure fuel line, a housing with a handle inside which the pressure gauge safety valve and a damper are placed [14].

The tightness of the fuel system is installed directly on the engine, both with the help of devices and without them.

In operation, the technical condition of the injectors is checked by the quality of the spray, the pressure of the beginning of fuel injection with the KI-9917 device. The remaining parameters of the technical condition of the injectors are determined in stationary conditions. In stationary conditions, the adjustment of the injectors is made by the devices KI-1609A, KI-562 and KI-3333.

3. Results and Discussion
The technical condition of the regulator affects the fuel efficiency of the engine [7, 14, 18]. The main parameters that characterize the technical condition of the regulator are: the maximum speed of the crankshaft at idle, the degree of unevenness, the degree of insensitivity, the total axial clearance of the rail relative to the coupling of the regulator roller, the axial clearance of the control lever of the regulator, the fluctuations in the speed of the crankshaft in various operating modes of the engine [1, 8, 17]. The parameters of the regulator can be measured most accurately on the adjustment stand in stationary conditions. The state of the fine filters is evaluated by the completeness of the dropout, the fineness of the dropout, and the throughput. The completeness of the dropout characterizes the relative decrease in the content of the pollutant in the fuel when passing through the filter [2, 19]. For diesels with a fuel pump plunger diameter of up to 12 mm, the dropout rate must be at least 0.90. The flow capacity characterizes the hydraulic resistance of the filter. It is determined by the fuel consumption at a certain pressure drop before and after the filter. The pumping pump is checked according to the following parameters: the maximum pressure developed by the pumping pump with the fuel injection line completely blocked and the nominal speed of the crankshaft rotation, the maximum pressure developed by the hand pump [6, 8, 16]. Pumping pumps with a maximum system pressure of less than 0.1...0.11 MPa are considered defective [1, 17].

4. Conclusions
1. Analysis of existing diagnostic tools for diesel engine fuel equipment allows us to conclude that the devices and stands produced by the domestic industry do not meet the modern requirements for diagnostic devices: the lack of modern electronic equipment, the high complexity of performing
diagnostic operations, requiring partial disassembly of the power supply system or removal from the engine, low accuracy of determining diagnostic parameters [2-4, 6, 9, 10, 13, 17, 19].

2. For use in mechanical repair shops, the following devices and equipment can be recommended: for adjusting and testing fuel pumps, stands KI-22201A, KI-6251, KI-22205, KI-15711, for adjusting automotive injectors, stands KI-1404 and KI-15713.

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