Development and testing of hardware-software complex for diagnostics of freight vehicles energy parameters

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Abstract Proposed method of energy parameters control of freight vehicles in a non-brake way is based on evaluation of their dynamic properties. An algorithm has been developed for calculating all the necessary energy parameters, on the basis of which analysis and correct technical and production operation of freight vehicles (FV) are carried out. The method of measuring speed and acceleration of FV was tested using a set of GPS and/or GLONASS sensors which showed its effectiveness.

Keywords: diagnostics, parameter control, power, transition process

1 Introduction

Freight transport is the most efficient kind of transport but it is also relatively expensive. The agro-industrial complex (AIC) is known as a complex system in which each element has its own unique function; in the case of failure or significant depletion of the resources of one of the elements the rest will not be able to function effectively [1]. With timely diagnosis and tracking of even minor losses in energy performance of machine and tractor stock and freight transport, serious problems in the operation of agricultural system can be prevented. Without making significant efforts and costs to control the parameters of the technical condition of freight vehicles engaged in cargo transportation in the AIC, the cost for repairing vehicles, thereby fuel costs as well as downtime of FV can be significantly reduced [2, 3, 4].

According to the results of a study on the example of an official DAF dealer in Russia, it was found that FV are operated with overload in 90% of cases. This type of operation leads to increased wear of parts and assemblies and as a result to a change in the energy parameters of the FV. In this case the frequency of maintenance does not correspond to the actual need, which can be established by constantly monitoring the parameters of FV using the developed hardware-software complex. Therefore, the task of developing and testing a hardware-software complex as well as software is an urgent task.
2. Materials and Methods

When introducing modern diagnostic methods, monitoring and data collection in the process of diagnostics and operation of FV, a non-brake method of diagnosis based on the assessment of dynamic properties of FV is promising and low-cost [5]. Engine power and torque are determined during its free acceleration without load [6, 7]. In this case, the angular acceleration of the engine crankshaft is measured at full fuel supply from the minimum stable idle speed to the maximum. A FV engine is loaded due to the inertia forces of moving and rotating parts of the engine and the car itself (the moment of inertia for each engine is a constant value) [8]. In our opinion, this type of diagnostics is faster than brake bench methods, in which the load applied to the engine crankshaft is created using a special brake. The data processing algorithm that implements the selected methods is shown in Figure 1.

Features of the hardware part of the complex:

- a set of GPS and / or GLONASS sensors, an accelerometer and a crankshaft sensor that provide a sufficient amount of data for calculations. During the development process, the prospect of adding additional sensors (pressure sensors before and after the oil filter, etc.) will be considered [11];
- a personal computer (PC) (at initial stages of development) that connects the sensors to a central processor with sufficient processing power to calculate the necessary parameters as well as an external storage device for storing them, during further development the possibility of adding a display to show the current parameters and performance indicators;
- bluetooth module and / or USB output, providing data output to various devices (personal computer, smartphone) for detailed display and analysis of parameters.

The software part of the complex will consist of the following modules:

- the main program for a PC (at the initial stages of development) and its own device (at the final stage of development) which will read data from sensors and calculate the necessary and additional parameters according to the developed algorithm, display basic information on an external storage device, then on the device’s display;
- additional software for a PC or a smartphone, which allows to get detailed information, graphically to display the received data.

The operation of the hardware-software complex is provided by entering the initial parameters: external speed characteristics of the engine, transmission efficiency, gear ratios of the gearbox and final drive, wheel sizes.

The next step in the algorithm is obtaining data from sensors for speed, time and angular velocity of the crankshaft of the engine and then filling in the data amount, calculating the traction and dynamic characteristics of the FV and construction of acceleration and free acceleration curves. After that a specially developed algorithm compares and analyzes the reference characteristics of the FV and experimental ones, gives recommendations and a forecast of technical conditions. The algorithm will work on the basis of an iterative method.

3. Results

Assessment of the dynamic properties of FV can be performed using a mathematical model based on the well-known equation of motion [9, 10]. FV power balance is shown in Figure 2. The equation of the FV movement (power balance) has the form:

\[ F_k - F_i - F_s - F_\alpha = 0 \]  \hspace{1cm} (1)

where \( F_k \) is tangent force on the wheel, the driving force of FV, N;
\( F_i \) is force expended to overcome the inertia of translational and rotational masses of the car, N;
\( F_s \) is force of resistance to movement (wheel rolling, air resistance), N;
\( F_\alpha \) is force expended to overcome ascent/descent, N.

\[ F_k = M_d \cdot \frac{l_{kpp}}{r_d} \cdot l_{gp} \cdot \eta, \]  \hspace{1cm} (2)

where \( M_d \) is torque developed by the engine, Nm;
\( l_{kpp} \) is gear ratio;\
\( l_{gp} \) is gear ratio of the main transmission (differential);
\( r_d \) is actual rolling radius of the wheel, m;
\( \eta \) is transmission efficiency.

\[
F_i = m_p \cdot a,
\]
where \( m_p \) is reduced mass of CV, kg;
\( a \) is developed acceleration, m/s\(^2\).

\[
F_s = F_{sk} + F_{sv}
\]
where \( F_{sk} \) is rolling resistance force of the car, these include friction force in bearings and rolling wheels, N;
\( F_{sv} \) is air resistance force, N.

\[
F_a = m \cdot g \cdot \sin(\alpha),
\]
where \( m \) is mass of FV, kg;
\( g \) is acceleration of gravity, m/s\(^2\);
\( \alpha \) is developed linear acceleration, m/s\(^2\).

\[
F_{sv} = C_x \cdot \frac{\theta^2 \cdot \rho}{2} \cdot S,
\]
where \( S \) is frontal section of a vehicle, projection of body onto a plane perpendicular to the longitudinal axis, m\(^2\);
\( \rho \) is air density, \( \rho = 1.29 \text{ kg/m}^3 \);
\( C_x \) is drag coefficient of a vehicle, \( C_x = 0.25 \ldots 0.5 \);
\( \theta \) is vehicle speed, m/s;
Figure 2. Power balance of FV

\[ F_{sk} = m \cdot g \cdot k_1 + k_2 \cdot \vartheta + k_3 \cdot \vartheta^2 \]  

(7)

where \( k_1 \) is coefficient of rolling resistance which characterizes the constant component of rolling, is numerically equal to tabular coefficients of road resistance / reference to the method;

\( k_2 \) is coefficient characterizing a linear increase in rolling resistance versus vehicle speed;

\( k_3 \) is coefficient characterizing the quadratic component of resistance growth versus vehicle speed;

The reduced mass of the FV is determined from the expression

\[ m_p = m \cdot \psi, \]  

(8)

where \( \psi \) is coefficient of accounting for rotating masses;

\( m \) is operating mass of FV, kg.

The coefficient of rotating masses accounting is determined by the known method [12]. To implement the proposed mathematical model it is necessary to use the developed data processing algorithm, shown in Figure 1.

In order to test the proposed model and the hardware-software complex, preliminary experimental studies were carried out using a passenger car as an example. The car was accelerated, that means acceleration from the minimum engine speed (at which stable motion is possible) to the maximum possible (maximum power) from second to fifth gear under conditions of very fast maximum fuel supply. This is necessary to transfer data to the hardware-software complex in order to calculate the tangential traction force on the wheel that moves the car.

Acceleration is made in both directions on the selected section of the road in order to exclude the influence of slope and wind. In addition, the road section is selected so that at the end of the acceleration there was sufficient road section for the braking distance. A fragment of the experimental data on the acceleration of the car is shown in figure 3. Data recording began when the car was not yet moving.

The first stage is preparation for acceleration. The driver starts the engine and accelerates the car to 30 ... 40 km/h, after that he engages the necessary gear, the accelerator pedal is smoothly being released until the engine speed reaches 500...800 rpm. It is necessary to withstand this mode of movement for 3..7 seconds, then press the accelerator pedal until stop. After reaching the maximum engine crankshaft speed, the driver turns on the neutral gear and waits 3 ... 4 seconds (so that the fact of acceleration end is clearly visible from the speed graph data obtained after processing the GPS data), and the car begins to brake.
Taking into account methodology features in order to obtain data that allow to assess more accurately characteristics of the vehicle it is advisable to accelerate it in all gears from minimum to maximum speed [12]. But in the first gear the acceleration is very short and as a result 3..4 points of the GPS graph are obtained, which does not allow to reliably determine the acceleration of the car. At higher gears: the fourth and the fifth, at maximum speed the car can accelerate to speeds of more than 140 km/h which increases both technical and administrative risks during the experiment.

Measurements of car run-out were made and experimental data fragment is presented in Figure 5. Free car run-out means the process of car rolling in neutral gear until it will stop completely. The higher the speed of accelerated car and accordingly the run-out path the more accurately rolling resistance forces can be determined. The car run-out is necessary in order to obtain the forces of resistance to movement: $F_t$, $F_s$, $F_a$. It is important to take into account that the maximum speed should be limited by a number of factors: length of chosen for research road section, traffic intensity, quality of coverage as well as other safety considerations. In this case a driver should try to drive the car strictly in a straight line and also avoid sharp maneuvers since they cause additional car braking. If the driver was forced to make a sharp maneuver the experiment should be repeated again. A fragment of experimental data on fixing car run-out is shown in Figure 4.
In specially worked out software that implements the developed algorithm, the resistance forces were calculated according to equation (1). The experimental data calculated by the iterative method and describing the resistance forces dependence from movement speed are shown in figure 5. Obviously, obtained dependence describes the studied regularities quite accurately.

4 Discussion

Figure 5 is of greatest practical interest with calculated data obtained by the developed algorithm. In this case, all the necessary parameters were calculated for making further decisions to improve efficiency of developed hardware-software complex. Having determined resistance strength to movement, the developed engine power and its fuel consumption indicators, which are especially accurately measured in diesel engines it is possible to build an effective system for technical and industrial operation of FT.
The developed complex is intended for diagnosing vehicles, detecting a malfunction, partial loss or reduction of power characteristics and operating modes monitoring. Power is the main indicator of both operability and efficiency of FT. The consumers of the final product will be manufacturers involved in freight transportation as well as industries where it is important to monitor the technical condition of transport and analyze its performance in order to reduce costs, since one of the priority tasks is reducing the cost of provided services. In turn, fuel costs are reduced, downtime and inefficient use of FT due to breakdowns are also significantly reduced.

Conclusions
The presented mathematical model, the algorithm that implements it and preliminary experimental data confirm correctness of the chosen research direction and show the fundamental possibility of monitoring the technical condition of freight vehicles using GPS and / or GLONASS systems, a hardware-software complex and its software.

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