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Assessment of modern rolling stock pulling drive gear reliability

S V Bobrytskyi^{1,4}, O A Logvinenko¹, O O Anatskyi² and I M Yehorova³

¹ Department of Mechanics and Machine Design, Ukrainian State University of Railway Transport, 61050 Feierbakh Sq. 7, Kharkiv, Ukraine

² Department of Maintenance and repair of rolling stock, Ukrainian State University of Railway Transport, 61050 Feierbakh Sq. 7, Kharkiv, Ukraine

³ Department of Structural Mechanics and Hydraulics, Ukrainian State University of Railway Transport, 61050 Feierbakh Sq. 7, Kharkiv, Ukraine

⁴ Email: s.bobrytskyi@gmail.com

Abstract. This paper presents an issue of rolling stock pulling drive gear (PDG) reliability assessment in operation, considering the gear and pitch wheel wear. Among main damages attributive to gear and pitch wheel reject are cheeping of teeth, peeling, plastic deformation. It is noted that the PDG reliability assessment shall be reasonably carried out upon a significant probability of their fail-safe operation that is determined by the rolling contact fatigue resistance. The provided mathematical study design on the PDG reliability assessment of ER-2 electrical multiple train and the corresponding mathematical model $P_{H,}=f(\Delta_1, \Delta_2)$ is developed. The auxiliary curve is added to the reasonable selection of gear-pitch wheel pair. The provided materials allow to reasonably select gear-pitch wheel pairs obtaining the maximum pulling drive gear fail-safe operation probability values that result in the reliability increase. Recommendations on the further application of the suggested approach during repair of pulling drive gears of modern rolling stock are provided.

1. Introduction

The railway operation performance is required to be assured on the highest level and it is directly connected with the traction rolling stock (TRS) serviceability increase, the majority of which is operated during the limit-exceeding period [1, 2]. This implies the need of the issues on reliability and durability of main units and components to be solved. With regard to findings of the authors' analysis of the mentioned rolling stock components, it was found that the main design module of traction rolling stock that directly impacts the operation safety is the pulling drive and integrated pulling drive gear [3]. Provided that the study found that, the TRS is accounted for the significant share of rolling stock equipment damages [4]. For this purpose, the issue of TRS reliability increase shall become critical.

Among main damages attributive to gear and pitch wheel reject are cheeping of teeth, peeling, plastic deformation. Since the mentioned damages are connected with the contact stress and occur due to catching [5, 6], authors suggest an approach on the TRS reliability assessment that is based on the fail-safe operation probability value that shall be determined by the rolling contact fatigue resistance criteria as the probability that the contact stress σ_H shall not exceed the surface endurance $\sigma_{H\lim}$ [7]:



$$P_H = \text{Prob}(\sigma_H < \sigma_{H \text{ lim}}). \quad (1)$$

The paper investigates the reliability of rolling stock pulling drive gear in operation, considering the gear and pitch wheel wear, in contrast to the work [7], which considers the possibility of evaluating the reliability of general-purpose gears at the stage of their design.

2. The basic part

The object of paper is to described the suggested approach on rolling stock pulling drive gear (PDG) reliability assessment in operation, considering the gear and pitch wheel wear. The key milestones are as follows:

1) Depending on a wear degree of gears and pitch wheels [8] according to the source and described [9] mathematical model values of contact stress are determined:

$$\sigma_H = 638,249 + 492,59 \cdot \bar{\Delta}_1 + 309,257 \cdot \bar{\Delta}_2 - 162,23 \cdot \bar{\Delta}_1^2 + 498,881 \cdot \bar{\Delta}_2^2 - 829,412 \cdot \bar{\Delta}_1 \cdot \bar{\Delta}_2. \quad (2)$$

2) Depending on gear surface machining technique the variation coefficient of base wheel long-term endurance limit $v_{H \text{ lim}}^0$ is selected.

3) An average value of the base wheel long-term endurance limit $\bar{\sigma}_{H \text{ lim}}^{-0}$ is calculated:

$$\bar{\sigma}_{H \text{ lim}}^{-0} = \frac{a \cdot \bar{H} + b}{1 + u_p \cdot v_{H \text{ lim}}^0}, \quad (3)$$

where a, b – are coefficients that are selected depending on wheel machining technique, u_p – a quantile of standard normal distribution that depends on the probability of endurance limit to be determined survival.

4) An average value of contact stress limit is determined:

$$\bar{\sigma}_{H \text{ lim}} = \bar{\sigma}_{H \text{ lim}}^{-0} \cdot K_{HL} \prod_{i=1}^m K_i, \quad (4)$$

where K_{HL} – durability factory by contact stress; $\prod_{i=1}^m K_i$ – product of m coefficients that take into account an impact of lubrication, pitch wheel dimensions, roughness of teeth meeting surfaces, line velocity.

5) The load variation coefficient is calculated:

$$v_{H\Sigma} = \sqrt{v_A^2 + v_{H\beta}^2 + v_{HV}^2 + v_{H\alpha}^2}, \quad (5)$$

where v_A – the variation coefficient of external load ratio $\bar{K}_{e.l.}$:

$$v_A = \frac{(K_{e.l.\text{max}} - K_{e.l.\text{min}})}{3 \times (K_{e.l.\text{min}} + K_{e.l.\text{max}})}, \quad (6)$$

$v_{H\beta}^2$ – the variation coefficient of load concentration coefficient $\bar{K}_{H\beta}$:

$$v_{H\beta} = \frac{1}{9} \frac{\overline{K_{H\beta}^{-1}}}{\overline{K_{H\beta}}}, \tag{7}$$

v_{HV}^2 – the variation coefficient of dynamic load factor $\overline{K_{HV}}$:

$$v_{HV} = 0,17 \frac{\overline{K_{HV}^{-1}}}{\overline{K_{HV}}}, \tag{8}$$

$v_{H\alpha}^2$ – the variation coefficient of teeth load distribution factor $\overline{K_{H\alpha}}$.

6) The contact stress variation coefficient is calculated:

$$v_{\sigma H} = 0,5 \cdot v_{H\Sigma}. \tag{9}$$

7) The probability of fail-safe operation by rolling contact fatigue criteria p_H depending on the quantile value:

$$u_P = \frac{\overline{n_H} - 1}{\sqrt{\overline{n_H} \cdot v_{H \lim}^2 + v_{\sigma H}^2}}, \tag{10}$$

where $\overline{n_H}$ – the factor of safety by average loads:

$$\overline{n_H} = \frac{\overline{\sigma_H \lim}}{\overline{\sigma_H}}. \tag{11}$$

Further stages of suggested approach application and results of probability of fail-safe operation of ER-2 electrical multiple train with different pitch wheel wear degrees obtained using the mathematical design of experiment are provided [10].

Initially, based on the orthogonal mathematical design for two variables varying on five levels (design matrix) the corresponding mathematical design was developed. The mathematical design are given in table 1.

On the second stage, the mathematical relation (generic mathematical model (GMM) with the reference to the developed mathematical design was obtained:

$$p_H = 1 - 0,0328 \cdot \Delta_1 + 0,0326 \cdot \Delta_2 - 0,00079 \cdot \Delta_1 \cdot \Delta_1 - 0,037 \cdot \Delta_2 \cdot \Delta_2 + 0,0349 \cdot \Delta_1 \cdot \Delta_2. \tag{12}$$

That describes the change of main index (TRS Fail-safe operation probability p_H) depending on varying of controlled variables (gear wear Δ_1 and pitch wheel wear Δ_2) and σ_H and p_H values were calculated for each design mode

The mathematical model accuracy test that was carried out by adequacy dispersion value proved its operability and possible further application.

On the third stage the auxiliary curve (binary section) indicating isolines of EP-2 electrical multiple train TRS fail-safe operation probability index, the value of which depends on gear and pitch wheel wear values was plot using the GMM. The auxiliary curve for determination of pulling drive gear fail-safe operation probability p_H is presented in figure 1.

Table 1. Mathematical study design.

Design Matrix Experiment Number	x_1	x_2	Gear wear, Δ_1 , mm	Pitch wheel wear, Δ_2 , mm	Contact stress, σ_H , MPa	Fail-safe operation probability, p_H
1	1	1	1,77975	2,772	923,4014244	0.935758
2	1	-1	1,77975	0,924	845,3400844	0.98298
3	-1	1	0,59325	2,772	943,1457294	0.914702
4	-1	-1	0,59325	0,924	763,4814194	0.997106
5	0	0	1,1865	1,848	858,5322275	0.978179
6	2	0	2,373	1,848	869,7162325	0.973271
7	-2	0	0	1,848	807,6018725	0.992095
8	0	2	1,1865	3,696	1048,507975	0.72044
9	0	-2	1,1865	0	790,782325	0.994534
10	2	2	2,373	3,696	958,08901	0.895697
11	2	-2	2,373	0	903,5693	0.952673
12	-2	2	0	3,696	1099,18059	0.584927
13	-2	-2	0	0	638,249	0.999914

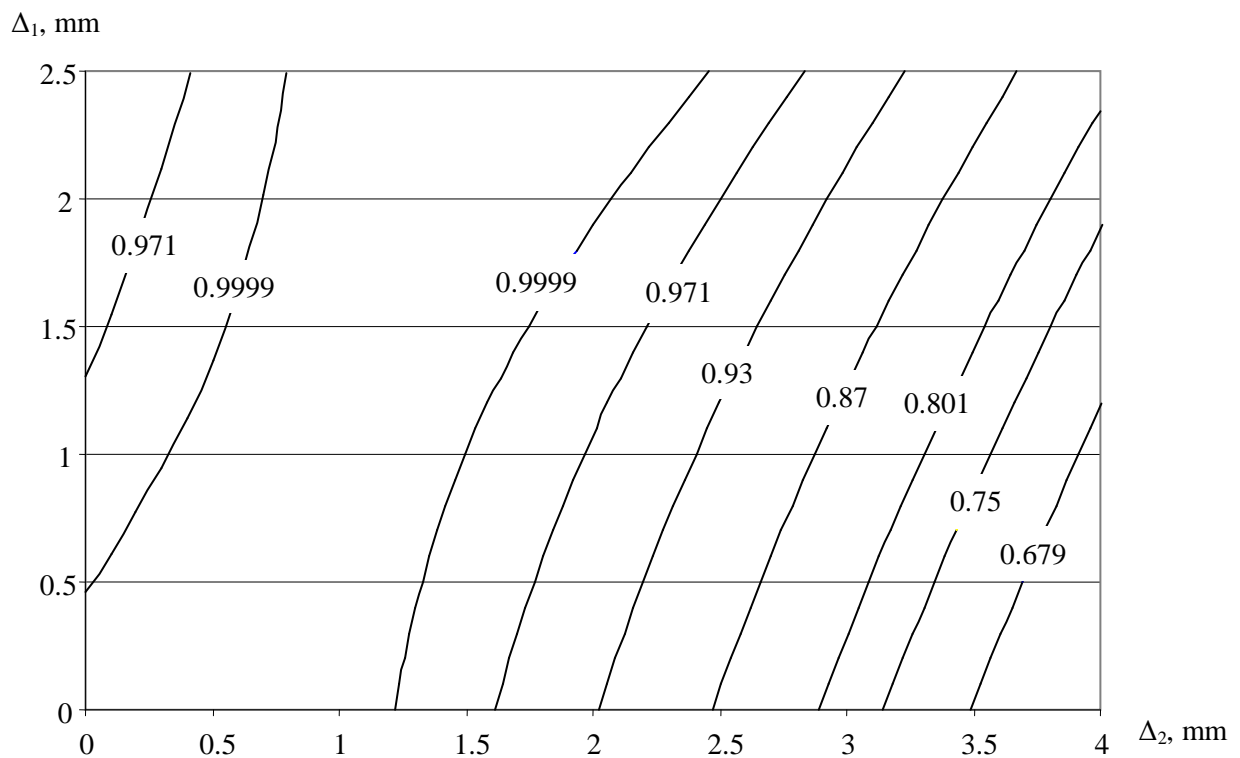


Figure 1. Auxiliary curve for determination of pulling drive gear fail-safe operation probability p_H .

3. Conclusions

The provided materials allow to reasonably select gear-pitch wheel pairs obtaining the maximum pulling drive gear fail-safe operation probability values that result in the reliability increase. Provided that the suggested approach is reasonable to use in roundhouse servicing.

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