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THE IMPORTANCE OF THE REGRESSIVE MODEL IN DETERMINING FUEL CONSUMPTION IN AUTOGRAINERS

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Abstract
The following article analyzes methods for determining fuel consumption under various operating conditions of motor graders and examines how diesel fuel consumption during the operation of motor graders in mountainous areas depends on several factors. The main advantage of the regressive (determination and forecasting) model and the process of simultaneously assessing the influence of several factors on fuel consumption are also shown.

Keywords: Avtogreyder, fuel consumption, cuvette, career, relief, engine.

Introduction

Among the modern equipment used in road construction, motor graders occupy a special place. These machines perform many technological processes, such as leveling the roadbed, spreading soil layers, forming profiles, and snow removal. The effective use of motor graders largely depends on their fuel consumption indicators, which is one of the main factors determining the operating costs of the equipment. Therefore, the accurate determination of fuel consumption, its analysis, and the development of ways to reduce it are of great scientific and practical importance in increasing the efficiency of road construction machinery.

Fuel consumption is an indicator expressing the amount of fuel consumed by the engine over a certain period of time or in relation to the volume of work performed. This parameter reflects not only the energy efficiency of the machine, but also its technical condition, operating mode, and interaction with the external environment. This indicates that the issue of optimizing fuel consumption is also relevant from an economic point of view.

Among natural factors, relief conditions are of particular importance. On flat terrain, the driving resistance is low, which ensures the stability of the engine load. In mountainous areas, climbing altitudes, frequent turns, and the need to operate low gears lead to increased fuel consumption. In addition, as altitude increases above sea level, the amount of oxygen in the air decreases, which can cause a certain decrease in engine power.

The fuel consumption of motor graders is formed under the influence of many factors. They can be conditionally divided into technical, technological, and environmental factors. Technical factors include engine power, transmission type, total machine weight, and technical condition. Deviation of the engine from the optimal operating mode, contamination of filters, or

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malfunctions in the fuel system lead to an increase in fuel consumption. Studies show that fuel consumption can increase by an average of 10-15% if maintenance requirements are not met.
Motor graders are widely used in railway construction, land reclamation, hydraulic engineering, and airfield construction. Most importantly, the construction and major repairs of roads, as well as their maintenance, are carried out by motor graders. With the help of motor graders, the surface of the roadbed is profiled and leveled, the base for the pavement base is laid, water is drained from the side reserves of the hill with a dam height of up to 1.5 m, cuvettes up to 1.2 m deep are dug, slopes are cut and profiled, gravel and crushed stone are mixed and leveled along the roads, hard pavements are laid on the road, mixing inert materials with binding materials. In road maintenance work, motor graders are used for cleaning cuvettes, side and drainage ditches, and cleaning roads from snowdrifts and silt. Autograders are widely used for leveling the surface of large areas.
As can be seen from above, in addition to road construction, road graders are widely used in other sectors of the national economy. Since we have different uses, energy consumption will also be different. Determining the specific fuel consumption in operating enterprises under various operating conditions presents a number of problems. Especially in mountainous and quarry conditions, the impossibility of determining fuel consumption using existing test methods has shown its results in the conducted research.
When motor graders operate in mountainous areas, diesel fuel consumption depends on several factors. They can be divided into main groups:

1. Technical factors:

Engine power, old-type engines usually consume more fuel.
If the engine, transmission, wheel, brakes, fuel supply, and cooling system are faulty, the consumption increases.
The service life and obsolescence of the grader, the low efficiency of old machines, and the high fuel consumption.

2. Operating conditions:

In mountainous areas, due to the rarefaction of altitude, engine efficiency decreases, and fuel consumption increases.
The load on the engine varies depending on the type of work, such as road leveling, snow removal, or soil cutting.
The terrain and road conditions are steep, there are many turns, and fuel consumption increases on inclined roads.
More fuel is also needed to heat the engine in weather conditions - winter in the cold.

3. Operating mode:

Incorrect machine speed and gear selection - improper speed and gear handling increases fuel consumption.
The number of stops and restarts increases the cost of stops and restarts.
In mountainous areas, idling (holostoy hod) often requires more fuel consumption.

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Figure 1. Operating conditions of motor graders

4. Operator factors:

The driver's skill is that an experienced operator saves fuel by operating the engine in the optimal mode.

Driving style - rough control, excessive technical or high-speed operation increases fuel consumption.

Let us consider the mathematical model of diesel consumption using several factors influencing the fuel consumption of the above-mentioned motor graders in the following sequence:

1. Mechanical/energy formulas - by calculating the effect (power) required for the machine;
2. Converting fuel consumption from this effect to liters/hour, taking into account engine efficiency;

- m- total mass of the grader (kg)
- g- gravitational acceleration of the earth = 9.81 m/s^2
- v- speed of movement (m/s)
- s- relative slope according to the equation on which the slope (grade) lies (for example, 10%=0.10)
- C_{rr} -wheel surface (usually around 0.015-0.03)
- C_d - aerodynamic drag coefficient (small, often neglected for mountain operating speeds)
- p- air density (kg/m3), depending on the region and altitude (at sea level = 1.225 kg/m3, decreases with increasing altitude).
- A- frontal area of the machine (m2)
- η- engine+transmission efficiency (as a percentage; e.g. 0.30-0.40)
- E_{yoqil}- fuel energy density (MJ/L). Approximately 35.8 MJ/L for diesel (approximate value)
  - P_{aux}- step-only electricity/aux or idle power (kW) -if used.

Step 1 - traction force calculation

To move the machine in mountainous conditions, it is necessary to overcome the following forces: steering rolling resistance, climbing slopes, aerodynamic resistance, and inertial (acceleration) components. Typically, motor graders have low speeds and small aerodynamic and acceleration sections.

but the general expression is:

$$F_t = F_{rr} + F_{level} + F_{air} + F_{interval}$$

that is:

• F_{rr}=mgC_{rr}
• F_{level}=$mg\ s$ (for small angles $\sin\theta\ \approx s$)
• $F_{air} = \frac{1}{2}pC_d Av^2$
• $F_{interval}$= ma (at constant velocity, if acceleration exists, it is 0)
As a result:

$$F_t = mg(C_{rr} + s) + \frac{1}{2}pC_d Av^2 + ma$$

Step 2 - Required power

The required power is found by multiplying the tractive force F_t by the velocity v:

$P_{req} = F_t \cdot v$ (Watt)

Converting to kW:

$$P_{req,kW} = \frac{F_t \cdot v}{1000}$$

If the car is in a downtime or on additional auxiliary power, the general requirement is: Auxiliary power (auxiliary force) is additional energy or power supplied to operate auxiliary devices in addition to the main system.

$P_{total} = P \downarrow_{kw} + \ P_{aux}$

Step 3 - calculate fuel consumption (L/hour)

Engine efficiency η is calculated based on unnecessary energy sources in liters/hour as follows: One kW per hour: 1kW=3.6 MJ/hour. Diesel power E_{fuel} (MJ/L) with:

$$\dot{V}_{fuel} = (\frac{L}{soat}) = \frac{P_{total}(kW) \cdot 3.6\ MJ/h}{\eta \cdot E_{fuel}(MJ/L)}$$

With a simplified constant (constant):

$$\dot{V}_{fuel} = P_{total} \cdot \frac{3.6}{\eta E_{fuel}}$$

for diesel: $E_{fuel} \approx 35.8\ MJ/L$ thus:

$$\dot{V}_{fuel} = \left(\frac{L}{soat}\right) \approx P_{total}(kW) \cdot \frac{0.10056}{\eta}$$

(that is 0.10056=3.6/35.8)

Full final formula (constant speed, acceleration=0)

$$\dot{V}_{fuel} = \frac{0.10056}{\eta}\left[\frac{v}{1000}\left(mg(C_{rr} + s) + \frac{1}{2}pC_d Av^2\right) + 1000\ P_{aux}\right]$$

If P_{aux} kW if given simply $P_{umumiy} = \frac{F_1 v}{1000} + P_{aux}$ and then the above

$$\dot{V}_{fuel} = P_{total} \cdot 0.10056/\ \eta$$

The main parameters for typical ranges (recommendation) are:
• m (grader): 12,000-20,000 kg (according to the model)
• C_{rr} :0,015-0,03
• s (10 %slope)=0.10; (20%)=0.20 etc.
• v - working speed 1-5 m/s (3 m/s ≈ 10.08 km/h total operating speed)
• η 0.30-0.40 (general: engine+transmission)

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• p - at sea level ≈ 1.225 kg/m^3, 3000 m at approximately 0.9 kg/ m^3 (consider height)

• $C_d A$ small for grader, or C_d ≈1.0, A≈ $3m^2$ Approximate values like will be used.

Using the above parameters, let's consider the following calculation:

m=16000 kg,

C_{rr}=0,02, s=0.10 (10% slope)

v =3.0 m/s (10.8 km/h)

η=0.35, neglect the aerodynamic part (low speed), P_{aux}= 0

$F_t = mg(C_{rr} + s) = 16000 \cdot 9.81 \cdot 0.12 \approx 18835\ N$

P_{req}=$F_{tv} \approx 18835 \cdot 3 = 56506\ W = 56.51 kW$

$\dot{V}_{fuel}$=5651$\cdot \frac{0.10056}{0.35} \approx 16.2\ L$/hour

This value can be roughly average for mountainous terrain, a 10% slope, and the above conditions. (If the slope, load, or speed increases, the cost also increases.)

To calibrate the model with real data (approaching accurate data), we perform the following sequence:

1. In each operating condition (speed, slope, load, height), real measured fuel L/hour and engine power/telemetry data are obtained;

2. Uncertain parameters in the model (for example C_{rr}, η, $C_d A$) is calibrated using regression (OLS) or optimization, for example, RMSE ($\dot{V}_{measured}$-$\dot{V}_{model}$)

3. If the operator factor is significant, k_{op} (operator coefficient) can be added multiplicatively as an additional indicator:

$\dot{V}_{fuel,adj}$=$k_{op} \cdot \dot{V}_{fuel}$

(catalog values: 0.9-1.2).

The multifactorial linear regression model is widely used for determining and forecasting the fuel consumption of motor graders. This model represents the mathematical relationship between the dependent variable - fuel consumption ($\dot{V}$) and the main factors influencing it. The model is presented as follows:

$$\dot{V} = \alpha + \beta_{1\,v} + \beta_{2\,s} + \beta_{3\,m} + \beta_4 T + \varepsilon$$

here:

$\dot{V}$– fuel consumption of the grader (for example, liters/hour);

α– initial value, representing fuel consumption when all independent variables are equal to zero;

v– the operating speed of the machine (km/h), β_1 shows its effect on fuel consumption;

s– the density of the sliding soil or the amount of load, β_2 the coefficient of influence of this parameter on fuel consumption;

m– the mass of the grader, β_3 represents the effect of the mass on fuel consumption;

T– external temperature or operating conditions, β_4 indicating its effect on fuel consumption;

ε– random changes or errors not explained by the model.

The main advantage of this regressive model is that it allows simultaneously assessing the influence of several factors on fuel consumption. Each β_i coefficient can have a positive or negative value, which shows how fuel consumption changes when the corresponding factor

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increases or decreases. For example, if β_1>0, fuel consumption increases with increasing vehicle speed, and if β_2<0, fuel consumption decreases with decreasing load.
Also, the ε error component takes into account random factors not explained by the model, such as soil softness, the operator's work style, or changes in weather conditions. At the same time, using this regression model, it is possible to forecast and optimize fuel consumption for future conditions, which is important for reducing operating costs and efficient use of resources.

CONCLUSION

Determining fuel consumption under various operating conditions of motor graders requires a comprehensive approach. The application of the results of practical measurements in combination with theoretical calculation methods increases the accuracy of calculations and ensures the efficiency of the use of equipment. In the future, the development of innovative management methods aimed at reducing fuel consumption will serve to further increase the economic efficiency of road construction work. Determining the fuel consumption of motor graders is an important element of effective management of road construction equipment.

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