THE REPUBLIC OF AZERBAIJAN

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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy
In Technical Sciences

RESEARCH OF OPERATIONAL PERFORMANCES OF ALTERNATING CURRENT LOCOMOTIVES AND THEIR CONSİDERATİON IN REPAIR BASE

Specialty: 3310.01-İndustrial technology

Field of science: Technical sciences

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GENERAL OVERVIEW

Subject relevance. Subject to the implementation of Order of the President of Azerbaijan Republic Ilham Aliyev dated from 06 July, 2010 on acceptance of “State Program for development of railway transport system of the Republic of Azerbaijan in 2010-2014 years”, renovation of rolling stock in accordance with modern requirements as specified in item 1 of State Program, along with commissioning of alternating current locomotives in Baku-West direction. With the commissioning of the Baku-Tbilisi-Kars project, trade turnover between the countries of the region will increase, tourism will develop, stability and security will be ensured in the region, and the geopolitical importance of the countries of the region will increase. The Baku-Tbilisi-Kars project is of great importance. Through this project, Azerbaijan will become an international transport hub as a landlocked country. - 60% of the total length of the Kars project. The volume of transportation has increased over the past few years, reaching 14.151 million ton-km in freight transportation and 1,024,000 passenger-km in passenger transportation.

Possibility to enhance the mobile freight train weight from 2500 tons up to 4500 tons with the operation of AC (alternating current) locomotives, where the indicators of operation reliability is greater than that of DC (direct current) locomotives means possibility to repair both electric and diesel locomotives due to establishment of maintenance base of new AC locomotives in Azerbaijan Railways. In this work is also highlighted to use the loco tractor for shunting operations instead of diesel locomotives.

Objective of the work. To investigate the possibility of establishing a maintenance base for new AC locomotives to be operated in connection with the transfer of the power supply system in Azerbaijan railways from 3 kV DC to 25 kV, 50 Hz AC, at the same time to provide a comparative investigations of AC locomotives’ reliability indicators with DC locomotives and to identify economic efficiency to be obtained from the operation of AC locomotives, also to identify gained economic benefits from proposed shunting loco tractor, increasing the operational efficiency of vehicles operating in logistics systems through the improvement of energy supply.

Scientific innovation:

1. According to the "Theory of Reliability" of electric locomotives with alternating current, asynchronous traction motors, the operational reliability of the "Polumarkov" model was studied.

2. According to the "Reliability Theory" of AC locomotives with alternating current, asynchronous motors, the reliability of the performance of the "Polumarkov" model has been proved to be greater than that of existing DC locomotives.

3. For the first time, the issue of operation of alternating current locomotives on the Azerbaijani railways was raised and a new repair and maintenance program was initially developed.

4. For the first time in the history of Azerbaijan Railways, a preliminary design concept was created for the creation of a repair base for alternating current locomotives.

5. For the first time after the traction report, the operation of innovative, unmanned, remote-controlled shunting vehicles was proposed at the repair base.

The subject and the object of study is exploring and substantiating the possibility of commissioning of AC locomotives in logistics and freight transportation of “Azerbaijan Railways” Closed Joint-Stock Company, increasing their service life, increasing maneuverability, increasing their service life in order to ensure operational efficiency by properly designing the performance of these locomotives, reducing repair times.

The theoretical basis of the dissertation is a comparative research of technical characteristics of AZ8A locomotives planned for operation in Azerbaijan Railways with the characteristics of existing DC electric locomotives based on the semi-Markov model in accordance with reliability theory. During the studies, it was proved that the value of inter failure term quantity $\overline{T}_1$ is 140 hours more for Azerbaijan Railways DC locomotives than for AC locomotives, on the contrary $\overline{K}_\Gamma$ availability ratio comprises 2% and restoration period is more than 13 hours, so AC locomotives have greater operational reliability than DC locomotives.

Practical significance of dissertation: the issue of new locomotives’ operation investigated in this dissertation work is of great practical importance. Dynamic tests of locomotives proved that on smaller slopes of the road AZ8A type locomotives will carry trains weighing 4500-600 tons. Along the electric locomotives, repair of diesel locomotives is the part of practical relevance of the work in proposed repair base, equipped with modern diagnostic equipment. Considering the practical relevance of the work, it was considered satisfactory by the chief of Locomotive Service of Azerbaijan Railways CJSC and approved by the act dated from November 06, 2015.

Approbation of the work: The subject of dissertation work was reported and discussed at XVIII Republic Scientific Conference (Baku, 2013); at Republic Scientific Conference on Azerbaijan education and National leader Heydar Aliyev (Baku, 2013); at Republic Scientific Conference on “Techno-Economical Problems of the High Technologies in Azerbaijan” (Baku, 2013), ISCEEN Conference on Material Sciencce and Engineering (Kharkiv, Ukraine, 2020) and at XIII International Scientific and Practical Conference on "Experimental and Theoretical Research in Modern Science” (Novosibirsk, 2018).

Published articles: the results of dissertation work were published in 13 reputable magazines and conference materials, where most of them are the magazines recommended by AAC. Furthermore, one the articles published in the USA and one article is at the stage of registration in Scopus system.

Personal attendance of the author. The research conducted in the dissertation was carried out with the direct participation of the applicant. Materials on the performance of locomotives and the reasons for downtime were collected in Azerbaijan and Kazakhstan. Based on the reliability theory, the Polumarkov model was applied and a comparative study of the performance of the existing direct current and the proposed new alternating current locomotives was conducted. As a result of the reports, it has been scientifically proven that the reliability of the proposed new AC locomotives is greater than the reliability of the existing DC locomotives.

Scope of dissertation work. The dissertation consists of an introduction, three chapters, the main results and the list of used literature. Overall scope of dissertation is comprised of 146 pages, along with 32 images, 27 tables, 2 diagrams and 92 used literature descriptions. The dissertation work contains 173521 symbols excluding images, tables, diagrams and the list of used literate.

SUMMARY OF WORK

The introduction substantiates the relevance of the dissertation, defines the purpose of research and the issues to be addressed. It specifies practical importance of applying the research results in the railway system of Azerbaijan.

Chapter 1 analyzes the current situation of locomotive fleet in Azerbaijan railways and informs about technical status of locomotives. Besides, provides basic information related with important projects currently being implemented on the railways and priorities of technical specification of new type asynchronous electrical AC locomotives manufactured by Alstom company, France. Moreover, outlines the significance of new railway line Baku-Tbilisi-Gars commissioned on 30.10.2017 in Caucasus region and in the countries of Central Asia region, as well as analyzes the annual forecast of loads to be transported via this railway line. A summary of the technical performance requirements of the proposed locomotives in connection with the transition of the railway electric traction system from 3 kV direct current to 25 kV, 50 Hz alternating current is given. The KZ8 locomotives are current in operation in Kazakhstan are the most modern asynchronous locomotive which assembled on the basis of the Prima 2 locomotives and Russian VL 80 locomotives[1]. The locomotives are capable of carrying a freight train (the weight of locomotive is 192-200 tons; the train consists of 51 freight trains weighing 83-84 tons each) with 4,500 tons weight at a minimum speed of 43 km/h with minimum slope of 2%. Traction force of locomotive

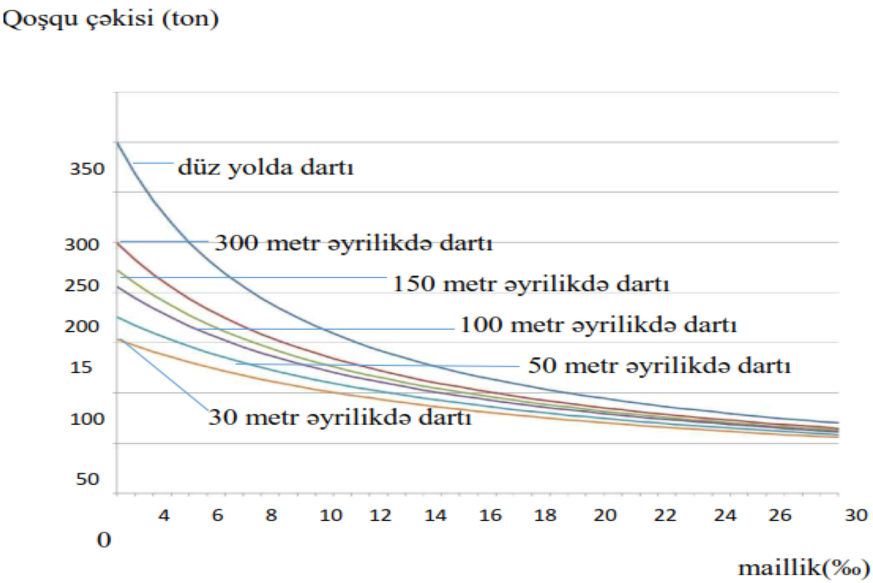
[1] Aslanov, C.G., Organization of control over the technical condition of locomotives using modern diagnostic methods // Materials of the XVIII Republican scientific conference of doctoral students and young researchers "Department of Mechanics and Mechanical Engineering", - Baku: - December 19-20, -2013, – p. 228-230.

is 8800 kW. All arrows are leading. The diameter of the wheel in full condition is 1250 mm, the distance from the lowest part of the locomotive to the rail head is a minimum of 165 mm, and the pneumatic braking force on the axle is a minimum of 150 kN. The overall dimensions of the locomotives meet the requirements of 1 T GOST 9238, which allows the locomotive to pass through the radius of curves without hindrance while driving on the existing roads of ADY. For the first time, these locomotives were insulated and equipped with bipolar transistors. Environmental conditions The environment in which the locomotives are located is a dry and subtropical climate with hot summers and mild winters. Locomotive transformers are a product of IBA and are successfully combined with thyristors and bipolar transistors that meet the requirements of the latest technologies. ADY's highway operates mainly under the combination of semi-desert and dry steppe climate with cold winters and hot summers. The average annual temperature is + 14.5oC, the average low temperature in January is +1.7 o C, and the average high temperature in July is +27.9 o C. The environmental conditions in which the locomotives will be operated are as follows:

maximum temperature	50ºC
minimum temperature	25ºC
daily change of humidity in summer	20 - 80%
daily change of humidity in winter	40 - 75%
average atmospheric pressure (barometric pressure)	746 - 763 mm
average height above sea level	956 m
minimum height above sea level	27.0 m

The efficiency of the locomotive on the test bench is 86%.

For shunting in depot, area is proposed special shunting machine loco tractor and its technical performances are given below.



Graphic 1. Traction performances of loco tractor

Table 1.
Electric locomotives in operation

Type of locomotive	Numb. (pcs)	Capacity	Passenger transportation	Technical status	Service life
VL8	65	38	15	12 are faulty	45 years
VL10/11	48	35	---	13 are faulty	19 years
VL23	2	1	---	1 is faulty	51 years
E4S	6	---	6	Functional	19 years
Total	121	74	21	26 are faulty	

Relevant calculations were made for 3 railway sections to determine the number of locomotives required to transport 30 million tons of cargo in the direction of Baku-Boyuk Kesik:

I. Big Cut - Ujar,
II. Ujar - Hajigabul,
III. Hajigabul - Bilajari

I. Boyuk Kesik - Ujar railway area: 250 km from Boyuk Kesik station to Ujar station 30 mln. The determination of the number of locomotives required to transport a ton of cargo is shown below.

The average speed of the train is 50 km / h (V), the weight of the train is 4000 tons, the idle time of the locomotive is t = 5 hours, the number of double trains is N = 29, the freight during the year is 30 million. ton, L = 250km, locomotive rotation time Q = 2L / V + ∑T = 10 + 5 = 15 lok * hours, if the locomotive demand coefficient of the double train is K = Q / 24 = 15/24 = 0.625, the number of required locomotive fleet is the formula Calculated by M = ∑N * K (1+ (repair * repair) / T) = 29 * 0.625 * 1.01 = 18.30 locomotive according to the formula 1.3.6, M = 18.30 will be the locomotive that where - repair = 1 number of repairs in which the electric locomotive is in a month, repair = 8 hours is the time spent on repairs. Thus, 18 locomotives in this direction will be enough to provide cargo transportation. In the next phase of the project, the demand for locomotives will increase. If we take into account that the traction will extend to a distance of 250 km, then 18 locomotives will be needed to carry cargo in the direction of Boyuk Kesik - Ujar. II. On the Ujar-Hajigabul railway section: The determination of the number of locomotives required to transport 30 million tons of freight on a 122 km traction line from Ujar station to Hajigabul station is given below. The average speed of the train is 50 km / h (V), the weight of the train is 4000 tons, the idle time of the locomotive is t = 2 hours, the number of double trains is N = 29, the freight during the year is 30 million. tons, L = 122km, the turnaround time of the locomotive will be Q = 2L / V + ∑T = 4.88 + 2 = 6.88 lok * hours.

The demand coefficient for a locomotive of double trains is K = Q / 24 = 6.88 / 24 = 0.28, and the number of required locomotive fleet is M = ∑N * K (1+ (repair * repair) / T) = 29 * 0.28 * 1.01 = There will be 8.2 locomotives.

where- repair = 1 number of repairs of electric locomotive in a month,

repair = 8 hours is the time spent on repair. Thus, 8.2 locomotives in this direction will be enough to provide cargo transportation.
III. On the Hajigabul-Bilajari railway section: The determination of the number of locomotives required to transport 30 million tons of freight on a 112 km traction line from Hajigabul station to Bilajari station is given below. The average speed of the train is 50 km / h (V), the weight of the train is 4000 tons, the idle time of the locomotive is t = 2 hours, the number of double trains is N = 29, the freight is 30 million tons per year. tons, L = 112 km, locomotive rotation time Q = 2L / V + ∑T = 4.48 + 2 = 6.48 loc * hours, double locomotive demand coefficient K = Q / 24 = 6.48 / 24 = 0.27, and the number of required locomotive fleet, M = ∑N * K (1 + (ntemir * ttemir) / T) = 29 * 0.27 * 1.01 = 7.9 units of locomotives that
where- repair = 1 number of repairs of electric locomotive in a month, repair = 8 hours is the time spent on repair. 8 locomotives will be enough in this direction to provide cargo transportation. It is clear from the report that 30 mln. ADY CJSC needs 34 AC locomotives to transport tons of cargo. In order to replace 2 AC electric locomotives working in Alabashli Gushchu area, 1 AC electric locomotive working in Mingachevir area and 3 alternating electric locomotives to be repaired in the direction of Baku Boyuk Kesik, 30 mln. 40 AC electric locomotives would be enough to carry a ton of cargo. In general, with the increase in the capacity of locomotives, freight turnover increases, and as a result, the economic efficiency of railway transport increases. Alstom's activity in Azerbaijan is expected to develop not only in the railway, but also in the Baku metro in the coming years. Currently, the company is working on the design of signaling and communication systems for several stations in the Baku metro.

Chapter 2 explains and identifies the reason of establishment the maintenance base in the territory of current Bilajari locomotive depo; provides comparative analysis of the activities of alternating current maintenance bases in the CIS countries; analyzes the diagnostic processes applied to alternating current locomotives before and after repair services. DC locomotives are used on a large scale by Russian Railways, the world's second largest railway network. If we take the example of depots located on the suburbs of Moscow, there are more than 40 of them. The operation of all these depots is aimed at maintaining the operational locomotives in a serviceable condition by providing repair and maintenance. Repair depots for asynchronous AC locomotives currently operate only on the railways of Kazakhstan and Uzbekistan among the CIS countries. It should be noted that the depots located on both railways are assembled in a design that meets the latest Euro standards and are equipped with the latest facilities and equipment. 34% of the factors that lead to the main failures of asynchronous traction motors are technological, 48% are operational, and 18% are structural reasons, depending on the level of intensity of operation. In general, asynchronous traction motors have a number of technical advantages over commutated motors. Some of these key benefits are listed below:

- Practically inedible construction due to simple design, low cost;
- high quality of operation;
- high coefficient of force due to very low friction losses;
- very simple management scheme;
- 30-35% more power in the shaft of the anchor than in the collector motors. Electric traction accounts for 70% of Kazakhstan's rail freight.

Having achieved great success in modernizing the locomotive fleet of the Railways of the Republic of Kazakhstan, it has managed to operate and manufacture AC electric locomotives manufactured by the French company Alstom. Demand for electric locomotives has increased since 2008 with a demand for a 20% reduction in diesel consumption on Kazakhstan's railways. The technical characteristics of these new locomotives KZ8 allow Nur-Sultan to work in very harsh climates. Locomotives are used for uninterrupted freight transportation even at temperatures of -50 ° C. The dissertation provides detailed information on the operation of depots and locomotives located in the capital Astana. The total length of Kazakhstan Railways, the 19th largest railway network in the world, is about 16,000 km. One of the main goals of the country's railways is to achieve a speed limit of 140-180 km / h for freight trains and 200 km / h for passenger trains along the Almaty-Nursultan corridor. The very large annual volume of freight traffic on the territory of the country and by rail has created the need for uninterrupted and efficient operation of new freight locomotives.

Currently, 38 new AC locomotives are being operated on the country's railways, and it is planned to increase the fleet of these locomotives to 250 by 2025. The total area of the depot is 2731 m2, consisting of 6 repair areas, 3 roads in the main workshop, power supply (traction system), test site, office building and warehouse. All working roads are equipped with lifting jacks and 20-ton cranes. According to the technical inspection and repair plan of KZ8 series locomotives, all work is being done on the technological map. Depending on the type of service provided in the repair base offered in Azerbaijan, the work is carried out in the areas of repair, maintenance and operation. According to the volume of work, locomotive depots are divided into 4 classes. In order to increase the service life of the locomotive fleet, the percentage of locomotives in the types of repairs should be 20% for maintenance, 20% for maintenance, 20% for depot repairs, 60% for factory repairs. Repair depots carry out CT2 and CT3 repairs of locomotives registered only in other depots. This class of depots is not registered on the balance of the locomotive. Maintenance depots carry out all types of repairs, including maintenance of locomotives on their balance sheet, provided that they are not less than 300 sections per year. Operating locomotive depots, unlike other depots, carry out only TB3, TB4, CT1 repairs and maintenance of locomotives on their balance. The operation of newly purchased locomotives, in turn, is divided into 2 classes, the operation of 1st class locomotives during the warranty period, the operation period after the end of the 2nd class warranty period. All locomotive depots are divided into groups according to the number of locomotive sections they repair and are evaluated by points. Locomotive depots are rated at a minimum of 380 points in Group I, 180 ÷ 380 points in Group II, 80 ÷ 180 points in Group III, and a maximum of 80 points in Group IV. The scoring of locomotive depots is calculated on an average monthly basis, and the coefficients for repairs are estimated at 5.0 for current repairs 3, 3.0 for current repairs 2, 1.0 for current repairs 1, 0.4 for maintenance 3, and 0.3 for maintenance 4, respectively.

In turnover depots, these figures are calculated by the average daily number of locomotives entering the station, as there must be a minimum of 100 locomotives in Group I, 50 ÷ 100 in Group II, 26 ÷

50 in Group III, and a maximum of 26 locomotives in Group IV. High information technologies have also been used in the application of technical diagnostics in the organization of maintenance and repair services in locomotive depots. Establishment of repair base of alternating current locomotives in Bilajari Locomotive Depot, one of the main enterprises of Azerbaijan Railways Closed Joint-Stock Company, is one of the most priority issues in the current situation. Just as the electrification of the USSR railways in Azerbaijan was the first, the introduction of the AC system was the first in the history of the Azerbaijani railways. At the initial stage, most of the work will be carried out at the repair base to be established in Bilajari, and in the coming years at the auxiliary depot to be built in Ganja. Work on the establishment of a repair service center will be carried out in two phases: Phase 1 will clean the space, fence and build a warehouse for storage of basic equipment, and Phase 2 will include repair shops and work on the locomotive, including the roof. is the construction of a building.

The traction report of proposed locomotive for Baku-Boyuk Kesik section of Azerbaijan Railways was drawn up. This locomotives first time equipped with IGBT transistors[2].

Target slope - the mentioned parameter is the most important parameter in the organization of train traffic in the selected direction and plays a significant role in determining the estimated speed and traction of the locomotive.

Target slope is accepted as $i_p = +12{,}0\%$.

The train weight based on a target slope is calculated in the following way:

$$m_c = \frac{F_{êð} - \left(w_o^{'} + i_p\right) * m_{ë} * g}{\left(w_o^{''} + i_p\right) * g}, \qquad (1)$$

[2] Aslanov, C.G. Analysis of isolated bipolar transistors and their application for the first time in alternating current locomotives // - Baku: Azerbaijan Technical University Scientific Works, Technical Sciences Series, − 2015. №3, − p. 129-131.

where $F_{кр}$ is expected traction force; $F_{кр} = 76600N$, $w_o^{'}$ is a special resistance in the traction mode of locomotive; kgf/t, $w_o^{''}$ is a special resistance of wagons; kgf/t, $m_л$ is a target weight of locomotive, 200 t; g is a gravitational acceleration and $g = 9{,}81\, м/c^2$

.

Special resistance of locomotive in the traction mode is calculated as follows:

$$w_o^{'} = 1{,}9 + 0{,}01 * v_p + 0{,}0003 * v_p^2 = 1{,}9 + 0{,}01 * 24{,}2 + 0{,}0003 * 24{,}2^2 =$$

$$= 2{,}32 \text{kgf/t}$$

where v_p is a target speed of locomotive and equals to $v_p = 24{,}2 km / hour$.

The formula for calculation of wagon's special resistance:

$$w_o^{''} = \alpha_4 * w_{04}^{''} + \alpha_6 * w_{06}^{''} + \alpha_8 * w_{08}^{''}, \text{kgf/t},$$

Where $\alpha_4, \alpha_6, \alpha_8$ is a distribution value of axle wagon no.4,6 and 8. $\alpha_4 = 0{,}6; \alpha_6 = 0{,}4$;

$w_{04}^{''}, w_{06}^{''}, w_{08}^{''}$ is a special resistance of a proper wagon.
Special resistance of 4-axle wagon is calculated as follows:

$$w_{04}^{''} = 0{,}7 + \frac{3 + 0{,}1 * v_p + 0{,}0025 * v_p^2}{m_{во}}, \text{ kgf/t} \quad (2),$$

where $m_{во}$ is a load per wagon axle, in 4-axle wagons is $m_{âî} = 20$.
Special resistance of 6-axle wagon is calculated in the following way:

$$w_o^{''} = 0{,}6 * 1{,}044 + 0{,}4 * 1{,}044 = 1{,}044 \text{kgf/t}$$

$$m_c = \frac{76600 - (2{,}32 + 12{,}0) * 200 * 9{,}81}{(1{,}044 + 12{,}0) * 9{,}81} = 5600e \text{ т.}$$

Wagon weight calculation at the triggering moment on a target slope:
Calculation of the freight train at the triggering moment on a target slope by weight is calculated with the following formula:

$$m_{тр} = \frac{F_{ктр}}{\left(w_{тр} + i_p\right) * g} - m_{ё}, \text{т}, \qquad (3)$$

where $F_{ктр}$ is a traction force at triggering moment $F_{ктр} = 833000\text{kgf/t}$, $w_{тр}$ special resistance at triggering moment is calculated as follows:

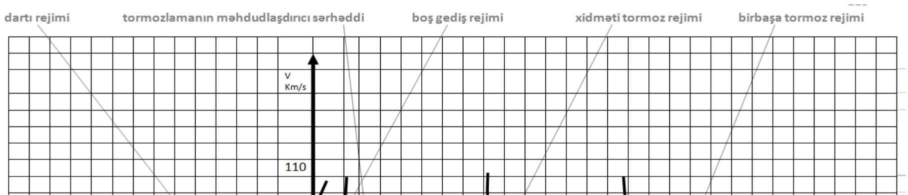
$$w_{тр} = \frac{28}{\left(m_{во} + 7\right)} = \frac{28}{\left(20 + 7\right)} = 1{,}037\text{kgf/t}, \qquad (4)$$

Table 2.

Traction characteristics of AZ8A locomotive

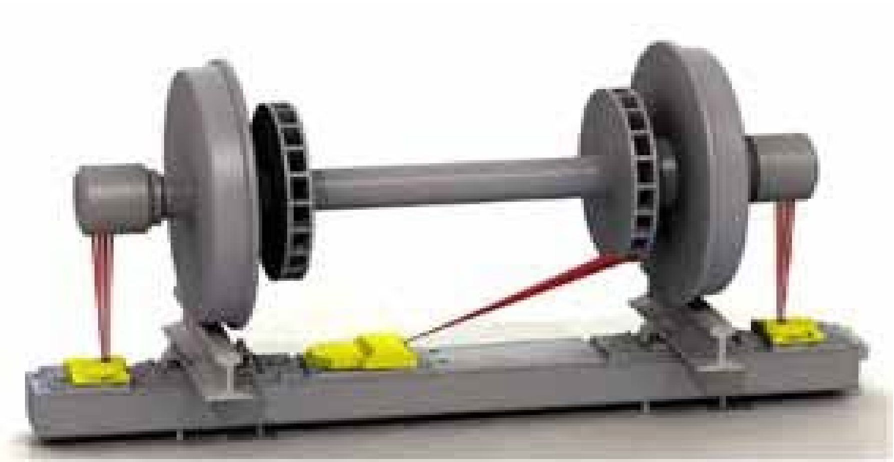
$v, km/hour$	$F_к, N$
0	833000
10	720000
40	580000
60	440000
80	320000
100	270000
110	250000

Subject to calculations, traction force of locomotives with $v_{cp} = 57{,}1 km/hour$ speed rate will be $F_{кср} = 430700N$.



Graphic 2. General traction diagram of locomotive

This chapter also provides information on the diagnostic systems applied to locomotives before and after repairs. One of the key issues to ensure the functional efficiency of locomotive operation is to reduce operating costs, and the other is the sustainability of the maintenance schedule, which requires the use of modern diagnostic systems to address all these issues. A description of the diagnostic device that monitors the temperature of the cushion nodes of locomotives is given in Figure 2.4.1. The device is a hardware-software complex designed to continuously monitor the heating of the cushion knots above the critical temperature during the operation of the locomotive. The technical capabilities of the system allow to control the heating of the pillow knots and record the information during the movement of the locomotive, to transmit information about the overheating of the knots in case of an accident, as well as to the local network of the warehouse for further processing and use. , even if it is possible to give to the duty officer. The device includes a temperature module, a terminal module, a set of thermal actuators, a set of connecting cables. The heat exchanger set uses a DS-1820-type temperature regulator, which is housed in an airtight housing. During the installation of the system's heat actuator set, they are firmly attached to the locomotive's cushion nodes. The temperature module maintains constant contact with each thermal actuator and processes the information obtained on the temperature of the cushion nodes. The terminal module of the system is designed to feed its individual elements and manage information about the status of the system on the integrated alphabetical-digital display. Temperature information automatically determines the temperature of the air surrounding each heat exchanger. The module gives a warning signal about the value of the temperature difference of the set critical value and collects information about the location of the overheated heat exchanger on the screen. BSKT allows you to control the temperature range of 100 ° C ± 3 ° C and - 40 ° C. The maximum heating temperature of the locomotive cushion nodes is determined by the program at the time of release from production and can be changed at the request of the customer. One of the most important issues during operation is the ability to provide maintenance services for all specific parts of locomotives in accordance with their technical condition by predicting their individual technical condition.



Picture 1. Device for controlling temperature of bearings

Chapter 3 presents the study of operational reliability of asynchronous electric locomotives with semi-Markov model based on theory of reliability, Markov recovery system[3] as well as the calculations of economic benefits from the operation of alternating current locomotives.

Let's analyze system of independently operating elements based on semi-Markov model. Assume that the activity of each i element describes the continuous recovery processes (uninterrupted running time, IRT) $\alpha_1^{(i)}\left(P\left\{\alpha_1^{(i)} \leq t\right\} = F_1^i(t)\right)$ and recovery period $\alpha_0^{(i)}\left(P\left\{\alpha_0^{(i)} \leq t\right\} = F_0^{(i)}(t)\right)$. The system is considered productive if $p(1 \leq p \leq n)$ is more than element (operation of locomotive specified in chapter 4 $p = n$). For clarity, we assume that overall elements commence functioning at start time $t = 0$. Determining the reliability characteristics of the system: stationary availability ratio K_Γ, average time between refusals T_1 and average time for recovery period T_0.

Assume that the following conditions are seen:

A1. Random growth of URT elements (TB) $\alpha_1^{(i)}$ –, $\alpha_0^{(i)}$ –

Recovery period elements (RP), $i = \overline{1,n}$ (n – number of elements in a system) are generally independent, limited average value $0 \leq M\alpha_1^{(i)} = T_1^{(i)} < \infty, 0 \leq M\alpha_0^{(i)} = T_0^{(i)} < \infty$.

A2. Distribution functions (DF) TB $\alpha_1^{(i)}$ and $\alpha_0^{(i)}, i = \overline{1,n}$, $F_1^{(i)}(t)$ and $F_0^{(i)}(t)$ are appropriate and completely uninterrupted compared to Lebega size.

The function $\xi^{(i)}(t)$ of each i element is modeled through semi-Markov processes (SMP), majority of situations $E^{(i)} = \{0,1\}$ and semi-Markov matrixes.

$$Q^{(i)}(x) = \begin{pmatrix} 0 & F_0^{(i)}(x) \\ F_1^{(i)}(x) & 0 \end{pmatrix}, \qquad (5)$$

[3]Akhmedov G.M., Aslanov J.G., Application of semi-Markov models of recoverable systems for calculating the main indicators of reliability of alternating current electric locomotives // Universum, - Moscow:– 2018. №3(48), – P. 72-75.

As to the problem solution, the initial distribution equals to $P\{\xi_i(0)=1\}=1$. If the process $\xi_i(t)$ element i is running within a time period t , the value is 1 and equals to 0 if restored within a time period t.

$u_i(t)=t-sup\{u: u\leq t, \xi^{(i)}(u)\neq\xi^{(i)}(t)\}$, $i=\overline{1,n}$, process on an incomplete leap is determined based on per each time slot of minimum incomplete leaps and $(t)=\min\limits_{i=1,2,\dots,n}\{u_i(t)\}$, where an incomplete leap of initial processes that occurred in one of the previous leaps will be $v_i(t)=u_i(t)-u(t)$. If we look over the super positions of semi-Markov processes $\xi_i(t)$, $\xi(t)=\{\xi_1(t),\dots,\xi_n(t); v_1(t),\dots,v_n(t)\}$ at initial distributions will be $P\{\xi(0)=(1,1,\dots,1;0,0,\dots,0)\}=1$.

For example, $d=(d_1,\dots,d_n)n$ is a binary vector, then $d_j=\overline{0,1}$ will be equal to $j=\overline{1,n}$. Note that $|d|=\sum_{j=1}^{n}d_j$ will be equal to the number of units in $|d|$ d vector, where D is a majority in n numbers in all possible majorities. Assume that $x^{(i)}=(x_1,\dots,x_{k-1},0,x_{k+1},\dots,\xi_n)$, i.e. $x^{(k)}$ is a vector comprised of nonnegative components in n number. One of $(k-я)$ absolutely equals to zero. Note overall $x^{(k)}$ vector majorities with $R_+^{n,k}$.

The majority of situations of processes $\xi(t)$ is indicated with $Z=\{(d:x^{(k)}): d\epsilon D, x^{(k)}\epsilon R_+^{n,k}, k=\overline{1,n}\}$. Depending on conditions of the task $Z=Z_1\cup Z_0$, where $Z_1=\{(d:x^{(k)}): d\epsilon D, |d|\geq p, x^{(k)}\epsilon R_+^{p,k}, k=\overline{1,n}\}$ equals to majority of good (working) situations, whereas $Z_0=\{(d:x^{(k)}): d\epsilon D, |d|<p,\ x^{(k)}\epsilon R_+^{n,k}, k=\overline{1,n}\}$ matches with majority of rejection situations.

When A_1, A_2 conditions are met, the below specified expression are valid for K_Γ, T_1 and T_0:

$$K_\Gamma=\sum_{|d|\geq p}\prod_{i=1}^{n}T_{d_i}^{(i)}\Big/\sum_{|d|\geq p-1}T_{d_i}^{(i)}\ ; \qquad (6)$$

$$T_1=\left(\sum_{|d|\geq p}\prod_{i=1}^{n}T_{d_i}^{(i)}\right)\Bigg/\left(\sum_{|d|=p-1}\ \sum_{\{j:d_j=0\}}\ \prod_{i\neq j}T_{d_i}^{(i)}\right); \qquad (7)$$

$$T_{0=}\left(\sum_{|d|=p-1}\prod_{i=1}^{n}T_{d_i}^{(i)}\right)\bigg/\left(\sum_{|d|=p-1}\sum_{\{j:d_j=0\}}\prod_{i\neq j}T_{d_i}^{(i)}\right), \qquad (8)$$

where is determined with equality $T_{d_i}^{(i)}$ (12).

Apparently, $|d| \geq p$ strong dc vector majorities and $|d| < p$ vector is compatible with D_1 and D_0 majorities. For strong majority $|d| = p - 1$ that is derived from $d\epsilon D_0$ vectors, only $j\epsilon I(d)$ conversion happens in one component. The vector d converses to unit from zero in the majority D_1 and equals to D_0' comprised of $d\epsilon D_1$vectors. In variable $j\epsilon G(d)$ for only one of its component, the vector converses to unit from zero and is equivalent to D_1'.

Furthermore, the issue of unscheduled maintenance for 2016 of both AZ type asynchronous motor AC electric locomotives proposed to be operated in Azerbaijan Railways and DC electric locomotives being currently operated has been overviewed. Unscheduled maintenance of the above mentioned locomotives is due to the following malfunctions: failure of small gear wheel (SGW) – $i = 1$, compressor failure (K) $-i = 2$, pantograph failure (P) $-i = 3$ and traction motor (TM) failure $-i = 4$. Initially, the idle downtime for 2016 of existing DC electric locomotives being operated in Azerbaijan Railways will be considered. The investigation was carried out with the consideration of downtime and failures of 11 DC electric locomotives.

$(j = 1, \dots, 11)$:

1) VL11-274 : $\alpha_{0,1}^{(3)} = 78{,}4;$

2) VL11-341 : $\alpha_{0,2}^{(2)} = 98{,}5;\ \alpha_{0,2}^{(4)} = 98;\ 60{,}25;$

3) VL11-351 : $\alpha_{0,3}^{(2)} = 8;\ 85{,}4;\ \alpha_{0,3}^{(3)} = 62;\ \alpha_{0,3}^{(3)} = 28;$

4) VL11-353 : $\alpha_{0,4}^{(1)} = 118,;$

5) VL11-364 : $\alpha_{0,5}^{(3)} = 74;$

6) VL11-402 : $\alpha_{0,6}^{(1)} = 110{,}25;\ 101{,}5;\ \alpha_{0,6}^{(2)} = 21{,}4;$

7) VL11-460: $\alpha_{0,7}^{(2)} = 89{,}7;$

8) VL11-461: $\alpha_{0,8}^{(1)} = 342;$

9) VL11-462 : $\alpha_{0,9}^{(2)} = 58; 58,6;$

10) VL11-463 : $\alpha_{0,10}^{(2)} = 250; \alpha_{0,10}^{(4)} = 56,5;$

11) VL11-464 : $\alpha_{0,11}^{(2)} = 39; 59,4.$

Accordingly, several investigations have been carried out related with downtime cases due to failures of AC electric locomotives planned to be operated in Azerbaijan Railways in 2016 in Kazakhstan Railways.

1) KZ8: $\alpha_{0,1}^{(3)} = 8$; $\alpha_{0,1}^{(4)} = 4$; 2) KZ 9: $\alpha_{0,2}^{(2)} = 4$; $\alpha_{0,2}^{(4)} = 3$; 3) KZ 12: $\alpha_{0,3}^{(1)} = 40; 46$; $\alpha_{0,3}^{(2)} = 14$; $\alpha_{0,3}^{(3)} = 5$, $\alpha_{0,3}^{(4)} = 64$; 4) KZ 15: $\alpha_{0,4}^{(1)} = 48$; $\alpha_{0,4}^{(2)} = 22$; 5) KZ 17: $\alpha_{0,5}^{(1)} = 200$; 6) KZ 18: $\alpha_{0,6}^{(1)} = 72$; 7) KZ 20: $\alpha_{0,7}^{(1)} = 150$; $\alpha_{0,7}^{(2)} = 19$; $\alpha_{0,7}^{(3)} = 13$; 8) KZ 21: $\alpha_{0,8}^{(3)} = 8$; $\alpha_{0,8}^{(4)} = 4$; 9) KZ 27: $\alpha_{0,9}^{(2)} = 45$; $\alpha_{0,9}^{(3)} = 10$; $\alpha_{0,9}^{(4)} = 15$; 10) KZ 29: $\alpha_{0,10}^{(2)} = 25$; $\alpha_{0,10}^{(4)} = 7$; 11) KZ 34: $\alpha_{0,11}^{(2)} = 8$; $\alpha_{0,11}^{(3)} = 11$.

According to the data, taking into account the time on the Azerbaijan Railway (ADY) 365x12x24 = 8760 hours, RP (recover period) and URT (uninterrupted running time) for $T_{0,j}^{(i)}$ (hour) and $T_{1,j}^{(i)}(hour)$ of element number i of j locomotive will be:

1) $T_{1,1}^{(i)} = (8760 - 78{,}4)/2 = 4340{,}8 \ (i = \overline{1{,}4})$; $T_{0,1}^{(3)} = 78{,}4$, $T_{0,1}^{(i)} = 0 \ (i \neq 3)$;

2) $T_{1,2}^{(i)} = [8760 - (98{,}5 + 98 + 60{,}25)]/4 = 2125{,}8 \ (i = \overline{1{,}4})$; $T_{0,2}^{(1)} = 0$, $T_{0,2}^{(2)} = 98{,}5$; $T_{0,2}^{(3)} = 0$; $T_{0,2}^{(3)} = 0$; $T_{0,2}^{(4)} = (38 + 60{,}25)/2 = 49{,}125$

Analogically, let's calculate the other elements of quantities $T_{0,j}^{(i)}$ and $T_{0,j}^{(i)}$:

3) $T_{1,3}^{(i)} = 1715{,}3 \ (i = \overline{1{,}4})$; $T_{0,3}^{(1)} = 0$; $T_{0,3}^{(2)} = 46{,}7$; $T_{0,3}^{(3)} = 62$; $T_{0,3}^{(4)} = 28$;

4) $T_{1,4}^{(i)} = 4321 \ (i = \overline{1{,}4})$, $T_{0,4}^{(1)} = 118$; $T_{0,4}^{(i)} = 0 \ (i \neq 1)$;

5) $T_{1,5}^{(i)} = 4343\ (i = \overline{1,4})$; $T_{0,5}^{(i)} = 74$; $T_{0,5}^{(i)} = 0\ (i \neq 3)$;
6) $T_{1,6}^{(i)} = 2131{,}7\ (i = \overline{1,4})$, $T_{0,6}^{(1)} = 105{,}875$; $T_{0,6}^{(2)} = 21{,}4$; $T_{0,6}^{(3)} = T_{0,6}^{(4)} = 0$;
7) $T_{1,7}^{(i)} = 4335{,}15\ (i = \overline{1,4})$; $T_{0,7}^{(2)} = 89{,}7$; $T_{0,7}^{(i)} = 0\ (i \neq 2)$;
8) $T_{1,8}^{(i)} = 4209\ (i = \overline{1,4})$; $T_{0,8}^{(1)} = 342$; $T_{0,8}^{(i)} = 0\ (i \neq 1)$;
9) $T_{1,9}^{(i)} = 2881{,}13\ (i = \overline{1,4})$; $T_{0,9}^{(1)} = 58{,}3$; $T_{0,9}^{(i)} = 0\ (i \neq 2)$;
10) $T_{1,10}^{(i)} = 2817{,}83\ (i = \overline{1,4})$; $T_{0,10}^{(1)} = 0$; $T_{0,10}^{(3)} = 0$; $T_{1,10}^{(4)} = 56{,}5$;
11) $T_{1,11}^{(i)} = 2145{,}15\ (i = \overline{1,4})$; $T_{0,11}^{(1)} = 81$; $T_{0,11}^{(2)} = 49{,}2$; $T_{0,11}^{(3)} = T_{0,11}^{(4)} = 0$.

Incompatibility of the elements of the system under review equals to $T_{1,j}^{(1)} = T_{2,j}^{(2)} = \cdots T_{1,j}^{(n)} = const = T_{1,j}^{\text{сист}}$, where $T_{1,j}^{\text{сист}}$ is the average time period spent on rejections and is determined as follows:

$$T_{1,j}^{\text{сист}} = \left(8760 - T_{0,j}^{\text{сист}}\right) / \left(r_j + 1\right), \quad T_{0,j}^{\text{сист}} = \sum_{i=1}^{n} T_{0,j}^{(i)}, \quad r_j = \sum_{i=1}^{n} r_j^{(i)},$$

where $r_j^{(i)}$ is the number of rejections of $- i$ element.

The average value of the time interval between the rejections of $T_{1,j}^{\text{сист}}/n$ and $T_{0,j}^{\text{сист}}/n$ ratios can be explained as time interval spent for system restoration and marked as follows $T_{1,j}^{\text{элем}} = T_{1,j}^{\text{сист}}/n$ and $T_{0,j}^{\text{элем.}} = T_{0,j}^{\text{сист}}/n$.

In this case will be $K_{\Gamma,j}^{\text{элем}} = T_{1,j}^{\text{элем}} / \left(T_{1,j}^{\text{элем}} + T_{0,j}^{\text{элем}}\right)$ [88]. Consequently, the explanations of $K_{\Gamma,j}, T_{1,j}$ and $T_{0,j}$ elements are specified as $K_{\Gamma,j}^{\text{сист}}$, $T_{1,j}^{\text{сист}}$ and $T_{0,j}^{\text{сист}}$ system parameters in formulas (14)-(16). It can be concluded that the following equation with extinction is true for system j:

$$K_{\Gamma,j}^{\text{сист}} = K_{\Gamma,j}^{\text{элем}}, \quad T_{1,j}^{\text{сист}} = T_{1,j}^{\text{элем}}, \quad T_{0,j}^{\text{сист}} = T_{0,j}^{\text{элем}}$$

And equivalent to the following simple formula:

$$K_{\Gamma,j} = T_{1,j}^{\text{сист}}/\left(T_{1,j}^{\text{сист}} + T_{0,j}^{\text{сист}}\right) = T_{1,j}^{\text{элем}}/\left(T_{1,j}^{\text{элем}} + T_{0,j}^{\text{элем}}\right), \quad (9)$$

$$T_{1,j} = T_{0,j}^{\text{сист}}/n = T_{1,j}^{\text{элем}}, \quad (10)$$

$$T_{0,j} = T_{0,j}^{\text{сист}}/n = T_{0,j}^{\text{элем}} . \quad (11)$$

Average characteristics of stationary reliability with system extinction is equal to proper characteristics of elements. By applying formulas (9)-(11) the result for ADY is as follows:

1) $K_{\Gamma,1} = 0{,}982; T_{1,1} = 1085{,}2; T_{0,1} = 19{,}6;$
2) $K_{\Gamma,2} = 0{,}935; T_{1,2} = 531{,}45; \quad T_{0,2} = 36{,}9;$
3) $K_{\Gamma,3} = 0{,}926; T_{1,3} = 428{,}825; T_{0,3} = 34{,}175;$
4) $K_{\Gamma,4} = 0{,}973; \quad T_{1,4} = 1080{,}25; T_{0,4} = 29{,}5;$
5) $K_{\Gamma,5} = 0{,}983; T_{1,5} = 1085{,}75; T_{0,5} = 18{,}5;$
6) $K_{\Gamma,6} = 0{,}9; T_{1,6} = 532{,}295; T_{0,6} = 58{,}287;$
7) $K_{\Gamma,7} = 0{,}98; T_{1,7} = 1083{,}787; T_{0,7} = 22{,}425;$
8) $K_{\Gamma,8} = 0{,}925; T_{1,8} = 1052{,}25; T_{0,8} = 85{,}5;$
9) $K_{\Gamma,9} = 0{,}96; T_{1,9} = 720{,}282; \quad T_{0,9} = 19{,}43;$
10) $K_{\Gamma,10} = 0{,}9; T_{1,10} = 704{,}457; T_{0,10} = 76{,}625;$
11) $K_{\Gamma,11} = 0{,}923; T_{1,11} = 536{,}287; T_{0,11} = 44{,}85.$

Calculation of K_Γ, T_1 and T_0, elements' value for n=11 locomotive:

The results for AC locomotives proposed to be operated in Azerbaijan Railways (currently operated in Kazakhstan):

1) $T_{1,1}^{(i)} = 2916$ $(i = \overline{1,4})$; $T_{0,1}^{(1)} = T_{0,1}^{(2)} = 0$, $T_{0,1}^{(3)} = 8$; $T_{0,1}^{(4)} = 4$; 2) $T_{1,2}^{(i)} = 2917$ $(i = \overline{1,4})$; $T_{0,2}^{(1)} = T_{0,2}^{(3)} = 0$; $T_{0,2}^{(2)} = 4$; $T_{0,2}^{(4)} = 3$; 3) $T_{1,3}^{(i)} = 1438{,}5$ $(i = \overline{1,4})$; $T_{0,3}^{(1)} = 43$; $T_{0,3}^{(2)} = 14$; $T_{0,3}^{(3)} = 5$; $T_{0,3}^{(4)} = 24$; 4) $T_{1,4}^{(i)} = 2896{,}66$ $(i = \overline{1,4})$, $T_{0,4}^{(1)} = 48$; $T_{0,4}^{(2)} = 22$; $T_{0,4}^{(3)} = T_{0,4}^{(4)} = 0$; 5) $T_{1,5}^{(i)} 1706$ $(i = \overline{1,4})$; $T_{0,5}^{(1)} = 200$; $T_{0,5}^{(2)} = 0$; $T_{0,5}^{(3)} = 4$; $T_{0,5}^{(4)} = 13$; 6) $T_{1,6}^{(i)} = 4344$ $(i = \overline{1,4})$, $T_{0,6}^{(1)} = 72$; $T_{0,6}^{(1)} = 0$

$(i \neq 1)$; 7) $T_{1,7}^{(i)} = 2144{,}5$ $(i = \overline{1{,}4})$; $T_{0,7}^{(1)} = 15{,}0$; $T_{0,7}^{(2)} = 19$; $T_{0,7}^{(3)} = 13$; $T_{0,7}^{(4)} = 0$; 8) $T_{1,8}^{(i)} = 2916$ $(i = \overline{1{,}4})$; $T_{0,8}^{(1)} = T_{0,8}^{(2)} = 0$; $T_{0,8}^{(3)} = 4$; 9) $T_{1,9}^{(i)} = 2172{,}5$ $(i = \overline{1{,}4})$; $T_{0,9}^{(1)} = 0$; $T_{0,9}^{(2)} = 45$; $T_{0,9}^{(3)} = 10$; $T_{0,9}^{(4)} = 0$; 10) $T_{1,10}^{(i)} = 2919$ $(i = \overline{1{,}4})$; $T_{0,10}^{(1)} = T_{0,10}^{(3)} = 0$; $T_{0,10}^{(2)} = 25$; $T_{0,10}^{(4)} = 7$; 11) $T_{1,11}^{(i)} = 2913{,}66$ $(i = \overline{1{,}4})$; $T_{0,11}^{(1)} = T_{0,11}^{(4)} = 0$; $T_{0,11}^{(2)} = 8$; $T_{0,11}^{(3)} = 11$.

The below mentioned result are achieved by using formulas (9)-(11) and datas:
1) $K_{\Gamma,1} = 0{,}996$; $T_{1,1} = 72{,}9$; $T_{0,1} = 3$; 2) $K_{\Gamma,2} = 0{,}997$; $T_{1,2} = 729{,}415$; $T_{0,2} = 1{,}75$; 3) $K_{\Gamma,3} = 0{,}918$; $T_{1,3} = 359{,}625$; $T_{0,3} = 32{,}25$; 4) $K_{\Gamma,4} = 0{,}976$; $T_{1,4} = 724{,}165$; $T_{0,4} = 17{,}5$; 5) $K_{\Gamma,5} = 0{,}88$; $T_{1,5} = 426{,}5$; $T_{0,5} = 57{,}5$; 6) $K_{\Gamma,6} = 0{,}984$; $T_{1,6} = 1086$; $T_{0,6} = 18$; 7) $K_{\Gamma,7} = 0{,}922$; $T_{1,7} = 536{,}125$; $T_{0,7} = 45{,}5$; 8) $K_{\Gamma,8} = 0{,}996$; $T_{1,8} = 729$; $T_{0,8} = 3$; 9) $K_{\Gamma,9} = 0{,}969$; $T_{1,9} = 543{,}125$; $T_{0,9} = 17{,}5$; 10) $K_{\Gamma,10} = 0{,}989$; $T_{1,10} = 729{,}75$; $T_{0,10} = 8$; 11) $K_{\Gamma,11} = 0{,}993$; $T_{1,11} = 728{,}415$; $T_{0,11} = 4{,}75$.

By calculating the average ratio of $\overline{K}_\Gamma$, $\overline{T}_1$ *and* $\overline{T}_0$ sums the result will be: Calculation for AC locomotives

$$\overline{K}_\Gamma = 0{,}965,\ \overline{T}_1 = 665{,}56(hour) \quad \overline{T}_0 = 17{,}52(hour) \qquad (13)$$

Calculation for DC locomotives

$$\overline{K}_\Gamma = 0{,}944,\ \overline{T}_1 = 803{,}71(hour), \quad \overline{T}_0 = 40{,}48(hour) \qquad (14)$$

Consequently, as it is seen from the report, the value of $\overline{T}_1$ sum in the average interval between rejections for ADY direct current locomotives, which is 140 hours longer than for AC locomotives, the availability ratio $\overline{K}_\Gamma$ is 2% and recovery time is 13 hours longer. As to the results of this report, alternating current locomotives are more reliable than direct current locomotives.

RESULT

Thanks to the research, the following results and recommendations were achieved:

1. As the services life of locomotive fleet of "Azerbaijan Railways" Closed Joint Stock Company is more than 30 years, operation and maintenance of new type 8-axis asynchronous electrical AC locomotives manufactured by Alstom company is an innovation in the history of Republic's railway and of a great economic importance, and labor required to carry out maintenance and repair works will be less, whereas the productivity will be higher.
2. Subject to the investigation hold in Bilajari locomotive depo, it was determined that the efficiency to be obtained from the operation of AC locomotives would be approximately 1156200 AZN within 5 years.
3. By increasing the average weight of trains from 2,500 tons to 4,500-6,000 tons, the volume of freight traffic at ADY will increase rapidly.
4. Maintenance and repair works for both electric and diesel locomotives will be possible in the new maintenance base supplied with modern diagnostic systems.
5. As to the theory of reliability, the semi-Markov model proved that the value of reliability indicators of new AC locomotives is higher than that of DC locomotives.
6. Using the proposed Loco tractor shunting machine, annual yield will be 77124 AZN.
7. Due to the fact that the load capacity of the proposed locomotives is two and three times higher than the load capacity of existing locomotives, the number of locomotives to be involved in the transport of goods on the corridors of the Azerbaijani railway, as well as the demand for drivers will decrease.

The list of articles reflecting dissertation materials

1. Aslanov C.G., Lokomotivlərin texniki vəziyyətinə müasir diaqnostik üsullardan istifadə etməklə nəzarətin təşkili //

Doktorantların və gənc tədqiqatçıların XVIII respublika elmi konfransının materialları "Mexanika və maşınqayırma bölməsi", – Bakı: – 19-20 dekabr, – 2013, – s. 228-230.
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