Determination of rational locomotive operating modes and resource costs based on information from global positioning systems

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Abstract. The article is devoted to the study of energy-efficient use of traction rolling stock for driving trains. It deals with the optimal driving mode and the main parameters of traction calculations. Based on the use of GPS/GLONASS satellite navigation units, a method for determining the basic resistance of cars in real time is proposed. The possibility of using the results obtained on locomotives with analog devices and no movement tracking is analyzed. The "Traction Calculations" software package in the C# programming language was modified in order to reduce the time and facilitate calculations of the locomotive traction service. In the course of the study, the equation of the main resistance of the cars of train No. 3612 was determined. On the basis of the uncoupled rolling stock, the dependences of speed, time, heating and current of traction electric motors, fuel consumption by the CHME3 locomotive of the Kharkiv-Sortirovochny locomotive depot for the transportation of cars from the Kharkiv-Sortirovochny station to Merefa station were calculated, with recommendations for the driver to use the position of the driver's controller in order to reduce costs and fulfill the train schedule.

1. Introduction

The current state of railway transport in Ukraine is characterized by noticeable wear and obsolescence of fixed assets. The reform of railway transport is directly related to the development and implementation of a set of measures aimed at increasing the carrying capacity and reducing the cost of fuel and energy resources for train traction [7, 8]. During operation, there is a constant change in the parameters that characterize the quality of operation of the rolling stock. The decrease in operational characteristics is associated with the deterioration of the technical condition of individual equipment elements [1, 10]. This is due to increased wear of mechanical equipment parts and aging of insulation of electrical machines, which leads to a decrease in the service life of assembly units and parts. This results in an increase in drag forces, a decrease in braking and traction forces, with a consequent increase in the cost of pulling trains [4, 9]. Systemic analysis of traction calculations has been carried out throughout the existence of railway transport. The accuracy of the results obtained affects the cost
of resources for traction and, as a result, reduces the cost of transportation [6, 8]. The definition of rational weight standards is the basis for increasing the carrying capacity of railways and cutting the repair cost of rolling stock. The development of microprocessor equipment and mathematical modeling of train movement parameters allows us to find hidden reserves in improving the efficiency of operation of traction rolling stock, efficient use of locomotive power and their rational modes of operation. The development of global vehicle positioning systems has become widespread in the world. It helps quickly get information about the movement and location of objects in space. Railway transport in Ukraine is strategically important for the functioning of the economy and social infrastructure, so the introduction of GPS/GLONASS systems in the locomotive facilities has led to the informative location of traction vehicles on the monitors of dispatching and other services [11, 12]. Improving the accuracy of determining the main parameters of movement, increasing the processing capabilities of electronic computers and automated systems, as well as the bandwidth of information transmission channels for processing and analyzing the received data, creation of guidelines on fuel economy in the operation of locomotives and train driving modes, their implementation in the transportation and training process of locomotive crews, will minimize the repair and operation cost [2, 3]. On the basis of analysis of the works [13-16], the relevance and main directions of development of traction calculations in the world are determined, the need for microprocessor control and the use of systems of increased reliability of information in the process of train movement is formed. Reducing the calculation time is the basis for algorithmization of processes. Software products for calculating traction parameters and optimizing energy consumption have been developed on the basis of algorithmization of processes. The most widely used specialized complexes are ISKRA-PTR, ERA, VECTRUM and MoveRW. The main parameters of the traction can be calculated and build a model of train coupling can be built to adapt the modes of reference when the timetable is changed. However, they have a number of disadvantages, such as high cost and technical requirements for electronic computing, insufficient accuracy of the impact of the track on the rolling stock, and the inability to respond flexibly to changing technical characteristics of the rolling stock. A material drawback of the operation is the lack of accounting for information received from the global positioning units GPS/GLONASS.

Since the parameters that characterize the quality of operation of the rolling stock are constantly changing during the operation, there is a need to create an adaptive train driving mode, the adaptation of which would include changes in the values of traction forces and fuel consumption. In [9], a software product is presented by optimizing the algorithm so that the set goals can be achieved. In order to establish the dependencies of the resistance forces to the movement of a real train, there is a need to diagnose them in real time. This is possible only when using an expression that can take into account all factors affecting the rolling stock-the law of conservation of mechanical energy. So the solution is to develop on the basis of the law of conservation of mechanical energy, using data blocks GPS/GLONASS, the equation of running resistance and determining the adaptive mode of the train with flexible adjustment of input parameters.

2. Formulation of the problem
The purpose of the work is to develop a model for determining the rational mode of driving a train, taking into account information from global positioning systems. To do this, on the basis of tracking (figure 1) and information from the global positioning system of train No. 3612, the equation of the main resistivity of cars should be determined. A mathematical model and software for determining the rational driving of the train in order to reduce the resources for traction should be developed.

Based on the results obtained, the resource consumption for traction should be optimized, the dependence of speed, time, heating and current of traction motors should be built for a CHME3 diesel locomotive for transporting cars from the Kharkiv-Sortirovochny station to Merefa. the minimum fuel consumption when running the train schedule should be determined, and the locomotive traction points should be set in the form of a table recommendation to the driver.
3. Solution

In general, the search for rational modes of locomotive operation (figure 2) is reduced to solving the integral type of equation (1) and establishing the time intervals of the stage run between stations. It is necessary to take into account the equal average speed in the time interval \( (t_1, t_3) \), but this leads to a decrease in the acceleration of the train and an increase in the time interval \( (t_1, t_2) \).

\[
\int_{t_1}^{t_2} g_i(t) dt + \int_{t_2}^{t_3} g_{xx}(t) dt > \int_{t_1}^{t_3} g_j(t) dt,
\]

(1)

where \( g_i(t) \), \( g_{xx}(t) \), \( g_j(t) \) accordingly, is a function of specific energy consumption on the position of controller of the driver "i", no load and on the position of controller of the driver "j" corresponding to the speed of movement; \( t_1, t_2, t_3 \) are time interval specific functions.

It is proposed to use data on resource costs and hyperbolic characteristics of traction forces to install an energy-efficient position of the driver's controller. The logical interpretation of this statement...
is based on the need to determine the value of the traction force relative to fuel or electricity consumption. The mathematical representation of the coefficient $\eta_{ib}$ is calculated using the expression

$$\eta_{ib} = F_{kv} \cdot G_v^{-1},$$

(2)

where $F_{kv}$ and $G_v$ this is, respectively, the locomotive's traction force and energy consumption at the position of the driver's controller "n" and "j" corresponding to the speed of movement.

During operation, the technical parameters of locomotives change. We use the law of conservation of mechanical energy to determine the nature of the influence of the resulting sum of forces acting on the train during movement on the rails

$$\xi \cdot S \cdot (f_k - a - b_T) = 0.5 \cdot (V_2^2 - V_1^2) + g \cdot (h_2 - h_1),$$

(3)

where $V_1, V_2$ are the speed at the beginning and end of the profile element, respectively; $m$ is the mass of the train; $g$ is the acceleration of gravity; $h_1, h_2$ are the heights at the beginning and end of the profile element, respectively; $S$ is the length of the travel section; $\xi$ is the coefficient of specific acceleration; $f_k, a, b_T$ are, respectively, the specific force of traction, resistance to movement and braking.

The specific forces of resistance to movement are the sum of the forces of the main and additional resistance with the magnitude of the impact in accordance with the mass

$$\omega = (P + Q)^{-1} \cdot (P \cdot \omega'_o + Q \cdot \omega'^*_o) + \omega_D,$$

(4)

where $P, Q$ are, respectively, the mass of the locomotive and the train; $\omega'_o, \omega'^*_o, \omega_D$ are, respectively, the specific forces of resistance to the movement of the locomotive, the composition, and additional. Since the additional resistance $\omega_D$ includes the potential influence of the profile, we will not take into account the part of expression (3) $g \cdot (h_2 - h_1)$. The effect of $\omega_D$ for cars with rolling bearings is determined by the expression

$$\omega_D = i + 200 \cdot R^{-1} + 1.5 \cdot V^2 / 1296 \cdot R \cdot h \cdot g \cdot S_k + 280 \cdot (q_0 + 70)^{-1} + \omega_o \cdot (k_{HT} + k_b - 2),$$

(5)

where $i$ is the steepness of the resulting ascent; $R$ this is the radius of the curve; $q_0$ is the axial load of the rolling stock; $h$ is the difference between the heights of the rail heads; $S_k$ is the distance between the rolling circles of the rolling stock wheelset; $k_{HT}$ this is the coefficient of exposure to low temperatures; $k_b$ is the coefficient of influence of air masses (wind).

In general, $\omega'_o, \omega'^*_o$ are functions of a quadratic equation with corresponding coefficients [2, 3]. According to the requirements of [3] and the definition of data for the entire speed range, we present the forces of the main drag of cars in the form of the equation

$$\omega'_o = a' \cdot V^2 + b' \cdot V + c',$$

(6)

$$\omega'^*_o = a^*_o \cdot V^2 + b^*_o \cdot V + c^*,$$

(7)

where $a', b', c', a^*, b^*, c^*$ are, respectively, unknown coefficients of the locomotive and car resistivity equation. The coefficients of resistivity $a', b', c'$ can be obtained during light running of the locomotive or from the data [2, 3]. On the basis of information from the GPS/GLONASS global positioning units integrated on the VL11 locomotive, we obtain accurate values of speed, time, and path with a minor error [11, 12]. Then the calculation of the real values of the main resistance of cars will be determined by the expression
\[ \varpi_o = Q^{-1} \cdot (P + Q) \cdot \left[ f_k - b_T \frac{V_2^2 - V_1^2}{2 \cdot \xi \cdot S} - \frac{P}{P + Q} \cdot (a' \cdot f \frac{V_2 - V_1}{2} + b' \cdot \frac{V_2 - V_1}{2} + c') \right], \quad (8) \]

We calculate the coefficients \( a', b', c' \) using the least squares approximation of GPS/GLONASS block data

\[ \begin{align*}
    a'' & \cdot \sum_{i=1}^{n} V_i^4 + b'' \cdot \sum_{i=1}^{n} V_i^3 + c'' \cdot \sum_{i=1}^{n} V_i^2 = \sum_{i=1}^{n} V_i^2 \varpi_{o_i}, \\
    a'' & \cdot \sum_{i=1}^{n} V_i^3 + b'' \cdot \sum_{i=1}^{n} V_i^2 + c'' \cdot \sum_{i=1}^{n} V_i = \sum_{i=1}^{n} V_i \varpi_{o_i}, \\
    a'' & \cdot \sum_{i=1}^{n} V_i^2 + b'' \cdot \sum_{i=1}^{n} V_i + c'' \cdot n = \sum_{i=1}^{n} \varpi_{o_i}.
\end{align*} \quad (9) \]

where \( n \) is the number of data registrations by the GPS/GLONASS unit.

As a result of calculating the tracking of train No.3612 from Osnova station to Kharkiv-Sortirovchny station using the expressions (5, 8, 9), we obtained the equation of the main resistivity of a freight train weighing 4,483 tons, with 220 axles of gondola cars with rolling bearings, at a wind speed of 0.7 m/s and a temperature of 22 °C

\[ \varpi_o = 0.00009915 V^2 + 0.00420327 V + 0.87334037, \quad (10) \]

One of the tasks of this work is to prove that the system as a whole works with small volumes of global positioning blocks. Therefore, as an example of the interaction of information from the systems integrated in electrical locomotives VL11 and locomotives without GPS/GLONASS, let us consider the following case: upon arrival at the station Kharkiv-Sortirovchny, 7 cars from the end of the freight train weighing 571 tons, total 28 axles were coupled with the CHME3 diesel locomotive to transport cargo to the destination station Merefa. The temperature of traction motors is set to 37.3 °C before shipment. We use the software package “Traction calculations” developed by the authors of the article [5] in the Visual C# programming language and create a modification in the form of an energy-efficient train driving mode.

The essence of the modification will be as follows: to perform the train schedule, we use the balance method for calculating the time of passage of a section element. That is, the movement occurs according to the schedule and expression (2), which makes it possible to optimize fuel consumption in the time interval of the stage. Let us create an application that takes into account equation (10) for rational use of power and resources for traction. A graphical representation of the rationality of the driver’s controller position, according to (2), CHME3 relative to the speed is shown in figure 3.

\[ \text{Figure 3. Rationality of the position of the driver’s controller CHME3.} \]
Determining the speed on the path interval using (3) will be determined by the expression

\[ V_2 = \left[ V_1^2 + 2 \cdot \xi \cdot S \cdot ( f_k - b_f - \omega) \right]^{1/2}, \]

(11)

On the other hand, \( V_2 \) speed can be calculated as

\[ V_2 = V_1 + S \cdot \Delta t^{-1}, \]

(12)

where \( \Delta t \) is the growth time. Substitute (12) in (11) and perform the conversion, then the time increment is determined by the expression

\[ \Delta t = S \cdot \left[ \left( V_1^2 + 2 \cdot \xi \cdot S \cdot ( f_k - b_f - \omega) \right)^{1/2} - V_1 \right]^{-1}, \]

(13)

The train schedule is essentially the sum of the driving time for races, then the relationship between \( \Delta t \) and the time of the stage run \( t_p \) must be directed by the expression

\[ \sum_{i=1}^{n} \Delta t_i \geq t_p \text{ and } \sum_{i=1}^{n} \Delta t_i - t_p \to 0, \]

(14)

If the left and right members of equation (14) do not match, increase the value of \( S \cdot f_k \) in equation (11, 13) and repeat the calculation until condition (14) is met. The calculation results are shown in figure 4. Recommendations to the driver on the mode of operation of the locomotive on the route are shown in table 1

**Table 1. Recommendations to the driver on the mode of driving the train.**

| Beginning of the thrust (km) | Position | End of thrust (km) | Fuel consumption (kg) | Note |
|-----------------------------|----------|--------------------|-----------------------|------|
| 774                         | 1        | 774.006            | 0.042                 |      |
| 774.006                     | 2        | 774.011            | 0.042                 |      |
| 774.011                     | 6        | 774.02             | 0.157                 |      |
| 774.02                      | 8        | 774.029            | 0.177                 | Sand |
| 774.029                     | 6        | 774.222            | 1.296                 |      |
| 775.014                     | 6        | 775.946            | 4.008                 |      |
| 777.232                     | 6        | 777.952            | 2.882                 |      |
| 779.495                     | 6        | 781.092            | 7.524                 |      |
| 782.314                     | 6        | 782.416            | 0.486                 |      |
| 784.03                      | 6        | 791.5              | 36.2                  |      |

| \( \sum_{i=1}^{n} G_{x_i} = 4.256 \text{ kg} \) | \( \sum_{i=1}^{n} G_{t_i} = 52.814 \text{ kg} \) | \( \sum_{i=1}^{n} G_i = 57.07 \text{ kg} \) |

The results shown in table 1 fully correspond to the characteristics of the current load limitation of traction motors (Te-006) and the main generator (TD-802) \([2-3]\), the fulfillment of the condition of wheel coupling with rails relative to speed \([2-3]\), heating of electric machines in accordance with the insulation class (F) \([2-3]\) of the CHME3 locomotive. The fuel consumption of a traction unit for moving trains in compliance with the traffic schedule and the weight mode map of a given section according to [4] is determined by the expression

\[ G = \int_{t_1}^{t_2} G(\tau) \cdot d\tau, \]

(15)
where \( \tau_k \) and \( \tau_1 \) are the time intervals for moving the train at the corresponding positions of the driver's controller; \( G(\tau) \) is a function of fuel consumption relative to the speed and position of the driver's controller.

![Graphical results of the calculation.](image)

Based on the results of the calculations, the fuel economy is set at 12.75\% compared to [4]. Using the balance mode of train driving will allow you to fulfill the schedule and reduce the consumption of fuel and energy resources for train traction. However, this requires diagnostic equipment and large-scale practical testing in the workplace.

### 4. Summary

This study solves the problem of determining the energy-efficient use of traction rolling stock for driving trains. The necessity of revising outdated methods of training locomotive crews in train driving is proved. Based on the law of conservation of mechanical energy and the use of GPS/GLONASS satellite navigation units, a method for determining the basic resistance of cars in real time is proposed. The possibility of using the results obtained on locomotives with analog devices and no movement tracking is analyzed. In the course of the study, the equation of the main resistance of the cars of train No. 3612 was determined. It is practically proved that resources can be saved with a few train tracking tools installed on mainline VL11 locomotives. The results of calculations of the main resistance are implemented in the optimization of the software complex algorithm in the C# programming language for calculating the uncoupled train at Kharkiv-
Sortirovochny station. On the basis of the uncoupled rolling stock, the dependences of speed, time, heating and current of traction electric motors, fuel consumption by the CHME3 locomotive of Kharkiv-Sortirovochny locomotive depot on the transporting of cars from Kharkiv-Sortirovochny station to Merefa station were calculated with the issuance of recommendations to the driver to use the position of the driver's controller in order to reduce costs and fulfill the train schedule. The specified calculation algorithm allows implementing optimal solutions of resource-saving technologies in the process of cargo transportation. In the future, it is advisable to implement a mathematical model and software product in the locomotive economy in order to establish rational train driving modes, reduce traction resources and mass practical testing.

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