COMPUTATIONAL PROBLEMS OF ELECTRICAL ENGINEERING
Vol. 4, No. 1, 2014

THE FEATURES OF THE PROBLEM OF THE CONTROL BY THE TRACTION TRANSMISSION ROLLING ELECTRICAL COMPLEX IN CASE OF DEVIATION FROM SCHEDULE

Dmitro Kulagin, Petro Andrienko
Zaporizhzhya National Technical University, Ukraine
kulagindo@gmail.com

Abstract: The aim of work is the mathematical description of the problem traction control power to overcome movable electrotechnical complex deviation from the schedule. The mathematical description of the algorithm solves this problem traction control power.
Description problematic issue is based on unit variations. The object of analysis supports the specified performance criterion studied system, considered as a function of the significant parameters of the system and the environment. The aim optimization is to obtain the minimum work that it performs a moving unit complex electrical of points for given values trajectory. Resource optimization is the value of control variables traction motor and the control parameter pulling force complex parameters control the force component of inhibition.

Key words: schedule; control; movable electrotechnical complex; traction transmission; optimization; functionality; variation; deviation from schedule.

1. Introduction

Category movable electrical systems include a wide variety of objects used in the transportation process - trains, diesel trains and locomotives with traction power, electric cars, buses traction power, autonomous electric, moving farm machinery with electric drive (tractors, combines , self-installing) and others. For all these objects is to provide the basis of the planned execution of the transportation process and certain related or major technical problems (tillage, harvesting, snow removal, spraying, etc.).

Depending on various circumstances - the deviation of the true value of the estimated moving object weight, the presence of strong head or side wind condition by failure to comply with the time course of certain areas of path delays in boarding-disembarking or receiving cargo and other factors, possible deviations from the planned schedule.

In consequence of this is necessary to adjust the magnitude of the average velocity of motion to perform the set schedule [1-3].

2. Formulation of the problem in general

When setting the problem of rational control proceed from the presence of competing indices movable electrical operation of the complex - time and speed and energy costs. The problem of finding rational decision is to choose a compromise for a given set of parameters. Note the characteristic stages of the task that will be decided:

1. The object of analysis supports the specified performance criterion studied system, considered as a function of the significant parameters of the system and the environment - minimizing the time course of at least some area traction executable work.
2. The objective of the optimization is to obtain the minimum work that it takes an object at a given of points values trajectory. That is a criterion optimization choose the value of what it must do to navigate the complex path from one point to another.
3. Resource optimization is the value of control variables traction motor and power control settings traction control settings braking component of the force, which is determined by the action of mechanical brake and electric vehicles braking action. Note that these values are taken from continuous view of the technical features of modern systems of control traction units using on-board computers.
4. Optimization is performed subject to the limitations on movement phase coordinates (setting the parameters of certain regulations - time ranges of speed).

3. Analysis of recent research and publications

Research process parameter optimization of motion and process control traction at the same time the subject of many studies [1-7], which confirms the relevance of the subject. However, almost all of them on the characteristics of rolling stock, not including a wide range of characteristic differences of class moving electrical systems - no track appearance related technical problems along with task performance of the transportation process, the autonomy of a power transmission system of centralized power, etc.

In general, the problem of rational control law can be formulated as the problem of finding the extremum (the largest or smallest value) function $f(x)$ n-dimensional vector argument taking into account certain constraints. This task can be described by the following set of expressions:

$$\min f(x),$$

where there is identity

$$x \in X.$$

Here X – some subset n-dimensional Euclidean space E_n.

That is X – the permissible set of tasks, and the points belonging X – valid point problem.

As control variables are considering electromagnetic variables when the electromagnetic transients can be neglected compared to electromechanical.

The decision stated problem should generally provide:

1. Optimal Movement in the performance constraints imposed on data values from the schedule and related technical problems. It should be borne in mind that in the operational control of traction power by motion parameters may vary within certain limits, and may be given new and terminated the old limit speeds.

2. The best performance of the electric traction elements in the performance limits, depending on the parameters of the traction power and corresponding mechanical actuators of the electrical industry.

Where the duration of electromagnetic transients or parts thereof can not be neglected in comparison with electromechanical processes, consider the differential equation corresponding data variables. Then as vector controls are the corresponding electromagnetic transients or parts that can not be neglected in comparison with electromechanical processes and their characteristic differential equation coefficients, which as you can use the voltage.

To local constraints that appear in the original statement of the problem arising from the traction induction motor, include:

– Restrictions on heating, which is determined by the maximum allowable temperature curve elements traction machine;

– Restrictions on the maximum value of the module power supply;

– Limiting the power consumption associated with limiting characteristic diesel generator or primary source of energy;

– By limiting the mechanical strength of the rotor asynchronous traction machine.

The aim of this article is the mathematical description of the problem traction control power to overcome movable electrotechnical complex deviation from the schedule provided the main technical tasks assigned to the object.

4. The main material research

Suppose that a moving electrical complex left the starting point movement in time and came to a point curve motion coordinates (t_1, S_1) time, but for objective reasons described above, a point with coordinates (t_2, S_2) he did not arrive, ie there is a deviation curve schedule of numbers t_2 (Fig. 1).

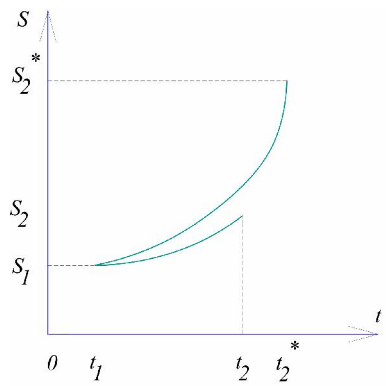


Fig. 1. Change the upper boundary curve movement conditions

Let a point with ordinate S_2 object arrived in time, ie the time t_2^* deviation from the schedule is:

$$\Delta t_2 = t_2 - t_2^*. \qquad (1)$$

We reduce the problem of change control settings traction power to overcome the actual deviation from the schedule to the problem of the calculus of variations with moving ends by the method in which the decision [8–12] and will be dealt with the task of overcoming the actual deviation from the schedule.

Suppose that the endpoint of the curve complex motion, given certain boundary conditions can move. Then the class of admissible curves connecting two points of the curve movements that given boundary conditions, expanding - except for the lame comparison with common boundary point of the curve to the study of motion, according to research [11] can still take curves with offset and limit points. So if for any type of curve $S = S(t)$ the condition of the existence of an extremum in the problem with moving boundary conditions, the condition for the existence of an extremum is achieved especially for a narrower class of curves with common boundary point on the curve type $S = S(t)$, and shall be implemented in accordance with the basic condition for achieving a extremum problem with moving boundary points [10] – function has to be a solution of the Euler equations.

That kind of curves $S = S(t)$ which is implemented in the extreme to the task to be extreme [9, 10].

According to the method of [12] we write the functional variation

$$\delta\phi = \left[\left(F - \frac{dS}{dt}\cdot\frac{\partial F}{\partial S'}\right)\delta t + \frac{\partial F}{\partial S'}\delta S\right]\Bigg|_{t_1}^{t_2} + \int_{t_1}^{t_2}\delta S\left[\frac{\partial F}{\partial S} - \frac{d}{dt}\left(\frac{\partial F}{\partial S'}\right)\right]dt. \quad (2)$$

Because according to [11] can only be extreme in making species

$$S = S(t, a_1, a_2), \quad (3)$$

where a_1, a_2 – options for Euler solution, then the solution of the problem it is necessary to consider the value of functional only on the functions of the family.

Then functionality $\phi[S(t, a_1, a_2)]$ becomes a function of parameters a_1, a_2 and boundary conditions t_1, t_2, and functional variation (1) coincides with the differential of this function.

Define the endpoint of the curve for the increment of movement within the gap with the schedule, ie the increment of the endpoint boundary traffic conditions within the time deviation from the schedule (1):

$$\Delta S_2 = S_2 - S_2^*, \quad (4)$$

where S_2^* – the final value curve ordinates of the object on the corresponding curve movement.

In accordance with the system of notation we introduce the following options:

$$\begin{cases} \delta t_2 = \Delta t_2; \\ \delta S_2 = \Delta S_2. \end{cases}$$

Curves $S = S(t)$ and $S = S(t) + \delta S$ can be considered close if you are following system requirements [12]:

$$\begin{cases} \delta t_2 \to \delta t_{2min}; \\ \delta S_2 \to \delta S_{2min}; \\ \delta S \to \delta S_{min}, \end{cases} \quad (5)$$

where $\delta t_{2min}, \delta S_{2min}, \delta S_{min}$ – the minimum possible value deviation curve parameters within the movement behind schedule.

Relevant adventurers that are possible solutions of the problem and which pass through the initial boundary conditions to form a bunch extremals the following:

$$S = S(t, a_1). \quad (6)$$

Then the functional $\phi[S(t, a_1)]$ curves bunch (6) is transformed into a function of two variables – t_2 and a_1.

If curved bunch (6) in the vicinity of adventurers who would be the best solution to the problem, do not overlap, the functionality $\phi[S(t, a_1)]$ can be seen as a unique function of the upper boundary conditions for solving the problem [12]. This is because the upper boundary conditions determine the motion curve extreme bunch curves (6) and thus determine the functional significance. The last statement is illustrated in Fig. 2, which shows a bunch of curves (6).

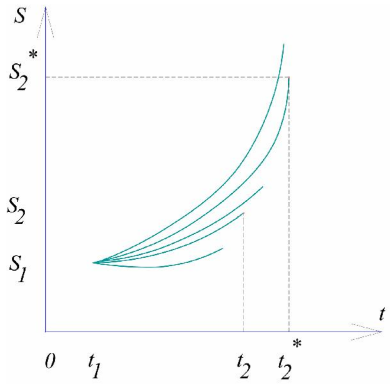


Fig. 2. The bunch curves of the form (6)

Perform calculations functional $\phi[S(t, a_1)]$ variation in extreme bunch $S = S(t, a_1)$ when moving boundary point curve movement with coordinates (t_2, S_2) in the coordinates (t_2^*, S_2^*).

Because the functional $\phi[S(t, a_1)]$ curves of the bunch is a function of the initial coordinates of the upper boundary condition given coordinates (t_2, S_2), it coincides with the differential variation of this function [9].

Isolate the main part of the increment $\Delta\phi$, the linear coordinate with relevant increments upper boundary conditions $\delta t_2, \delta S_2$. On the basis of (2), taking into account that $\Delta\phi = \delta\phi$, we have the following:

$$\Delta\phi = \int_{t_1}^{t_2+\delta t_2} F\left(t,\ S+\delta S, \frac{dS}{dt} + \frac{d(\delta S)}{dt}\right)dt + \int_{t_1}^{t_2}\left[F\left(t,\ S+\delta S, \frac{dS}{dt}+\frac{d(\delta S)}{dt}\right) - F\left(t,\ S, \frac{dS}{dt}\right)\right]dt. \quad (7)$$

The first term of the right-transform using the mean value theorem of [12] the following form:

$$\int_{t_1}^{t_2+\delta t_2} F\left(t,\ S+\delta S, \frac{dS}{dt}+\frac{d(\delta S)}{dt}\right)dt = F\Big|_{t=t_2+\sigma\delta t_2}\delta t_2, \quad (8)$$

where the value σ is limited as follows: $\sigma \in (0;1)$.

Given the continuity of the functions F can be considered, based on a study [8] that

$$F\Big|_{t=t_2+\sigma\delta t_2} = F\left(t,\ S, \frac{dS}{dt}\right)\Big|_{t=t_2} + \varepsilon_2, \quad (9)$$

where $\varepsilon_2 \to 0$ in the performance of system conditions (5). Then, on the basis of (9) we write the expression (8) as follows:

$$\int_{t_1}^{t_2+\delta t_2} F\left(t,\ S+\delta S, \frac{dS}{dt}+\frac{d(\delta S)}{dt}\right)dt = F\Big|_{t=t_2}\delta t_2 + \varepsilon_2\delta t_2. \quad (10)$$

In (7) the second term of the right of way of the development will transform the integrand in a Taylor series, we obtain the following result:

$$\int_{t_1}^{t_2}\left[\begin{array}{l} F\left(t,\ S+\delta S, \frac{dS}{dt}+\frac{d(\delta S)}{dt}\right) - \\ -F\left(t,\ S, \frac{dS}{dt}\right)\end{array}\right]dt = \int_{t_1}^{t_2}\left[\begin{array}{l} F_S\left(t,\ S, \frac{dS}{dt}\right)\delta S + \\ +F_{\frac{dS}{dt}}\left(t,\ S, \frac{dS}{dt}\right)\frac{d(\delta S)}{dt}\end{array}\right]dt + R_2, \quad (11)$$

which according to [10] for steel in terms of a problem with one set of output parameters value R_2 restrictions imposed following system:

$$\begin{cases} R_2 \to 0; \\ R_2 \gg \delta S; \\ R_2 \gg \dfrac{d(\delta S)}{dt}. \end{cases}$$

Perform integration by parts the second term of the integrand expression $\int_{t_1}^{t_2}\left[F_S\delta S + F_{\frac{dS}{dt}}\frac{d(\delta S)}{dt}\right]dt$, which is a record of the linear part of (11). As a result of integration will have the following:

$$\int_{t_1}^{t_2}\left[F_S\delta S + F_{\frac{dS}{dt}}\frac{d(\delta S)}{dt}\right]dt = \left[F_{\frac{dS}{dt}}\cdot\frac{d(\delta S)}{dt}\right]\Bigg|_{t_1}^{t_2} + \int_{t_1}^{t_2}\left[F_S - \frac{d}{dt}F_{\frac{dS}{dt}}\right]dt. \quad (12)$$

According to [9] to functional need only to find extreme. Then we can write the following identity:

$$F_S\left(t, S, \frac{dS}{dt}\right) \equiv \frac{d}{dt}F_{\frac{dS}{dt}}\left(t, S, \frac{dS}{dt}\right). \quad (13)$$

Based on the assumption of constant value of initial coordinates of the starting point of the route, defined as (t_1, S_1), then the expression

$$\delta S\big|_{t=t_1} = 0.$$

That is, (12) taking into account the last expression will have

$$\int_{t_1}^{t_2}\left[F_S\delta S + F_{\frac{dS}{dt}}\frac{d(\delta S)}{dt}\right]dt = \left[F_{\frac{dS}{dt}}\cdot\frac{d(\delta S)}{dt}\right]\Bigg|_{t=t_1}. \quad (14)$$

According to the comparison pryroschen differentials and corresponding functions for classical problems of the calculus of variations in [11] $\delta S\big|_{t=t_2}$ is not equal δS_2 – increment coordinates S_2, because δS_2 – this increment coordinates S_2 when moving boundary conditions ($t_2+\delta t_2$, $S_2+\delta S_2$), ie boundary point on the graph of the curve, the position coordinates ($t_2+\delta t_2$, $S_2+\delta S_2$), and $\delta S\big|_{t=t_1}$ – a point increment ordinates t_2 in the transition from extreme that passes through the points with coordinates (t_1, S_1) and (t_2, S_2) to the extreme that passes through the points (t_1, S_1) and ($t_2+\delta t_2$, $S_2+\delta S_2$). To investigate these allegations denote the boundary conditions of the points that according shown in Fig. 3.

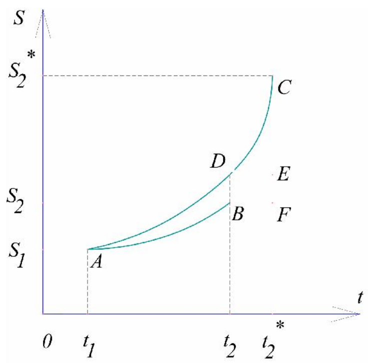


Fig. 3. Interpretation increment upper boundary conditions

Then, on the basis of studies [10], we write that $BD=\delta S\big|_{t=t_2}$, $FC=\delta S_2$, $EC\approx S(t_2)\delta t_2$ (given by the approximate equality [12] is valid to within infinitesimal of higher order) $BD=FC-EC$.

The geometric interpretation increment upper boundary condition allows ultimately add the following:

$$\delta S\big|_{t=t_2}=\delta S_2-S(t_2)\delta t_2. \qquad (15)$$

Then you can end a record that

$$\int_{t_1}^{t_2+\delta t_2} F dt = F\big|_{t=t_2}\delta t_2. \qquad (16)$$

Also, (15) we can write the following:

$$\int_{t_1}^{t_2}\left[\begin{array}{l} F\left(t,\ S+\delta S,\dfrac{dS}{dt}+\dfrac{d\left(\delta S\right)}{dt}\right)- \\ -F\left(t,\ S,\dfrac{dS}{dt}\right)\end{array}\right]dt\approx \qquad (17)$$

$$\approx F_{\frac{dS}{dt}}\Bigg|_{t=t_2}\cdot\left(\delta S_2-\frac{dS(t_2)}{dt}\delta t_2\right),$$

which is similar to the above given approximate equality in [12] is valid to within infinitesimal of higher order δS_2 and δt_2 .

Then the expression (7) will have

$$\Delta\phi=F\delta t_2+F_{\frac{dS}{dt}}\Bigg|_{t=t_2}\cdot\left(\delta S_2-\frac{dS(t_2)}{dt}\delta t_2\right). \qquad (18)$$

After analytic transformation and using the idea of the identity increment and differential functional mathematical value decomposition for which the axes of the coordinate system of the problem is shown in [11], we write (18) as

$$d\bar{\phi}\left(t_2,S_2\right)=\left(F-F_{\frac{dS}{dt}}\cdot\frac{dS}{dt}\right)\Bigg|_{t=t_2}dt_2+ \qquad (19)$$

$$+\left(F_{\frac{dS}{dt}}\right)\Bigg|_{t=t_2}dS_2,$$

where $\bar{\phi}\left(t_2,S_2\right)$ – the vector function, which becomes established in extreme functionality $S=S(t,a_1)$, and expressions for increments corresponding coordinates of boundary points of the curve movements and differentials of functions of the same variables are equivalent, that is performed by the equation: $\begin{cases} dt_2=\delta t_2=\Delta t_2; \\ dS_2=\delta S_2=\Delta S_2. \end{cases}$

The main prerequisite existence extremum $\delta\phi=0$ is as follows [12]:

$$\left(F-\frac{dS}{dt}\cdot F_{\frac{dS}{dt}}\right)\Bigg|_{t=t_2}\delta t_2+ \qquad (20)$$

$$+F_{\frac{dS}{dt}}\Bigg|_{t=t_2}\cdot\delta S_2=0.$$

If variations δS_2 and δt_2 independent, it is necessary to add the following system conditions [9]:

$$\begin{cases}\left(F-\dfrac{dS}{dt}\cdot F_{\frac{dS}{dt}}\right)\Bigg|_{t=t_2}=0; \\ F_{\frac{dS}{dt}}\Bigg|_{t=t_2}=0.\end{cases} \qquad (21)$$

Suppose that the upper boundary conditions curve movement can move along a certain curve (Fig. 4)

$$S=\varphi(t). \qquad (22)$$

This curve passing through all the possible locations of boundary conditions of the bunch adventurers that are variations of the solution of the problem (Fig. 4).

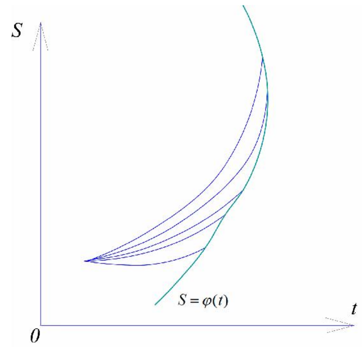


Fig. 4. The curve along which are the locus of the upper boundary curve movement conditions

Based on the present definition of mathematical consistency trajectory moving electrical elected complex system control traction power.

5. Conclusions

Using the mathematical sequence of process control modes allow efficient movement of change traction for catching the object schedule. To ensure the practical realization of the problem by using information and control system of a power transmission system as to implement traffic control algorithm defined sequence algorithmic solution. Further research in this direction is to complete construction of a mathematical model of control object and simulation solutions developed on its basis.

References

[1] G.K. Getman, V. Ye. Vasilyev “The analysis of power consumption for traction career trains”. *Visnyk Dnipropetrovskoho natsionalnoho universytetu zaliznychnoho transportu imeni akademika V. Lazariana*, no. 36, pp. 70-74, 2011.

[2] G.K. Getman *Theory of electric traction*. Dnipropetrovsk, Izd-vo Makovetskiy Publ., 2011. (Russian)

[3] G.K. Getman *Scientific basis of definition of rational power range of traction rolling stock.* Dnipropetrovsk, DNUZhT Publ., 2008. (Russian)

[4] D.O. Kulagin, P.D. Andriyenko *Mechanization, automation, informatization, telecommunications and communications in the sectors of industry*. Novosibirsk, Izd. «SibAK» Publ., 2014. (Russian)

[5] D.O. Kulagin *Designing of control systems of traction electrical transmission of EMU-trains.* Berdyansk, FO-P Tkachuk O.V. Publ., 2014. (Ukrainian)

[6] N.O. Lohvinova, D.O. Bosyi, O.M. Poliakh “Reducing operating costs by using energy-optimal motion of trains”. *Visnyk Dnipropetrovskoho natsionalnoho universytetu zaliznychnoho transportu imeni akademika V. Lazariana*, no. 42, pp. 110-113., 2012.

[7] V.V. Pankratov *Energy-optimal vector control of asynchronous electric drives*. Novosibirsk, Izdatelstvo NGTU Publ., 2005. (Russian)

[8] Cassel K.W. Variational Methods with Applications in Science and Engineering. Cambridge, Cambridge University Press Publ., 2013.

[9] I.M. Gelfand, S.V. Fomin *Calculus of Variations*. New York, Courier Dover Publications, 2000.

[10] L.P. Lebedev, M.J. Cloud *The Calculus of Variations and Functional Analysis with Optimal Control and Applications in Mechanics*. Singapore, World Scientific Publ., 2003.

[11] Logan David J. *Applied Mathematics*. 3rd ed. New York, John Wiley & Sons Publ., 2006.

[12] V.I. Vanko, O.V. Yermoshina *Calculus of variations and optimal control*. Moscow, MGTU im. N. Ye. Baumana Publ., 2006. (Russian)

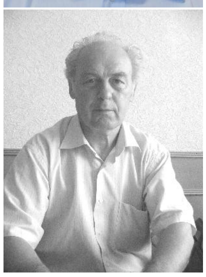
ОСОБЛИВОСТІ ЗАДАЧІ КЕРУВАННЯ ТЯГОВОЮ ЕЛЕКТРОПЕРЕДАЧЕЮ РУХОМОГО ЕЛЕКТРОТЕХНІЧНОГО КОМПЛЕКСУ ПРИ ВІДХИЛЕННІ ВІД ГРАФІКА РУХУ

Дмитро Кулагін, Петро Андрієнко

Авторами здійснено математичний опис задачі керування тяговою електропередачею для подолання рухомим електротехнічним комплексом відхилення від графіка руху. В статті запропоновано математичне описання алгоритму вирішення поставленої задачі керування тяговою електропередачею. Описання проблемного питання здійснено на основі апарату варіаційного числення. Об'єктом аналізу виступає заданий критерій ефективності досліджуваної системи.

Dmitro Kulagin, Ph.D., associate professor, doctoral student "Electricity industry" Zaporizhzhya National Technical University.

Engaged in research methodologies traffic control Electrical complexes with traction induction motors.



Petro Andrienko, D.Sc., Professor, head of "Electrical and electronic devices" Zaporizhzhya National Technical University.

Research interest modern conversion systems for rail transport and building optimum traction power systems based on them.