To the algorithmization of the task of optimizing the transportation work of locomotives

O. Ablyalimov

Abstract. A classification of optimization problems for the transportation work of locomotives and various possible methods of a numerical method for solving differential equations of the form \( y' = f(x, y) \) by the chord method are given. A verbal-operator format for the algorithm for solving the specified differential equations is proposed, taking into account the implementation of additional graphical constructions in the current integration interval for the average speed of the train. The algorithm for choosing a preliminary step of integration over the independent variable “path” is substantiated, the found value of which, according to the method of integrating a differential equation of the form \( y' = f(x, y) \) proposed for the author of this article, is used in subsequent calculations, including, which is very important, on the variable step of integration. It is recommended, based on the algorithms proposed by the author, to develop programs for traction and energy (economic) calculations for locomotives of electric traction and high-speed passenger trains.

Key words: Optimization problem, locomotive, algorithm, differential equation, chord method, integration step, operator, work option, logic circuit, independent variable, input.

1 Introduction

In a general sense, the goal of solving various optimization problems for all industries and transport is to obtain the final result with the best economic indicators, including the transportation work of locomotives under operating conditions. The efficiency of using locomotives directly depends both on the level of their operational reliability along the route of the rolling stock, and, directly, on the conditions for the implementation of their transportation work in the process of railway transportation of goods and passengers. Naturally, the organization of railway transportation, taking into account optimal train traffic control modes, first of all, determines an increase in the efficiency of using the railway locomotive fleet. A large number of scientific studies by foreign scientists [1-19] are devoted to substantiating the efficiency of using of locomotives electric [1-7] and diesel [12-18] tractions, as well as aviation [8-11] and automobile and tractor [19] internal combustion engines with from the point of view of developing design and technological solutions and recommendations that are not at all related to the issues of optimal management of...
Algorithmization of problems of optimizing the transportation operation of locomotives is the process of compiling algorithms for the purpose of solving applied problems through a certain set of actions and rules that describe the sequence of each action of a certain performer to achieve the desired result. Moreover, the solution to some specified optimization problem is performed in a finite, fixed number of steps, since the inherent sequence (order) of operations in the algorithm must necessarily be finite, otherwise it will not be an algorithm.

In practical conditions of the operational activities of railways, the transportation work of locomotives consists of individual trips performed at certain coordinates of the material base of the transportation process and the organization of work. A family of trips within the circulation boundaries of locomotives and the work shoulders of locomotive crews can be combined into transportation work options that have constant coordinates of the material base of the process and variable coordinates of the work options.

In accordance with the above, we can consider various problems of optimizing the transportation operation of locomotives, namely:

- each local trip;
- all trips of option of work;
- of locomotive depot;
- of regional railway junction;
- of railway direction in general.

2 Objects and methods of research

Having great practical importance, travel transportation optimization problems occur very often, and their goal is to ensure the greatest efficiency, in this case, to minimize energy consumption for tangential mechanical work of the locomotive by choosing the optimal control mode along the route of the rolling stock. In addition, trip optimization is necessary to solve other cases of problems of optimizing the transportation work of locomotives.

The tasks of optimizing travel trip options are also very common in the practical of operation of the locomotive complex.

It is typical for the work option that the material base of the transportation process will not change, that is, it is constant, and the coordinates of the work organization vector (mass of the train, number of axles, train running time, number of stops and parking, parking time, etc.) change within certain limits. Moreover, for each operating option the number of trips per day is significant, so it is still very difficult to make such calculations simultaneously for all trips.

As a rule, when performing calculations to optimize the transportation operation of locomotives for a depot and a regional railway junction, it is necessary to perform a set of calculations to optimize the family of trips of the work option. In this regard, the optimization of the transportation work of a depot and a regional railway hub consists of the results of optimizing the trips of the work option for the corresponding, specific cases of work.

Calculations for optimizing the transportation work of locomotives for railway directions are aimed at selecting the most advantageous coordinates of the material base of the transportation process and organization of work, the sphere of influence of which covers the direction under consideration, since within the direction the influence of one or another optimized coordinate appears. Usually these are directions that coincide with the boundaries of locomotive work areas, train formation and disbandment stations, track...
reconstruction areas, and so on. Such calculations represent the most general cases of optimizing the process of transportation work of locomotives.

In the practice of railways, one has to deal with various variants of optimization problems, so the purpose of this study is to substantiate some possible schemes for solving problems of optimizing the transportation operation of locomotives by algorithmizing them, taking into account the real conditions of organizing railway transportation, including freight.

It should be noted that regardless of the version of the optimization problem, its mathematical formulation is as follows. Equations of the state of the object are given that describe the process of transportation work of locomotives and the boundary conditions imposed on the state variables of the object, as well as restrictions imposed on the state and control variables taking into account the quality indicator (optimality criterion) of the control object. It is necessary to determine an admissible control such that the optimality criterion will be minimal or maximal.

To implement the formulated research goal, the author uses his proposed new numerical method for solving ordinary differential equations, as well as the object and subject of research.

The object of study is a differential equation of the form

\[ y' = f(x, y) \]

The peculiarity of the solution of which is that the increment in the train speed at each integration step along the route is taken for the average speed in the current interval, taking into account additional graphical constructions.

The subject of research is to develop algorithms for solving differential equations of the form

\[ y' = f(x, y) \]

using the chord method and selecting a preliminary step when integrating over the independent variable "path".

In practice, you can have several possible varieties (or techniques) of a numerical method for solving differential equations of the form

\[ y' = f(x, y) \]

which are implemented in two ways - numerical and grapho-analytical, and are presented in fig. 1.

Studies [21,22] considered issues related to the equation of train motion, analysis and evaluation of existing basic numerical methods for solving it, which showed a certain inconsistency, that is, some difficulties and difficulties in their practical use.

To implement the method proposed in [20] for solving differential equations of the form \( y' = f(x, y) \) in computer calculations, it is first necessary to select a preliminary step of integration over the independent variable.

The solution to the well-known differential equation of train motion (1) [22] is usually carried out by taking the “path” as the independent variable, since profile elements, speed limits, axes of separate points, and so on change depending on the distance traveled. Only in certain cases should integration be carried out over the “speed” variable, which is convenient to do within a particular profile element when the speed increment is greater than the limiting value \( a_{lim} \).

However, in all cases, a preliminary step of integration along the path is identified [20], taking into account all possible changes in traffic conditions - changing the profile of the path, limiting speeds, abscissa of the station, and so on. Only in certain cases are integrations carried out at a fixed, predetermined step \( h_p \), which occurs when finding points for changing the operating mode of locomotive power plants while driving a train.
3 Results and their discussion

$y' = f(x, y)$

$y'_n = f(x_n, y_n)$

$\Delta y_a = y'_n h_a$ if $|\Delta y_a| \leq |a_n|$

$h_1 = x_k - x_n$

$\Delta y_a = y'_n h_a$ if $|\Delta y_a| > |a_n|$

$h_1 = \frac{a_n}{y'_n}$ if $|\Delta y_a| > |a_n|$

$\Delta y_a = y'_n h_a$ if $|\Delta y_a| \leq |a_n|$

$h_1 = \frac{a_n}{y'_n}$ if $|\Delta y_a| > |a_n|$

$y'_n = f(x + \frac{h_a}{2}, y + \frac{\Delta y_a}{2})$ and in $y'_a >$

$y'_n = f(x_n + \frac{h_a}{2}, y + \frac{\Delta y_a}{2})$ and in $y'_a >$

$y'_n = f(x + \frac{h_a}{2}, y + \frac{\Delta y_a}{2})$ and in $y'_a >$
\[ \frac{1}{2} \Delta y_b = \frac{\Delta y_a \cdot y'_n}{2|y'_n|} \text{ and in } |\Delta y_b| < \frac{\Delta y_a}{2} >; \]

\[ h_b = h_a \frac{\Delta y_b}{\Delta y_a} \text{ and in } h_b >; \]

\[ P \{ |\Delta y_b| \leq |a_m| \} \]

\[ h_b \text{ in } h_a > \text{ and } \frac{\Delta y_b}{2} \text{ in } \frac{\Delta y_a}{2} >; \]

\[ y_c = y_n + \frac{\Delta y_b}{2} \]

\[ \Delta y_b \text{ in } \Delta y_a >; \]

\[ h_b \text{ in } h_a > \]

\[ P \{ |y'_n| \geq |y'_n| \} \]

\[ y'_c = \frac{y_n(y'_n - y'_a) + (y_n + h_a) y'_a}{2y'_n - y'_a}; \]

\[ y_{n+1} = 2y_c - y_n \]

\[ x_{n+1} = x_n + h_a \]

\[ P \{ |x_n - x_{n+1}| \leq a_k \} \]

\[ y_{n+1} \text{ in } y_n > \text{ and } x_{n+1} \text{ in } x_n > \]

\[ x_b = \frac{x_c(y'_a - y'_n) + (x_n + h_a) y'_a}{2y'_a - y'_n}; \]

\[ x_{n+1} = 2x_c - x_n \]

\[ y_{n+1} = y_n + \Delta y_a \]

\[ y_{n+1} = y_n \]

\[ h_1 = x_k - x_n \text{ in } h_1 \leq \frac{h_a}{2} >; \]

\[ y'_{n+1} = f(x_n + \frac{h_a}{2}, y_{n+1}) \]

\[ P \{ y'_n = 0 \} \]

\[ x_n \text{ in } x_{n+1} > \]

\[ \Pi_0 A_1 A_2 A_3 \]

\[ P_1 A_4 A_5 \]

\[ A_6 \]

\[ A_7 \]

\[ P_2 A_8 \]

\[ P_3 A_9 \]

\[ A_{13} \]

\[ A_{14} \]

\[ P_4 A_15 \]

\[ P_5 A_16 \]

\[ A_{17} \]

\[ A_{18} \]

\[ A_{19} \]

\[ A_{20} \]

\[ A_{21} \]

\[ A_{22} \]

\[ P_6 A_{23} \]

\[ P_7 A_{24} \]

\[ y' = f(x, y) \]

Fig. 2 - Numerical method for solving differential equations of the form \( y' = f(x, y) \). Logical diagram of which is shown in the image.

\[ A_{24} \]

\[ P_{24} \]
For the general case, the process of selecting a preliminary integration step under certain possible operating conditions on the stage is indicated in fig. 3 and is carried out in this sequence.

Now, let's dwell on the algorithm for choosing a preliminary integration step when integrating over the independent variable "path".

For the general case, the process of selecting a preliminary integration step under certain possible operating conditions on the stage is indicated in fig. 3 and is carried out in this sequence.
Fig. 3. Illustration of the choice of the preliminary integration step $\delta_1$ taking into account different cases of values $D_{t_1}$:

- $D_{t_1} = a_D$ if $\sum L_i - \sum L_{i-1} \leq a_D$.
- $D_{t_1} = \sum X_i - \sum L_{i-1}$ if $\sum L_i - \sum L_{i-1} \leq a_D$.

1. $P\{\sum L_i \geq |\sum X_i|\}$ if yes, then $\rightarrow 2$ is checked (it is necessary to take into account $\sum X_i$).

2. $P\{\sum L_i \leq 0\}$ if yes, then $\rightarrow 3$ (there will be a stop, which is conventionally reflected by the presence of a minus sign in front of $\sum X_i$); if no, then $\rightarrow 7$ (movement will be without stopping at the current station).

3. $P\{|\sum X_i| - |\sum L_i - 1| \leq a_D\}$ if yes, then $\rightarrow 4$ (it is necessary to determine the section $D_T$ from the difference in the abscissa of stations $\sum X_i$ and the length of the track section with the limiting speed the previous case $\sum L_i - 1$).

4. $D_T = |\sum X_i| - |\sum L_i - 1| \leq a_D$.
5. $D_T = a_D$.

6. $|\sum X_i| - D_T \leq |\sum X_i - D_T|$.

7. $P\{\sum L_i \leq 0\}$ if yes, then $\rightarrow 3$ (there will be a stop, which is conventionally reflected by the presence of a minus sign in front of $\sum X_i$); if no, then $\rightarrow 7$ (movement will be without stopping at the current station).

8. $D_T = 0$ if yes, then $\rightarrow 3$ (there will be a stop, which is conventionally reflected by the presence of a minus sign in front of $\sum X_i$); if no, then $\rightarrow 7$ (movement will be without stopping at the current station).

9. $D_T = a_D$ if yes, then $\rightarrow 3$ (there will be a stop, which is conventionally reflected by the presence of a minus sign in front of $\sum X_i$); if no, then $\rightarrow 7$ (movement will be without stopping at the current station).

10. $D_T = |\sum X_i| - |\sum L_i - 1| \leq a_D$.

11. $D_T = a_D$.

12. $\sum L_i - D_T \leq |\sum L_i - D_T|$. if yes, then $\rightarrow 10$ (the smallest possible value is defined $D_T$); if no, then $\rightarrow 11$ (we accept $D_T = a_D$).

13. $D_T = \sum X_i - \sum L_i - 1$ remember $<D_T> $.


15. $\sum L_i - D_T \leq |\sum L_i - D_T|$ if yes, then $\rightarrow 10$ (the smallest possible value is defined $D_T$); if no, then $\rightarrow 11$ (we accept $D_T = a_D$).

$P\{\sum X_i - \sum L_i - 1 \leq a_D\}$ if yes, then $\rightarrow 12$, (it is necessary to change the sign of the value $D_T$ to the opposite, which allows you to continue braking calculations); if no, then $\rightarrow 15$ (we select a preliminary step for a forward move).
14. $D_t = -D_t \sum L_n, \sum L_i, \sum X_i - D_t$ and $\sum L_i - D_t$ remember $< D_t >$

15. Compare $\sum L_n, \sum L_i, \sum X_i - D_t$ and $|\sum X_i| - D_t$ and take the smallest of these values $\sum \min$.

Here $\sum L_n$ — length of profile elements included in the current calculation.

16. Find preliminary step $h_1 = \sum \min - \sum h_n$ remember $< h_1 >$

Here $\sum h_n$ — total distance traveled (sum of steps taken).

In all cases, when $h_1 = 0$, there will be braking calculations, the $\Pi_t$ braking sign is generated and forward calculations are stopped.

At the distance $D_t$, the corresponding calculations will be made at a fixed integration step and the points for changing the train driving modes will be determined.

4 Conclusion

Based on the conducted research, the following general conclusions can be drawn.

1. Depending on the developing practical conditions of the operational activities of railways, it is recommended to consider the following problems of optimizing the transportation work of locomotives — for an individual trip, for a family of trips of option an work and a locomotive depot, as well as for a regional railway junction and, in general, the entire railway line.

2. A classification of possible varieties of the numerical method for solving differential equations of the form $y' = f(x, y)$ by the chord method and an algorithm for solving them in verbal operator form are proposed, taking into account the implementation of additional graphical constructions in the current integration interval for the average speed of the train.

3. Regardless of all possible cases of changes in traffic conditions associated with a change in the track profile, limiting speeds, station abscissas and others, the differential equation of train motion is solved using the independent variable “path”.

4. As a result of justifying the choice of a preliminary integration step along one of the independent variables, the thus found value of the preliminary integration step along the path $h_1$ is then used in subsequent calculations. Since the value of the mentioned step $h_1$ is variable, the integration method chosen to solve the differential equation of the form $y' = f(x, y)$ allows the solution to be carried out at a variable integration step.

5. It is recommended to continue these studies for locomotives of electric tractions and high-speed passenger trains and, based on the algorithms proposed by the author, to develop programs for traction and energy (economic) calculations for sections of Uzbek railways of varying complexity.

References


15. V. R. Vedruchenko, V. V. Krainov, E. S. Lazarev, Izvestia Transsib. 4, 18–28 (2014)


17. D. V. Balagin, Izvestia Transsib. 3(11), 12–19 (2012)


23. O. S. Ablyalimov, Ways to improve the method of rationing the consumption of fuel and energy resources for train traction and the choice of optimal control of train movement in real operating conditions. Text: direct // Monograph. – M.: NIC MISS, 2020