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Analysis and assessment of the reliability of rail elements

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Abstract. The article conducts a study and calculation of reliability indicators of rail elements of various types, taking into account structural diagrams that include series and parallel connection of elements. Taking into account the climatic characteristics of the Republic of Uzbekistan and taking into account the impact on various areas of the region, the article conducted a study of fastenings for various disturbing factors and ensuring trouble-free operation of system components. The goal of the work was to develop an algorithm for determining optimal parameters. As a result, an assessment of the distribution parameters was proposed taking into account the durability of the elements of the fastening unit. Analytical expressions were developed and a graph was presented.

1 Introduction

Many branches of railway transport are dealing with the key issues of extending the life cycle and ensuring the reliability of rail-to-rail adhesion elements. The introduction of modern methods for ensuring the safety of train traffic, namely weldless rail chains, makes it necessary not only to increase the reliability of the main elements of the track, but also to have an idea of the state of the upper structure of the continuous seamless rail track during short and long-term operations. In this case, there is a need for an in-depth study of the wear processes of a continuous-joint track, i.e. changes in the state of a continuous rail chain under the influence of climatic conditions, the weight of rolling stock, continuity of movement and shunting operations. Currently, the development of railway transport, namely rail roads, is carried out by laying seamless rail lines, that is, insulating joints are not used, as the study showed, at the moment there are a lot of such objects, while the construction was carried out under different conditions, for example, economic, climatic and operational, hence the assessment of changes occurring in sections of rail circuits, taking into account the qualitative and quantitative components [1].

The rapid development of technology in the CIS countries in all sectors of the national economy at the beginning of the 21st century affected all areas of activity, including the development of railway infrastructure [2]. It became possible to use advanced developments, including the laying of previously inaccessible Western European rail fastenings Vossloh, Pandrol, around the same time the first links with fastenings of Russian origin were laid -

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ARS and ZhBR fastenings. In the Republic of Belarus, the installation of SB-3 rail fastenings began. In the Republic of Kazakhstan, the emphasis was placed on the Vossloh W14 fastening unit system [3] All this time, countries did not abandon the Soviet TB (terminal-bolt) fastening system. But a new stage has already begun - a gradual transition to the use of fastenings with elastic terminals instead of the traditional TB fastening.

During the construction of continuous rail lines, in the main structure above the rails and on the main tracks of Uzbekistan Temir Yollari JSC, including in sections high-speed and high-speed trains, continuous rail lines are installed on reinforced concrete sleepers of the BFs70 type and using intermediate rail fastenings from the Pandrol Fastclip series. To press the base of the rail to the reinforced concrete sleepers, a fastening with an elastic rod clamp is used, which gives a tight press of the rails to the concrete sleeper. During high-speed and high-speed train traffic, it significantly holds the horseshoe on the concrete sleeper and protects it from asymmetrical movement, high loads and the influence of disturbing climatic factors [4]. The rules of technical operation and GOST provide for a requirement for the design of a continuous-joint track, which must provide a resistance of the rail fastening to the shear of the rails along the sleeper of at least 16.5 kN [5-8]. The regulatory documents in force at Uzbekistan Temir Yollari JSC do not regulate the minimum permissible force for pressing Pandrol Fastclip fastening terminals onto the base of the rails. OSJD recommendations [9, 10] provide rules for technical operation, which regulate the force requirements for pressing continuous rail lines to a concrete sleeper: “It is allowed (at positive rail temperatures) to weaken the pressing of rail bars to a concrete sleeper, but not more than 30% and at When the target value is achieved, it is necessary to restore the initial pressure of the rail to the concrete railway sleeper before the onset of cold weather.” But the instructions do not and do not contain methods for monitoring and controlling the clamping force of the terminals for attaching the Pandrol Fastclip to the base of the rail sole. The article evaluates the reliability of Pandrol Fastclip rail fastenings [11].

2 Main part. Analysis and reliability

For seamless rail circuits, elements connected in series are used, where the fastening unit is considered to be rail track elements that do not have duplicate elements. Therefore, even the failure of any one element greatly reduces the efficiency of fastening units and causes intense degradation and wear of adjacent parts, leading to an increase in track maintenance costs. The derived analytical expression gives the probability of failure-free operation of a node of such a system and is determined by the given formula:

$$P_o(t_i; t_y) = \prod_{y=1}^{n} P_{y+n}(t_i) + \prod_{i=1}^{n} P_{i+n}(t_y) \quad (1)$$

where

$P_y(t_i; t_y)$ is probability of free-failure operation of the i-th element at the moment of load and time change t_i.

$P_{i+n}(t_y)$ is probability of free-failure operation of the y-element at the moment of load and time change t_y

Based on the obtained analytical expressions, we apply the probability of not-failure operation of parallel-connected rail elements of the circuit, which are determined by:

$$P_o(t_i;\ t_y) = \frac{\left\{1+\left[2-\prod_{y=1}^{n} P_y(t_i)\right]^2\right\} * \left\{1+\left[2-\prod_{i=1}^{n} P_i(t_y)\right]^2\right\}}{\left(1+\left[2-\prod_{y=1}^{n} P_y(t_i)\right]^2\right)+\left(1+\left[2-\prod_{i=1}^{n} P_i(t_y)\right]^2\right)} \quad (2)$$

According to the studies carried out and based on data on failures of rail elements, sleeper fastenings are distributed according to the principle:

1) data is determined for the service interval of rail elements, and the number of failed rail track elements is grouped in order of increasing weight of trains passed through;

2) for each y and i-th operating interval, the failure rate of the y and i-th element $R_{\mathrm{y}}(t_i)$, $(R_i(t_{\mathrm{y}}))$ is calculated on an accrual basis;

3) according to the frequency $R_{\mathrm{y}}(t_i)$, $(R_i(t_{\mathrm{y}}))$, the value of the y and i-th element of the fastening unit $F_{\mathrm{y}}(t_i)$ is determined by the formula:

$$F(t) = \frac{R_{\mathrm{y}}(t_i)(R_i(t_{\mathrm{y}}))}{n} \quad (3)$$

4) the quantile U_p is found by frequency $F(t)$ using tabulated values of the Laplace functions.

Table 1 - Data on failures of elements of the Pandrol Fastclip fastening unit

Node element	Operating time t, mln.t gross	Frequency $R(t_{n+1})$, pcs/km	Probability of failure $F_j(t_i) = \frac{R_{\mathrm{y}}(t_i)(R_i(t_{\mathrm{y}}))}{n}$	Probability of failure-free operation $P(t_i) = 1 - F(t)$	Quantile U_p
cleat	100	1,2	0,0001	0,9998	3,5
	250	3,6	0,0005	0,9995	3,2
	400	4,9	0,0007	0,9993	3,19
Clamp insulators	100	4,8	0,00069	0,99931	3,196
	250	17,9	0,0026	0,9974	2,8
	400	24,7	0,0036	0,9966	2,7
Side insulators	100	0,1	0,000015	1,00005	4,2
	250	0,03	0,000044	1,00004	3,9
	400	0,4	0,000058	1,00003	3,8
Lining	100	0,9	0,000262	0,9997	3,4
	250	2,3	0,000670	0,9993	3,2
	400	3,4	0,001000	0,9990	3,0
Anker	100	0,1	0,000015	1,00005	4,2
	250	0,3	0,000044	1,00004	3,9
	400	0,7	0,000102	0,91	3,85

5) determination of the durability of the rail element of the sole fastening T_{mid} and σ_t are taken equal in order to evaluate the parameters of a clear distribution based on durability, therefore the least quadrant method in combination with the quantile method is operated and applied

6) The distribution parameters of the y-th element of the fastening unit T_{mid} and σ_t are determined and summarized in table 2

Calculation example (for Pandrol Fastclip):

A) for frequencies F(t), quantiles U_p are determined according to Appendix V and a system of R equations is compiled:

$$\begin{cases} T_{\text{cp}} + U_{P1}\sigma_t = t_1; \\ T_{\text{cp}} + U_{P2}\sigma_t = t_2; \\ \dots \\ T_{\text{cp}} + U_{Pr}\sigma_t = t_r \end{cases}$$

The resulting system of equations is solved using the least squares method, for which the left sides of each of the system equations are multiplied by $U_{P1}, U_{P2}, \dots, U_{Pr}$, respectively, and all R equations are added, resulting in the so-called first normal equation:

$$T_{mid} \sum_{i=1}^{r} U_{P_i} + \sigma_t \sum_{i=1}^{r} U_{P_i}^2 = \sum_{i=1}^{r} U_{P_i} t_i \quad (4)$$

$$T_{mid}12 - \sigma_t 35 = 3500$$

B) The resulting equations are solved with respect to the unknowns T_{mid} and σ_t, and thus their estimates are found.

$$T_{mid}12 - \sigma_t 35 = 3500$$

$$T_{mid}4 - \sigma_t 12 = 750$$

For the case under consideration, T_{mid}=2500 million tons, σ_t=800 million. T.

Table 2 - Parameters for the distribution of elements of the Pandrol Fastclip intermediate fastening unit

Fastening element	Parameters	
	T_{cp}	σ_t
Clamp	2600	700
Clamp insulators	1800	550
Side insulators	3500	830
Lining	2700	750
Anker	2800	600

7) To determine the integral function of the probability of failure-free operation of the i-th rail element of the fastening unit in the difference (0; t), the following expression is given:

$$P_y(t_i; t_y)P_i(t_y; t_i) = 1 - \left[F_o\left(\frac{T_{cp} - t_i}{\sigma_t}\right) + F_o\left(\frac{T_{cp}}{\sigma_t}\right)\right] \quad (5)$$

Where

$F_0(U_p)$ is the value of the tabulated Laplace function from the application The probability calculation is summarized in table 3

Table 3 - Determination of the number of fastener failures

Element node	Operating time t_i mln.t gross	Quantile $\frac{T_{mid}-t_i}{\sigma_t}$	$F_o(\frac{T_{mid}-t_i}{\sigma_t}$	Quantile $\frac{T_{mid}}{\sigma_t}$	$F_o(\frac{T_{mid}}{\sigma_t}$	Total probability of failure-free operation $P_j(t_i)P_i(t_j)$
Cleat	100	3,55	0,000193	3,70	0,000108	0,999700
	250	3,36	0,000390			0,999502
	400	3,13	0,000874			0,999018
Clamp insulators	100	3,17	0,000762	3,36	0,000390	0,998848
	250	2,89	0,001926			0,997684
	400	2,61	0,004527			0,995083
Side insulators	100	4,16	0,000016	4,29	0,000009	0,999975
	250	3,98	0,000034			0,999957
	400	3,80	0,000072			0,999919
Lining	100	3,45	0,000280	3,58	0,000172	0,999548

	250	3,25	0,000577			0,999251
	400	3,05	0,001144			0,998684
Anker	100	4,16	0,000016	4,32	0,000008	0,999976
	250	3,94	0,000041			0,999951
	400	3,70	0,000108			0,999884

8) depending on the weight of the trains, the probability of failure-free operation of the rail element fastening unit is determined. For this purpose, structural diagrams for analyzing the reliability of fastenings are drawn up. The blok-diagram is presented in Figure 1.

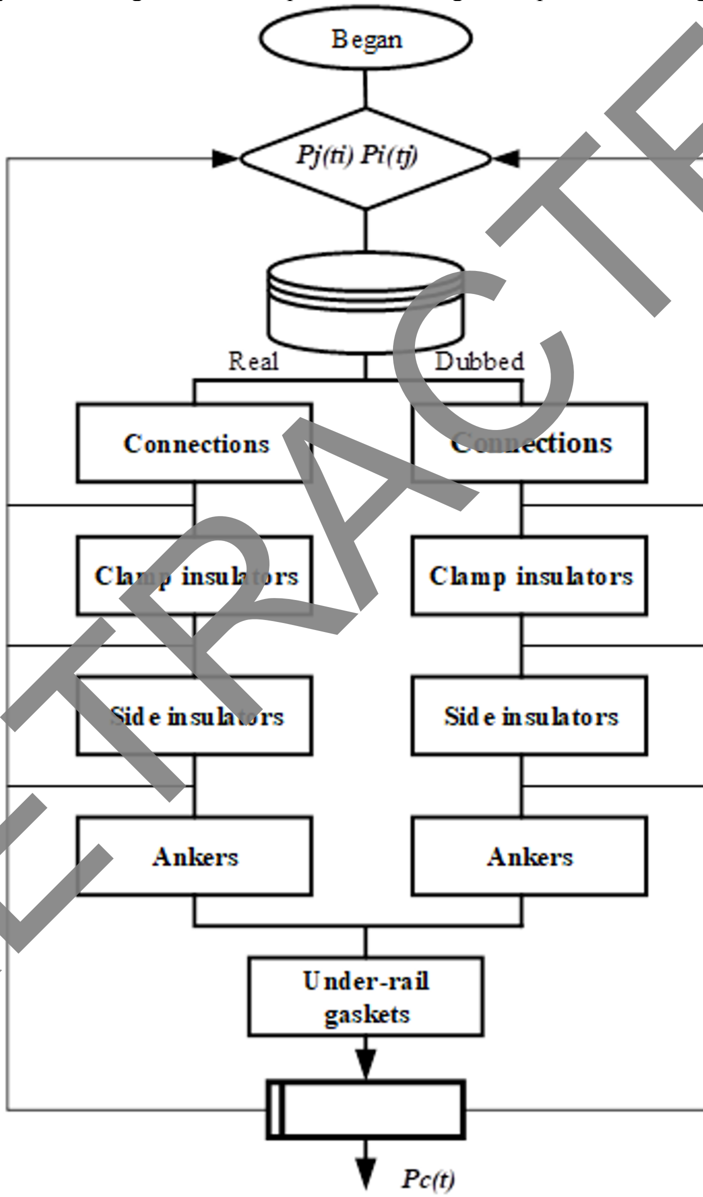


Fig. 1 - Block diagram of the Pandrol Fastclip fastening unit

At the Pandrol Fastclip fastener, if one of the terminals, the clamping and side insulators or the anchor fails, the operation of the assembly deteriorates. Therefore, in the logical reliability diagram, the circuits of these elements are considered duplicated. When drawing up a block diagram, the starting point is that a system of series-connected elements is operational if and only if all its elements are operational. With a parallel connection, system failure occurs when all parallel sections of the circuit fail.

3 Result and discussion

Taking into account the compliance of the structural diagram, the probability of failure-free operation of the fastening unit of the rail element of a continuous rail line is determined by the expression:

$$P_t = [1+ (2- \prod_{i=1}^{4} P_i P_y)^2]\, P_i P_y \tag{6}$$

During intensive operation and depending on the transportation of large loads, calculations are made and a graph of changes in the weight of the train is constructed to determine the probability of failure-free operation of the rail element fastening unit depending on the weight of the trains (Figure 2).

Using the resulting graph, additional criteria for a given class of track and the percentage of unusable rail elements are determined, the time for overhaul of a weldless rail line and replacement of the necessary rail elements is calculated. To do this, the value of the probability of failure-free operation of rail elements is displayed on the graph *P*y = (1-% of fasteners unsuitable for use).

Thus, the gross-net operating time is determined, at which it is necessary to carry out a partial revision of the fastening of the rail element assemblies with the replacement of all failed elements.

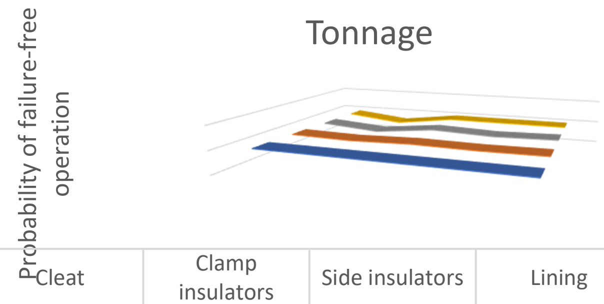
If the wear of the metal linings and under-rail rubber linings of the rail line is more than 15% in Pandrol Fastclip, we calculate the operating time of the fastening points of the rail elements that may fail, i.e., it is necessary to find ti at which $F(t) = 0.15$, respectively $P_i P_y = 1–F(t) = 0 .85$. Analyzing Table 1, we find the Pandrol Fastclip fastening elements with the highest failure rate: for example, clamping insulators. Then we find the quantile $U_{0,85} = 1.036$

For cleat T_{mid}=2615.7 million tons gross, σ_t =707 million tons gross:

$t_1 = T_{mid} - U_{0,85} \cdot \sigma = 2615,7 - 1,036 \cdot 706,66 = 1883,2 \approx 1883$ million tons gross.

For clamping insulators. T_{mid} = 1786.8 million. t gross, σ_t = 531.26 million. t gross: $t_2 = T_{mid} - U_{0,80} \cdot \sigma = 1786,8 - 1,036 \cdot 531,26 = 1236,4 \approx 1236$ million tons gross.

Thus, after passing 1000 million tons of gross cargo, it is necessary to carry out a partial revision of Pandrol Fastclip units with replacement of failed parts.



	Cleat	Clamp insulators	Side insulators	Lining	Anker
1	1	1	1	1	1
2	0.9998	0.9993	1.00005	0.9997	1
3	0.9995	0.9975	1.0003	0.99933	0.99995
4	0.9993	0.9965	0.99994	0.9999	0.9999

Fig. 2. Failure-free operation chart for Pandrol Fastclip fasteners The measurement results showed that the values of the pressing forces of the Pandrol Fastclip intermediate rail fastening terminals are within the normalized range established for these fastenings.

An assessment was made of the condition of the fastenings with the diagnostic tool DS-F01 of the "breathing" ends of the string of the investigated section of the continuous track, located within PC 14+651 – PC 16+716. Based on the results of assessing the condition of the fastenings with the diagnostic tool DS-F01, a graph was constructed, shown in Figure 2. The assessment results show that after missing tonnage for the study In the section of the continuous track, the pressing force of the Pandrol Fastclip fastener terminals decreased by 3% compared to the standard pressing force of the fastening cleat.

4 Conclusion

When calculating the reliability assessment of rail elements of various types of rail lines, structural diagrams were considered, including serial and parallel connections of elements. The probability of fastening elements was calculated: terminals, clamping insulators, side insulators, anchors, under-rail pads. An algorithm was drawn up, a program was written, and a graph of failure-free operation of Pandrol Fastclip fastening elements was obtained. Recommendations were given that after handling 1000 million tons of gross cargo, it is necessary to carry out a partial revision of Pandrol Fastclip units with replacement of failed parts.

Based on the above, the following conclusions can be drawn. Analysis of the end (support) insulator designs and diagnostic tools can be used in all modifications of fasteners: Pandrol Fastclip FC, Pandrol Fastclip FCA, Pandrol Fastclip FE, Pandrol 350, Pandrol SFC, Pandrol 1520, etc.

Reliability assessment using the DS-F01 diagnostic tool to measure the pressing force of the Pandrol Fastclip fastening terminals on the rail base is operational and functional. The high accuracy of the obtained measurement results has been confirmed, comparable to measuring the pressing force of the terminals by various means. The consistency of results was 96%.

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