

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

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RESEARCH ON EFFICIENCY OF
LOCOMOTIVE OPERATION TAKING
INTO ACCOUNT THE DYNAMICS OF
TRAFFIC VOLUMES

SUMMARY OF DOCTORAL DISSERTATION

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Introduction

The main target of Lithuania as of the other developing countries is the rapid growth of national economy and increase in competitive ability. Implementing this target in the national economy development policy, the greatest growth of economy in the nearest future is sought by distribution of public investments. One of the most important priorities of those investments is the transport improvement. In terms of development of the single market in Europe, the economic relations between member-states have intensified, number of states has increased, territory has extended, specialization of labour has grown up, and trade barriers have lessened. All these factors have promoted a rapid growth of flows of all kinds of transport. Continually increasing share of such growth falls on railway transport, since modern economy requires extreme flexibility and interactivity. Therefore, the role of railway transport will not decline in future notwithstanding new communication technologies and traditionally formed flows of water and land transport. Fluent and efficient transport is not only a kind of service that creates the large added value, but also an essential assumption for successful development of other economic branches and assurance of the high life quality of population. Railway transport is one of essential factors determining efficiency of operations of the national transport system and being of the vital importance for economic and social development of the country. It should be noted that in Lithuania more than 45 per cent of freight traffic fall on the railway transport.

This thesis presents investigation of one of the most effective ways of fuel saving by the railway track rolling stock – implementation of optimal times of movement at railway lines for suburban, passenger and freight trains and rational modes of truck control for rolling stock in main routes of Lithuanian railways.

Topicality of the problem

Globalization of the world economy, continual growth of economy in all Lithuanian sectors, and development of new economical regions increase volumes of freight traffic and the role of the transport, especially the railway transport, which is the most important in bulk freight traffic.

In the Guidelines for the Economic and Social Development of Lithuania for 2005–2011 and for the Period until 2015, it is emphasised that the increasing of the carrying capacity and throughput capacity of railways should be regarded as a main direction in the development of the national railway transport. Therefore, increase in the weight and length of freight trains is an important and effective direction of the technical transport policy.

A growth in the carrying capacity of railways can be achieved by organising regular traffic of long trains. When such trains move by track longitudinal profile grades, longitudinal dynamic forces may reach dangerous values. The inadequate stiffness of the rail vehicle bogie suspension and gauge drives or unstable moving traffic of the rolling stock can cause a traffic accident. Therefore, the movement control mode for the long train should be chosen taking into account the dynamic load of the rolling stock at each specific track section.

The task of saving of energy resources has been established alongside with the increase in carrying capacity and throughput capacity of railways. For railway traction and operational needs alone, AB “Lietuvos geležinkeliai” (State Company “Lithuanian Railways”) consume more than 72 MWh of electric power and more than 60 thousand tons of diesel fuel.

The thesis involves the performance of theoretical and experimental research of the mode of movement control of long trains seeking to minimize the time of movement at railway lines and traction fuel consumption. When considering these two criteria, the increase in longitudinal dynamic forces due to increase in weight of the train, as well as increased number of wagons and automatic clutches were taken into account.

The task that was established has been resolved through mathematical simulation and optimisation methods. The task solution involved the use of R. Bellman discrete dynamic programming method with regard to the corresponding changes included in the specifics of the task under consideration. The research performed has proposed a methodology for the optimisation of the times of movement at railway lines in the traffic schedule. This methodology evaluates the traction fuel consumption minimum criteria, taking into account the dynamic train load. An algorithm, which allows obtaining the optimal distribution of the times of movement at railway lines in a more effective manner, has been proposed for the optimisation of times of movement at railway lines of suburban diesel multi-units in accordance with the energy traction consumption criteria.

Research object

The train movement control and traffic scheduling.

Aim and tasks of the thesis

To perform the theoretical and experimental research of the rational modes of movement control of passenger, freight and suburban trains seeking to minimize the time of movement and traction fuel consumption, taking into account restrictions of longitudinal dynamic forces. Tasks of the thesis are as follows:

1. Analysis of methods for optimization of models of the rolling stock traction calculation and rational modes of the train movement control.

2. Development of an algorithm for selection of the long train control method using the principle of R. Bellman.

3. Development of software for calculations of the train traction to determine the minimum movement time and minimal fuel consumption, using C++ software package.

Definition and realization of the task for optimization of times of movement of suburban diesel multi-units at railway lines and fuel consumption optimization.

Comparison of the results of theoretical train traction and experimental movements of the rolling stock.

Methodology of research

Analysis of the literature and empirical research on the rolling stock traction performed by other scientists was applied for investigation of the scientific problem and setting of the research structure. The method of mathematical simulation was used for solution of formulated tasks and optimization of the certain technological parameters was performed. Service testing of the rolling stock was performed with measurements of times for movement at railway lines and fuel consumption by diesel-electric trains. During experimental movements the wagon-laboratory equipped with tensometric equipment sensors in the selected positions of the train. The results of the theoretical research were compared with the results of experimental movement, and adequacy thereof was determined.

Scientific novelty

The task of optimization was defined and solved allowing determining parameters of the rational train control mode using the dynamic programming method. In order to obtain mentioned parameters, two train mathematic models were used: a flexible inextensible thread and a system of masses which were connected by non-linear deformable elements.

Software was developed which implemented the methodology for the selection of the optimal train movement control mode with regard to changes in the train longitudinal dynamic forces. An algorithm was proposed for calculation of the train movement control modes applicable to work up the traffic schedules for long freight trains and suburban diesel multi-units. Using the dynamic programming method, the train movement control was optimized in accordance with the traction fuel consumption minimum criteria.

Practical value

The developed methodology for the selection of the long train movement control mode with regard to the longitudinal dynamic forces allows establishing the optimal traffic times at railway lines. The use of the optimal control modes

ensures the saving of fuel for traction by up to 5–8 % depending on the track profile. In the case of suburban traffic, the recording of the times of traffic allows saving up to 4 % of diesel fuel for traction. Developed software implements the methodology for the selection of the optimal train movement control mode with regard to the train longitudinal dynamic load.

Statements presented to defence

1. Development of methodology and algorithm for optimization of times of movement at railway lines for freight, passenger and suburban diesel multi-units that allows to assess the fuel consumption minimum criteria. These methodology and algorithm are used to work out the train traffic schedules.

2. Development of software for calculation of the optimal times of movement at railway lines and train movement control modes for freight, passenger trains and suburban diesel multi-units according to the fuel consumption minimum criteria.

3. Application of methodology proposed by the author allows to decrease by 1.5–2 times the train longitudinal dynamic forces and approx. 5–8 % – fuel consumption for movement of trains at railway lines with steep gradient inclines.

The practical approval of obtained results

The main results of the research have been used for decrease in times of movement at railway lines of AB “Lietuvos geležinkeliai” trains and optimisation of the long train control mode at those railway lines at the main transport corridors IXB (Kena–Vilnius–Kaišiadorys–Radviliškis–Šiauliai–Klaipėda) and IXD (Kaišiadorys–Kybartai) of AB “Lietuvos geležinkeliai” (State Company “Lithuanian Railways”).

Thesis structure

The thesis contains introduction, six chapters, conclusions, reference list, and list of the author publications. The scope of the thesis is 88 pages, 36 figures, 13 tables, and 1 annex. Reference list includes 103 bibliographic sources.

1. Evolution of studies on locomotive rational control and efficient scheduling

First chapter includes analysis of works under investigation created by the world and Lithuanian scientists, where parameters of movement and control of long trains are analyzed, and tasks of stimulation of the train movement and working out the traffic schedules are investigated. Famous the modern mathematical tools, methods of dynamic programming and problems of selection of the train optional control are widely investigated by famous Russian and Ukrainian scientists.

The traction calculation models currently used do not take into account the longitudinal dynamic forces of coupling devices. Such a model could be applied when the longitudinal forces are not high. Longitudinal dynamic forces of long (heavy) trains, in particular, which have achieved the critical values, are dangerous for wagons during the transitional mode of the train traffic. With the train length and weight growing, longitudinal forces increase and can reach dangerous values (in respect of vehicle stability and stable running on the gauge), which causes the necessity of their evaluation in tasks for the selection of long train control. Therefore, the task of development of such a model for the calculation (summarised traction calculation) of traction, which would allow considering from equivalent aspects the issues of fuel and energy consumption for train movement, longitudinal dynamics, and vehicle stability on the gauge, is an issue of immediate importance.

Having investigated the current situation, the target and tasks of research were defined and methodology of research was selected.

2. Mathematical model of train longitudinal dynamics

Second chapter presents the mathematical model of the train longitudinal dynamics.

The train movement is described by means of a system of differential equations:

$$\left\{ \begin{array}{l} \dot{v}_j(t) = (S_j(t) - S_{j-1}(t) + F_j(t, v_j, x, u(x), U_c)) / m_j; \quad (j=1 \div n, S_1 = S_{n+1} = 0); \\ \dot{q}_1(t) = \dot{x}_1(t) = v_1(t); \\ \dot{q}_j(t) = v_{j-1}(t) - v_j(t); \quad (j=2 \div n); \\ v_j(0) = v_{j0}; \quad q_j(0) = q_{j0}; \quad S_j(0) = S_{j0}. \end{array} \right\} \quad (1)$$

$$\left\{ \begin{array}{l} \frac{d(v^2)}{dx} = \frac{2 \cdot \xi}{P + Q} (F_r(v, u(x), U_c) - W(x, v, u(x)) - B_{st}(v, K(t), u(x), U_c)); \\ \frac{dT}{dx} = \frac{T_\infty (I_{TEV}(v, u(x), U_c)) - T(x)}{v(x) \cdot T(I_{TEV}(v, u(x), U_c))}. \end{array} \right\} \quad (2)$$

The main initial conditions:

$$x(0) = x_p, \quad v(0) = v_0, \quad T(0) = T$$

where v_j – the speed of the j -th carriage; $S_j S_{j+1}$ – forces in its couplings; $q_j = x_{j-1} - x_j$ – the absolute deformation of the j -th connection; q_j – speed of this deformation; m_j – the weight of the j -th carriage; n – the number of carriages; x_j – the absolute displacement of the centre of masses of the j -th carriage; F_j – the sum of the projections of external forces impacting the trajectory tangent; v – the speed of the centre of masses of the train; x – the absolute displacement of the centre of masses of the train; P, Q – the weight of the locomotive and wagons; F_{tr} – locomotive traction force; $W = W'_0(v, u(x)) + W''_0(v) + W_i(x) + W_R(x)$ – natural resistance of the train to slid movement; B_{st} – the braking force impacting the train (electrical braking and air braking); K_Σ – the total pressing effort of the brake-blocks of the train; T – the temperature of overheating of traction engines; T_∞ – the thermal characteristics of the electrical engine; I_{TEV} – traction engine flow (TEV); U_c – the voltage of electrically driven rolling stock at the pantograph $U_c = U_c(x)$; $u(x)$ – control (controller position number).

Model (1) describes the train movement as non-linear deformable elements, which takes into account spaces in clutches, running of a system of connected discrete masses. Model (2) describes the train running as that with the length L_{tr} flexible inextensible thread.

Therefore, each condition of a train during its movement will be matched by the point illustrating it in the phase space $(x, v, T, U_c, \{S\})$, where $\{S\}$ is derived as follows: $\{S\}(t) = \max_j S_j(t)$ and determined from the solution of the

system of equations (1).

The area of permissible phase trajectories is determined by the following limitations:

$$\{G\}(x, v, T, \{S\}): \begin{cases} x_p \leq x \leq x_g; \\ 0 \leq T \leq T_{permis}; \\ 0 \leq v \leq v^{\max}(x). \end{cases} \quad (3)$$

$$S^{-\max}(v) \leq \{S\} \leq S^{+\max}(v) \quad (4)$$

where x_p, x_g – the coordinates of the initial and final points of the track; T_{permis} – maximum permissible overheating temperature of the electric engine; $v^{\max}(x)$ – maximum permissible train speed; $(S^{-\max}(v)), (S^{+\max}(v))$ – maximum permissible clenching and stretch forces of the coupling devices.

That is related to the control vector $u(x) = \{u_1, u_2, \dots, u_m\}$, therefore, in accordance with the technical operation rules, all its possible values are subject to limitations, which may be indicated as follows:

$$\{U\}: \left\{ \begin{array}{l} I_{TEV}(v, U_c, u(x)) \leq I_{TEV}^{\max}; \\ F_{tr}(v, u(x), U_c) \leq \psi_{tr}(v) \cdot P; \\ K_{\Sigma}(t, u(x)) \cdot \phi_{tr}(v) \leq \psi_{tr}(v) \cdot q_0; \\ B_{ed}(v, u_j(x)) \leq B_{ed}^{\max}(v). \end{array} \right\} \quad (5)$$

where I_{TEV} – maximum permissible engine current; q_0 – carriage axle load; ψ_{tr} – wheel and rail coupling factor; K_{Σ} – wheelset brake-block pressing effort; ϕ_{tr} – brake-block and wheel friction factor.

The train optimal control law $u(x)$ should comply with the isoperimetric limitation (the train control laws can be compared only when the train traffic time is the same).

$$t_x(u) = \int_{x_p}^{x_g} \frac{dx}{v(x, u)} \equiv t_d \quad (6)$$

where t_x – traffic time at the railway line corresponding to the control $u(x)$; t_d – the prescribed traffic time at the section between stops of the train.

We will assume the functional, which illustrates the train traction fuel consumption at the section between stops of the train as the evaluation criterion for the control law $u(x)$.

$$A(u) = \int_{x_p}^{x_g} \frac{G(v, u) \cdot \eta_{ef}(v, u) dx}{v(x, u)} \quad (7)$$

where $G(v, u)$ – fuel consumption during a time unit; $\eta_{ef}(v, u)$ – locomotive efficiency factor.

Therefore, the task for the selection of the rational mode of long train movement control can be formulated as follows: to find such a control law $u(x) \in \{U\}$, so that the solution of the system of equations (1–2) corresponding to it would belong to the area $\tilde{G}$, the limitation (6) would be fulfilled, the optimality criterion (7) would have the minimum value, and the initial and final points of the trajectory would belong to certain sets Ω_0 and Ω_1 , where Ω_0 – is the set of initial values $(x_0, v_0, T_0, \{S_0\})$; Ω_1 – the set of final values $(x_g, v_g, T_g, \{S_g\})$.

The results of the solution of optimisation tasks for real track sections and their further check during trial running demonstrated that there is a possibility to reduce the level of longitudinal dynamic forces by 1.5–2 times and to save 5–8 % of fuel for traction.

4. Long train control rational mode selection program

Forth chapter presents a description of the programme for the selection of optimal control modes for long trains. Description is divided into structural schemes with explanations of purpose of functions and components of those schemes provided alongside. Seeking to simplify understanding of the programme operation for users, description of programme functions and functional components is presented “from the general to the specific”, i.e. transferring from description of the programme general structure to the separate functional components of the programme.

The track longitudinal profile of all traffic sections used for traffic of passenger and freight trains. User may not change data in the information base of the programme.

Information base of the train traffic sections includes data as follows:

1. Track longitudinal profile of all traffic sections used for traffic of passenger and freight trains (user may not change information);
2. Track layout of all traffic sections used for traffic of passenger and freight trains (user may not change information);
3. Arrangement of separate centres on all traffic sections used for traffic of trains (user may not change information);
4. Determination of the speed of traffic of passenger and freight trains on all traffic sections at railway lines and separate points (user may review and amend information);
5. Limitations for the speed of traffic of passenger and freight trains on all traffic sections at railway lines and separate points (user may review and amend information);
6. Points for check of efficiency of the train brakes in the course of traffic with indication of coordinates, initial and final speed values as well as length of braking (user may review and amend information).

A user is enabled to manage the database in full. In this base data on the certain number of trains is accumulated and stored. Later information on trains presented in the database is used for calculation of the train control modes and times of movement thereof at railway lines on all current train traffic sections. Train database includes 2 parts: freight trains and passenger trains.

Another important part of the programme presents a module for calculation of the control modes for freight and passenger trains and times of move-

ment thereof at railway sections on specific sections. The aim of calculation is to determine the train specific control modes on the specific sections according to the specific train traffic schedule seeking to minimize the fuel consumption. In this case the following limitations are applied:

1. Speed of the train may not exceed permissible limits on the entire running section;
2. Train should be driven not extending parameters of the locomotive traction and train braking;
3. Temperature of the generator and traction engines may not exceed permissible limits;
4. All requirements to efficiency of the train brakes checked during the running, should be executed in full;
5. Discrepancy of times of the train running at railway lines calculated on the specific running section from the one preliminary set up in the traffic schedules may not exceed permissible errors;
6. Train control may not cause dangerous longitudinal dynamic forces of the train stretch and compression.

Based on the results of calculations, two train documents shall be issued. The first document presents modes of the specific train for traffic on the specific section under the specific traffic schedule. The second document is the journal of the specific train on times of its movement at railway lines on the specific traffic section taking into account the whole time of the train movement from the departure station to the arrival station. The second calculation result form is useful for analysis of potential of saving of extra fuel used for the train traction. Saving is possible by redistribution of times of train movement at railway stations on the specific section. In this case, the schedule should only include indication of times of departure and arrival for those stations where train stops are planned under the schedule. In the course of calculations the most optimal (in terms of fuel saving) times of the train movement at railway lines taking into account the whole time of the train route.

5. Optimization of commuter diesel multiple units running station-to-station duration

Fifth part is dedicated to the optimisation of times of movement at railway lines for suburban diesel multi-units. The prescribed time of movement at the section can be broken down by times of movement at railway lines in different options. There appears the task to establish such distribution of times of movement at railway lines, under which fuel consumption for traction are minimal:

$$\min L(t_1, t_2, \dots, t_N) = \sum_{i=1}^N G_i(t_i) \quad (9)$$

$$\sum_{i=1}^N t_i = t_d, \quad t_{\min i} \leq t_i \leq t_{\max i}, \quad i = \overline{1, N} \quad (10)$$

where t_d – prescribed section movement time; t_i – movement time at the i -th railway line; N – the number of railway line; $G_i(t_i)$ – dependence of traffic movement fuel consumption on the movement time at the i -th railway line.

Under such assumptions, the following optimal trajectory equation in the differential form has been obtained for this task:

$$\frac{dt_i^*}{dt} = \left\{ \begin{array}{l} \text{const, if } t_i^* \in \text{field limit } \Omega; \\ \frac{f_{i-1}''(t - t_i^*)}{f_{i-1}''(t - t_i^*) + g_i''(t_i^*)}, \text{ if } t_i^* \in \text{int } \Omega \end{array} \right\} \quad (11)$$

with the limiting condition

$$t_i^*(t_i) = t_i \quad (12)$$

Ω – the area where a solution is being sought. When resolving the equations (11)–(12), it became possible to obtain the optimal trajectory condition of the task (9)–(10). The trajectories of the concave efficiency functions and of those efficiency functions which have bending points.

Since it is not always possible to resolve the equation (11) analytically, we proceed to the final, differential form with the use of a certain differential scheme:

$$t_i^*(t + \Delta) = \frac{v(t, t_i^*, \Delta)}{v(t, t_i^*, \Delta) + U(t_i^*, \Delta)} \cdot \Delta + H \quad (13)$$

where H – the constant, which is determined from (12).

The essence of the proposed method is that we obtain a solution by the method of functional equations, but when creating Bellman function with the use of equation (13), we improve the search method which is included in the method of functional equation, i.e. actually, we extract a secondary Ω' area from Ω area and look for a solution in the secondary area in accordance with the method of functional equations.

The thesis provides a comparison of the gross method, dynamic programming method, and proposed method by the number of the checked points. The proposed algorithm is illustrated by the task of the distribution of movement times of the diesel multi-unit A–B section railway line in accordance with the traction fuel consumption minimum criterion ($\Delta = 0.25$ min., $N = 29$). The solution of the task proposes a diesel multi-unit traffic schedule for the railway lines, which is more efficient (in terms of fuel consumption) by 4 % compared to the existing actual schedule.

Software drawn up in the algorithm language C++ Builder for *Windows XP/2000/Vista/7* environment and an instruction for the preparation of initial information are provided.

6. Long train performance tests

Sixth part is dedicated to description of service testing at the transport main corridors of the Lithuanian Railways and comparison of results of theoretical and experimental research. The objective of the real running of the rolling stock is to study longitudinal dynamic forces in long trains when running on long-distance sections with complicated track profile. The running of the lead locomotive and auxiliary locomotive was controlled in accordance with the calculated mode cards obtained in accordance with the developed methodology for the calculation of summarised traction.

The experimental research allowed performing the final adjustment of the calculated mode cards and providing recommendations on rational and safe methods of control of locomotive traction and brake devices. The impact of incompatible actions of the engine drivers of the lead locomotive and auxiliary locomotive on the level of longitudinal dynamic forces in various train running modes was studied in real conditions.

The analysis of change in the control modes demonstrates that failure to observe by engine drivers the recommendations on rational and safe methods of control of locomotive traction and brake devices could have an impact on the occurrence of significant longitudinal forces and even the traffic accidents.

Mode cards for the control of long train movement at the transport main corridors of the Lithuanian Railways have been provided. The trial running of the rolling stock confirmed decrease in the longitudinal dynamic forces by 1.5–2 times and reduction of fuel consumption by up to 5–8 %.

General conclusions

1. The methodology for optimization of times of train movement at railway lines and algorithm for selection of the long train control method, taking

into account the minimum criteria of fuel consumption have been developed. These methodology and algorithm are recommended for application in working out traffic schedules.

2. The method of dynamic programming in the discrete form serves as the basis for the algorithm of calculation of the train control modes.

3. The hybrid mathematical model for the long train movement control – flexible inextensible thread as the system of discrete masses, which are connected by non-linear deformable elements, including spaces in clutches) has been developed. Such model allows increasing the speed of the task solution by times.

4. Trial operational movements confirmed the correctness of the theoretical assumption and methodology for the selection of long train movement control modes which allows, if applied, to decrease the longitudinal dynamic forces by 1.5–2 times and to save 5–8 % of fuel for traction when long freight trains run at the track profile with the steep slopes (grades).

5. Software for optimization of times of movement at railway lines for diesel multi-units according to the fuel consumption minimum criteria has been developed.

6. The modes of control of movement long trains with the double header diesel-electric locomotives at the main Lithuanian railway corridors IXB (Kena–Vilnius–Kaišiadorys–Radviliškis–Šiauliai–Klaipėda) and IXD (Kaišiadorys–Kybartai) have been tested and corrected in the course of trial movements.

7. The programme for selection of optimal control modes and simulation of the train traffic at the selected Lithuanian railway lines has been developed.

8. The annual economic benefit of AB “Lietuvos geležinkeliai” due to adaptation of traffic schedules to optional times of movement at railway lines and implementation of corresponding modes of the long freight train movement would make up approx. 2.0 million Lithuanian Litas.

List of published works on the topic of the dissertation In the reviewed scientific periodical publications

Liudvinavičius, L.; Lingaitis, L. P.; Dailydka, S.; Jastremskas, V. 2009. The aspect of vector control using the asynchronous traction motor in locomotives, *Transport* 24(4): 318–324. Vilnius: Technika. ISSN 1648-4142. (Thomson Reuters Web of knowledge); [Citav. rod.: 2,552(F) (2009)].

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LOKOMOTYVŲ EFEKTYVAUS NAUDOJIMO TYRIMAS VERTINANT VĖŽIMŲ APIMČIŲ DINAMIKĄ

Geležinkelių transportas yra vienas iš esminių veiksnių, nulemiančių šalies transporto sistemos veiklos efektyvumą bei turinčių gyvybinę reikšmę šalies ekonomikos ir socialinei raidai. Pažymėtina, kad mūsų šalyje geležinkeliais vežama daugiau kaip 45 procentai visų krovinių.

Šiame darbe išnagrinėtas vienas iš veiksmingiausių geležinkelio traukos riedmenų degalų ekonomijos būdų – priemiestinių, keleivinių ir prekių traukinių optimalių važiavimo tarpstočiais traukinių ir riedmenų racionalių traukos valdymo režimų, pagrindiniuose Lietuvos geležinkelių maršrutuose, diegimas.

Mokslo problemos aktualumas

Šalies geležinkelių pajėgumo padidinimas gali būti pasiektas suorganizu-
vus reguliarių ilgųjų traukinių eismą. Važiuojant tokiems traukiniams kelio išil-
ginio profilio nuolydžiais, sąstato išilginės dinaminės jėgos gali pasiekti pavo-
jingas reikšmes. Dėl važiuoklių bei pakabų nepakankamo stiprumo arba dėl
nestabilaus riedmenų važiavimo bėgiais gali kilti eismo įvykis. Taigi, ilgojo
traukinio valdymo režimą būtina parinkti pagal riedmenų dinamines apkrovas
važiuojant kiekvienu konkrečiu kelio ruožu.

Kartu su geležinkelių pajėgumo ir pralaidumo didinimu aktualus ir energie-
tinių resursų taupymas eksploatuojant riedmenis. AB „Lietuvos geležinkeliai“
vien tik traukinių traukai ir eksploatacinėms reikmėms per metus sunaudoja
daugiau kaip 72 MWh elektros energijos ir daugiau kaip 60 tūkstančių tonų
dyzelino.

Darbe atlikti teoriniai ir eksperimentiniai ilgųjų traukinių valdymo režimų
tyrimai, siekiant minimizuoti traukinių važiavimo tarpstočiais trukmę ir degalų
traukai sąnaudas. Įvertinant šiuos du kriterijus, buvo atsižvelgiama į išilginių
dinaminių jėgų padidėjimą dėl išaugusios traukinio masės ir didesnio vagonų
bei automatinių sankabų skaičiaus.

Atliktuose tyrimuose pasiūlyta važiavimo tarpstočiais trukmės optimiza-
vimo, sudarant traukinių eismo grafikus, metodika. Ši metodika vertina degalų
traukai sąnaudų minimumo kriterijų, atsižvelgiant į dinaminę traukinio apkro-
vą. Priemiestinių dyzelinių traukinių tarpstočių važiavimo trukmės optimizavi-
mui pagal degalų traukos sąnaudų kriterijų pasiūlytas algoritmas, kuris leidžia
optimalia paskirstyti dyzelinių traukinių važiavimo tarpstočiais trukmę.

Mokslinių tyrimų objektas

Traukinių važiavimo valdymas ir eismo grafikų sudarymas.

Darbo tikslas

Atlikti teorinius ir eksperimentinius keleivinių, prekių bei priemiestinių
traukinių valdymo racionalių režimų tyrimus, siekiant minimizuoti važiavimo
trukmę bei degalų sąnaudas traukai įvertinant sąstato išilginių dinaminių jėgų
apribojimus.

Darbo uždaviniai

1. Riedmenų traukos skaičiavimo modelių bei traukinių racionalaus valdymo režimų optimizavimo metodų analizė.
2. Ilgojo traukinio valdymo režimų parinkimo algoritmo sudarymas, naudojant R. Bellmano principą.
3. Traukinio traukos skaičiavimų, nustatant minimalią važiavimo trukmę bei minimalų degalų sunaudojimą, programos sudarymas naudojant C++ programinę paketą.
4. Priemiestinių dyzelinių traukinių važiavimo tarpstočiais trukmės bei degalų sąnaudų optimizavimo uždavinio sudarymas ir realizavimas.
5. Traukinio traukos teorinių ir riedmenų eksperimentinių važiavimų rezultatų palyginimas.

Tyrimo metodika

Literatūros bei kitų mokslininkų atliktų empirinių riedmenų traukos tyrimų analizė buvo taikyta mokslinei problemai ištirti ir tyrimų struktūrai nustatyti. Suformuluotų uždavinių sprendimui panaudotas matematinis modeliavimas ir atliktas tam tikrų technologinių parametų optimizavimas. Atlikti riedmenų eksploataciniai bandymai, matuojant važiavimo tarpstočiais trukmes ir šilumvežių degalų sąnaudas. Eksperimentinių važiavimų metu buvo naudojamas vagonas laboratorija su tenzometrinės aparatūros jutikliais pasirinktuose traukinio taškuose. Teorinių tyrimų rezultatai palyginti su traukinių eksploatacinių bandymų rezultatais ir nustatytas jų adekvatumas.

Mokslinis naujumas

Suformuluotas ir išspręstas optimizavimo uždavinys traukinio racionalaus valdymo parametrams nustatyti panaudojant dinaminio programavimo metodą. Minėtiems parametrams gauti panaudoti du traukinio matematiniai modeliai: lankstusis neišsitempiantis siūlas ir diskretinių masių sistema sujungta netiesiniais deformuojamaisiais elementais.

Nustatytas traukinių valdymo režimų skaičiavimo algoritmas, taikytinas ilgųjų prekinųjų traukinių ir priemiestinių dyzelinių traukinių eismo grafikams sudaryti. Nustatyta priemiestinių traukinių optimali važiavimo tarpstočiais trukmė.

Darbo rezultatų praktinė reikšmė

Sudaryta ilgųjų traukinių valdymo režimų parinkimo, atsižvelgiant į išilgines dinamines jėgas, metodika, pagal kurią galima nustatyti eismo grafiko važiavimo tarpstočiais racionalias trukmes. Racionalių valdymo režimų naudojimas užtikrina degalų traukai ekonomiją iki 5–8 %, priklausomai nuo kelio profilio ir vagonų

skaičiaus. Sudaryta kompiuterinė programa, realizuojanti traukinio racionalaus valdymo režimo parinkimą pagal sąstato išilginę, kintančią kiekvienoje autosankaboje, dinaminę apkrovą bei įvertinanti konkretų kelio profilį. Visi programos moduliai parašyti C++ programavimo kalba, taikomųjų programų C++ *Builder XE2* plėtojimo aplinkoje. Programos pagrindą sudaro jos duomenų bazė bei traukinių valdymo režimų ir jų važiavimo tarpstočiais atskiruose traukinių judėjimo ruožuose skaičiavimo modulis. Programos duomenų bazę sudaro 3 dalys: traukinių judėjimo ruožų duomenų bazė; traukinių duomenų bazės ir traukinių eismo tvarkaraščių duomenų bazės.

Taikant šią metodiką 1,5–2 kartus sumažintos sąstato išilginės dinaminės jėgos, o degalų sąnaudos – apie 5–8 %, traukiniams važiuojant kelio ruožais su stačiais nuolydžiais.

Ginamieji teiginiai

1. Sudaryta prekinųjų, keleivinių bei priemiestinių dyzelinių traukinių važiavimo tarpstočiais laiko optimizacijos metodika ir algoritmas, įvertinantis degalų sąnaudų minimumo kriterijų. Ši metodika ir algoritmas naudojami sudarant traukinių eismo grafiką.

2. Sukurta prekinųjų, keleivinių bei priemiestinių dyzelinių traukinių važiavimo tarpstočiais racionalių trukmių ir traukinio valdymo režimų skaičiavimo pagal degalų sąnaudų minimumo kriterijų programa.

3. Taikant autoriaus siūlomą metodiką 1,5–2 kartus sumažintos sąstato išilginės dinaminės jėgos, o degalų sąnaudos – apie 5–8 %, traukiniams važiuojant kelio ruožais su stačiais nuolydžiais.

Gautų rezultatų apibavimas

Pagrindiniai tyrimų rezultatai panaudoti AB „Lietuvos geležinkeliai“ traukinių važiavimo tarpstočiais trukmės mažinimui ir šių tarpstočių ilgujų traukinių valdymo pagrindiniuose transporto koridoriuose – IXB (Kena–Vilnius–Kaišiadorys–Radviliškis–Šiauliai–Klaipėda) ir IXD (Kaišiadorys–Kybartai) – traukinių valdymo režimams optimizuoti.

Disertacijos struktūra

Disertaciją sudaro įvadas, šeši skyriai, išvados, literatūros sąrašas ir autoriaus publikacijų sąrašas. Darbo apimtis 88 puslapiai, 36 paveikslai, 13 lentelių ir 1 priedas. Literatūros sąrašė yra pateiktas 103 literatūros šaltinis.

Pirmame skyriuje išanalizuoti pasaulio ir Lietuvos mokslininkų tiriamieji darbai, analizuojantys ilgujų traukinių važiavimo bei valdymo parametrus, nag-

rinėjantys traukinių važiavimo modeliavimo ir eismo grafikų sudarymo uždavinius.

Antrame skyriuje pateiktas traukinio išilginės dinamikos matematinis modelis.

Trečiasis skyrius skirtas uždavinio algoritmo suformavimui, kuris remiasi R. Bellmano funkcinių lygčių metodu.

Parodytas dinaminio programavimo metodo taikymo tikslingumas uždavinio sprendimui. Pateiktas įvairių traukinio modelių (materialusis taškas, lankstus neišsitempiantis siūlas, masių sistema) palyginimas, esant nustatytajam valdymo dėsniui.

Ketvirtame skyriuje aprašoma sukurtos programos struktūra, jos funkciniai moduliai ir jų atliekamos funkcijos.

Penktas skyrius skirtas priemiestinių dyzelinių traukinių tarpstočių važiavimo trukmės optimizuoti.

Pateikta programa, surašyta algoritmine kalba C++ Builder, Windows XP/2000/Vista/7 aplinkai. Pateiktas pradinės informacijos paruošimo aprašas.

Šeštasis skyrius skirtas ilgujų traukinių eksploataciniams bandymams pagrindiniais Lietuvos geležinkelių koridoriais aprašymui ir teorinių bei eksperimentinių rezultatų palyginimui

Riedmenų bandomieji važiavimai patvirtino išilginių dinaminį jėgų sumažinimą (1,5–2) kartus ir degalų sąnaudų sumažėjimą iki 5–8 %.

Bendrosios išvados

AB „Lietuvos geležinkeliai“ viena iš svarbiausių sąnaudų dalių yra degalų sąnaudos. Kasmet, priklausomai nuo pervežimų apimčių, sunaudojama nuo 45 000 t iki 60 000 t degalų. Traukos riemenų eksploataavimo metu degalų sąnaudos sudaro apie 80% tiesioginių sąnaudų. Taigi degalų taupymas viena iš svarbiausių užduočių bendrovėje siekiant išlikti konkurencingiems bei patraukliems klientų atžvilgiu. Šis darbas tai dar vienas žingsnis mažesnių degalų sąnaudų link naudojant dinaminio programavimo ir matematinio modeliavimo metodus.

1. Sukurta traukinių važiavimo tarpstočiais trukmių optimizavimo metodika ir traukinių valdymo režimų nustatymo algoritmas, įvertinantis minimalias degalų sąnaudas. Ši metodika ir algoritmas rekomenduojami naudoti sudarant traukinių eismo grafikus. Sudarytas mišrus ilgojo traukinio valdymo matematinis modelis – lankstusis neišsitempiantis siūlas, kaip diskrečiųjų masių sistema, sudaryta iš netiesinių deformuojamųjų elementų su tarpais sujungimuose. Toks modelis leidžia padidinti uždavinio sprendimo spartą. Panaudojant Belmano metodą

- buvo išspręstas optimizavimo uždavinys, kuriame nustatyti optimalūs traukinių valdymo režimai.
2. Panaudojant Belmano metodą buvo išspręstas priemestinių traukinių važiavimo tarpstočiais optimizavimo uždavinys, kuriame nustatytos optimalios važiavimo tarpstočiais trukmės bei minimizuotos degalų sąnaudos.
 3. Sukurta traukinių valdymo režimų, pasirinktais tarpstočiais, programa. Pasinaudojant programa galima nustatyti racionalius valdymo režimus bet kokiame ruože, įvairaus tipo ir svorio riedmenims.
 4. Vadovaujantis racionaliais valdymo režimais atlikti bandomieji eksploataciniai važiavimai patvirtino teorinių prielaidų ir ilgųjų traukinių racionalių valdymo režimų pasirinkimo metodikos validumą. Rezultate (1,5–2) kartus sumažintas sąstato išilginių dinaminių jėgų dydis ir sutaupyta iki (5–8) % degalų sąnaudų.
 5. Priemestinių traukinių važiavimo tarpstočiais racionalių trukmių pritaikymo eismo grafikuose ir ilgųjų prekinų traukinių valdymo režimų įdiegimo LG metinis ekonominis efektas sudarytų apie 2,0 mln. Lt.

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RESEARCH ON EFFICIENCY OF LOCOMOTIVE OPERATION TAKING INTO
ACCOUNT THE DYNAMICS OF TRAFFIC VOLUMES

Summary of Doctoral Dissertation

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Virgilijus JASTREMSKAS

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