ABSTRACT
of the dissertation work of
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"Development of an optimal model for the safe control and management of train traffic", submitted for the degree of Doctor of Philosophy (PhD) on speciality 6D090100 - "Organisation of transportations, movement and operation of transport".

Introduction

In recent years, the volume of railway traffic has increased, and the development of the transport and logistics industry is given great importance, as evidenced by the Message of the Head of State Kasym-Jomart Tokayev to the people of Kazakhstan entitled "Economic orientation of equitable development. Kazakhstan" dated 1 September 2023: "One of the tasks of strategic importance is the full use of the potential of the transport and logistics industry. Now a new economic space is being formed in the world. It is expected that the volume of goods sent from China to Europe, Russia, Central Asia and from these regions to China will increase significantly. Kazakhstan is located at a global crossroads connecting north and south, west and east. This gives our country great opportunities. Therefore, the transport and logistics industry should become one of the main forces that will advance our economy" [1].

However, in railway transport there are several limitations in the implementation of this task, one of which is the unsatisfactory technical condition of existing automation systems and installations specified in the document [2], which affects the life and health of passengers, the safety of transported goods, infrastructure facilities and rolling stock of railway transport, the safety of the environment, it is emphasised that this increases the occurrence of hazardous factors.

Also, according to [2], while one of the problems affecting the stability and safety of transport infrastructure and transport services is digitalisation, automation, regulation, traffic control and inefficient use of management tools, the problem affecting the overall efficiency of transport services is and infrastructure management is modern digital, noted the lack of development and use of technology and automated systems for planning and management of transport services.

In addition, according to [3], the main strategic objectives of the Joint Stock Company National Company Kazakhstan Temir Zholy (KTZ) are to increase the transit capacity of the Republic of Kazakhstan, and organise container transport and high-speed passenger traffic. To achieve these goals, it is planned to renew the rolling stock fleet to ensure the required level of speed and comfort, modernise signalling, centralisation and interlocking (SCB) devices and develop new technological standards for the organisation of the transport process.

Therefore, it is necessary to constantly improve the quality indicators of the transport process to ensure the timely delivery of goods by rail, ensure passenger

comfort and safety, and increase the capacity of the sections. The most effective way of solving this problem is to improve and optimise methods of interval regulation of train traffic.

Because in the current method of interval regulation, the technology of regulation of train traffic is carried out by transmitting information about the coordinates of the last carriage of the approaching train to the control centre and the last train by radio communication. If the communication between the control centre and the train is interrupted for any reason, the train driver will have to slow down the speed instantly, even in an emergency, which in turn reduces the efficiency of the system.

Considering these problems, the relevance of this dissertation work is the development of an optimal-safe model of interval train control in order to carry out the transportation process without stopping when there are problems in the communication channel between the control centre and trains.

At present, several studies have been carried out to improve the coordinate methods and systems of interval regulation of train traffic, among them F. P. Bestemyanov, V. M. Lisenkov, J. Pachl, P. Stanley, J. Trinckauf, A. M. Romanchikov, E. N. Rosenberg, N. Furness, P. A. Kravtsov and others.

The relevance of the dissertation research is the improvement and application of the coordinate method of interval regulation of train traffic on existing railway sections, as only this method allows to increase the capacity of the section. In this context, an optimal-safe model of interval regulation of train traffic is proposed and the efficiency resulting from the integration of regulation technology through moving block (MBS) and fixed block (FBS) sections is proved.

The aim and objectives of the study are to develop an optimal and safe model of train traffic organisation by coordinate interval control method.

According to the set goal, there is a sequence of fulfilment of the following tasks:

- research and analysis of experience of operation of coordinate systems of interval train control (CSIRTC) and causes of radio communication failures;
- development of an optimised structural-functional model and algorithm of operation of CSIRTC with the proposal of vibroacoustic technology application;
- study of the use of an optimal-safe model of train traffic organisation on the existing railway network on the basis of computer modelling;
- modelling of the dynamic characteristics of the locomotive traction engine in order to study the influence of the rolling stock characteristics on the efficiency of operation of the CSIRTC.

Object of study. Working process of the coordinate system of interval regulation of train movement.

The subject of the study is the interval regulation of train movement with the coordinate method.

Research Methods. In order to solve the set research tasks the methods of data analysis of scientific and technical literature on CSIRTC, mathematical modelling on the basis of the theory of automatic regulation, statistical research,

computer modelling on the basis of applied and simulation software were applied.

The main provisions put forward for defence:

- optimised structure and algorithm of operation of the CSIRDP, which simultaneously uses mobile and fixed block-parties according to the technology of interval regulation of train movement;

- a model of communication between the control centre and trains in the coordinate system of interval train control;

- an optimally safe model of the organisation of train traffic through the CSIRTC;

- synthesis of the optimised system of stable control of the asynchronous electric drive of the rolling stock locomotive and its parameters.

Scientific novelty of the thesis work.

- the complex analysis of the structure of coordinate systems of interval regulation of trains movement is carried out, the quantitative estimation of occurrence of defects in a channel of communication is given;

- an optimum-safe model and method of the organisation of train traffic on the coordinate system of interval regulation of train traffic is developed;

- a model of the communication system ensuring reliable operation of the CSIRDP is developed;

- methods for evaluating the use of the optimal-safe model of train traffic management on the basis of simulation modelling have been proposed.

- in order to improve the efficiency of the operation of the CSIRTC the optimal control system of the asynchronous electric drive of the rolling stock locomotive has been developed and the synthesis of its parameters has been worked out.

The practical significance of the results of the work consists in the improvement of the hardware structure and algorithm of the system of interval regulation of train movement with the coordinate method, a new solution for the organisation of communication between the control centre and trains, solutions using the technology of vibroacoustic sensing.

Realisation of the results of the work.

The basic results of research on the doctoral dissertation are used in research and development "Frauscher Sensortechnik GmbH", as well as included in the educational process of the department "Transport services and business" of the ALT University, in addition, in the development of strategic plans for the development of LLP "TransCom" and in the development of rolling stock and trains of LLP "ALSTOM KAZAKHSTAN" recommended to apply in the development, localisation, improvement and operation of control systems, as well as JSC "Transtelecom".

Conformity of work to the directions of development of science or state programmes. Dissertation work is carried out within the framework of the project AP15473668 "Research and optimisation of algorithms of intellectual digital control system of train traffic", intended for grant financing of young scientists under the project "Zhas galym" for 2022-2024.

Approbation of the work.

The main provisions of the thesis are outlined and discussed at the following international conferences: XLII International Scientific and Practical Conference "Innovative technologies in transport: education, science, practice", Almaty, 2018; Mechatronics, automation and management in transport. Material of the III All-Russian scientific-practical conference. Samara, 2021; At the I International scientific-practical conference "Innovative technologies in transport: education, science, practice", Almaty, 2021.

Publications. According to the results of the research, carried out in accordance with the topic of the doctoral dissertation, 7 scientific papers have been published, including 1 paper published in the publications included in the international database Scopus (percentile of the journal in the direction of Transportation - not lower than 25), 6 papers - in the publications recommended by the Committee for Quality Assurance in the field of science and higher education of the Ministry of Science and Higher Education of the Republic of Kazakhstan, 1 monograph, as well as received 2 certificate and 1 patent for a utility model.

Structure and volume of the dissertation.

The thesis consists of an introduction, 4 sections, a conclusion, 102 lists of used sources, 5 appendices, 91 figures, 12 tables. The total volume of the text of the dissertation work is 121 pages.

The main content of the thesis is outlined in four chapters.

The introduction reflects the relevance of the topic and the direction of scientific research. The goals, objectives of the work and the expected ways of solution are formulated. Research methods are described. The main provisions put forward for defence are given, the information about the scientific significance, novelty and practical value of the research results, implementation and approbation of the work is outlined.

The first chapter analyses the existing coordinate systems for interval train control around the world. In order to determine the task and direction of the thesis research, the current state of existing interval train control systems on KTZ's railway network was analysed and a quantitative assessment was made of the share of each system in the railway network. The experience of using the SIRDP-E coordinate system of interval train control on KTZ's main railway lines is analysed, and the results of research carried out to modernise the composition of communications equipment as the main component of the system are described. The reasons for the appearance of communication systems in coordinate systems of interval regulation of train traffic are given. As a result of the analyses carried out in this section, the tasks and objectives of the thesis research are formulated.

In the second chapter, a technical solution for redundancy of the system's communication channel based on DAS technology is developed in order to increase the capacity of the section, continuing the coordinate principles of interval regulation of train movement in case of communication channel failures.

The principle of DAS technology operation is explained and the conditions of communication with the railway infrastructure are considered.

In order to verify the correctness of the proposed optimal-safe model of the coordinate system of interval regulation of train traffic, a model was created in MATLAB environment, and it is proved that the simulation results show that the redundancy of communication channels, including fibre-optic communication, is resistant to external noise, allows to obtain the highest value of rolling stock speed.

In the third chapter, the implementation of interval train control methods applied by fixed and moving block-parties in one CSIRTC system allows to increase the capacity of a railway section, as it is recommended to reliably regulate train traffic by one of the two methods with a guaranteed interval at any time.

In this section, a simulation model is developed in AnyLogic of the important Dostyk-Zhezkazgan-Iletsk transit corridor used for container trains through Kazakhstan. The expected outcome was the identification of traffic restriction sections and during the simulation it was determined that these were the Zhezkazgan-Saksaul sections and the reasons for the reduction in train speed along the section were investigated.

In addition, in this section of the thesis, a computer model of the railway section based on the OpenTrack microscopic software product has been developed to determine the capacity of the Zhetygen-Altynkol section, which uses the coordinate system of interval regulation of train traffic, implementing the concept of mobile block-partitions and as one of the main corridors of transit passage of container trains from China to Europe. In the course of modelling, train traffic was organised on the 40 km Kurozek-Zharsu section on the basis of MBS and FBS technologies. The tables of various dependencies and schedules of simulated train movements obtained in the results of the study showed the effectiveness of the optimal-safe model of train traffic organisation presented in the thesis.

In the fourth chapter, in order to comprehensively study the topic of the thesis work, a model for determining the stability of the nonlinear control system of locomotive electric drive using MATLAB modelling environment has been developed, as a result of which a description of the traction motor transients has been obtained, allowing to obtain coordinated modes of speeds and torques.

In MATLAB modelling environment the structural scheme of the induction motor model, differential equations of the automatic regulation system are developed, and the synthesis of the parameters of the automatic regulation system of the locomotive asynchronous electric drive is considered, parameters k_P, k_Z, k_Y, $k_{OS,}$ T, obtained as a result of the synthesis programme, are proved by transient plots to ensure the stability of the automatic regulation system.

The possibilities of integration of research results obtained in MATLAB modelling environment as a result of API for implementation of transfer and perception principles from OpenTrack modelling environment are outlined.

Conclusion.

The following results were achieved in the course of the thesis work:

1. The first chapter of the thesis analyses the existing coordinate systems of interval train control worldwide and investigates the current state of the existing systems of interval train control on the railway network of KTZ NC JSC. The

experience of using the SIRDP-E coordinate system of interval train control on KTZ's main railway lines is analysed, the results of research carried out to modernise the composition of communications equipment as the main component of the system are described, and the reasons for the emergence of communications systems in coordinate systems of interval train control are given.

2. In the second chapter of the thesis work, a technical solution of the system communication channel redundancy based on DAS technology is developed in order to increase the capacity of the section, continuing the coordinate principles of interval regulation of train movement in the presence of failures in communication channels, the conditions of communication of DAS technology with the railway infrastructure are considered. It has also been proved that in order to verify the correctness of the proposed optimal-safe model of the coordinate system of interval regulation of train traffic, a model has been created in MATLAB environment, the simulation results of which allow to obtain the highest value of rolling stock speed, demonstrating the redundancy of communication channels, including the stability of the fibre-optic communication channel to external noise.

3. In the third chapter of the dissertation work, the implementation of interval train control methods applied by fixed and moving block-parties in one CSIRTC system will increase the throughput capacity of the railway section, as at any moment it will be possible to reliably regulate train traffic by one of the two methods with a guaranteed interval. A simulation model has been developed for another important transit corridor, Dostyk-Zhezkazgan-Iletsk, which will be used for container trains through Kazakhstan.

The expected result was the identification of traffic restriction areas and the modelling identified that the Zhezkazgan-Saksaul sections, the reasons for the reduction in train speed along the section are dependent on CSIRTC system. In addition, in order to determine the capacity of the introduced Zhetygen-Altynkol section based on the implementation of the mobile block sections concept, a computer model of the railway section was developed based on the OpenTrack microscopic software product. In the course of modelling, train traffic on the 40 km Kurozek-Zharsu section was organised on the basis of MBS and FBS technologies. The tables of various dependencies and schedules of simulated train movements obtained in the results of the study showed the correctness of the optimal-safe model of train traffic organisation presented in the thesis work.

4. In the fourth chapter of the dissertation work, in order to comprehensively study the topic of work, a model for determining the stability of the nonlinear control system of the locomotive electric drive using MATLAB modelling environment is developed, as a result of which a description of the traction motor transients is obtained, allowing to obtain coordinated modes of speeds and torques.

In MATLAB modelling environment the structural scheme of the induction motor model, differential equations of the automatic regulation system are developed, and the synthesis of the parameters of the automatic regulation system of the locomotive asynchronous electric drive is considered, parameters k_P, k_Z, k_Y, $k_{OS,}$ T, obtained as a result of the synthesis programme, are proved by

transient plots to ensure the stability of the automatic regulation system.

The possibilities of integration of research results obtained in MATLAB modelling environment as a result of API for implementation of transfer and perception principles from OpenTrack modelling environment are outlined.

On the basis of the thesis work the patent for utility model No. 7983 and author's certificates No. 9213, No. 30873 were obtained. And also results of researches in research and development "Frauscher Sensortechnik GmbH", educational process of department "Transport services and business" of the ALT University, working out of strategic plans of development of JSC "Transtelecom", LLP "TransCom", working out of control systems of movement of rolling stock and trains of LLP "ALSTOM KAZAKHSTAN", localisation, improvement and use of the presented implementation and application.