

## Assessment of Innovative Methods of the Rolling Stock Brake System Efficiency Increasing

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**This paper deals with problem of brake elements unstable operation caused by temperature increase in the friction pair contact during braking. Analysis of constructive solutions for heat dissipation from the brake elements is carried out. It is known that the most used design of ventilated brake disks has disadvantage of creating resistance to movement, which reduces the power of the train. Methods and technical solutions for improving the braking system efficiency by stabilizing the friction contact temperature are investigated. Technical solution dealing with heat removing from the friction surfaces was proposed. Materials with phase transition is used in the design of the braking elements. The expert evaluation system software module in Microsoft Excel was developed to calculate the significance of methods for stabilizing temperature in the friction contact. The expert evaluation results of innovative methods for modern rolling stock brake systems efficiency increase are presented.**

**Keywords:** Brake systems, Temperature of Friction Contact, Stabilization, Expert Evaluations Method

### 1 Introduction

Security of the vehicle strongly depends on stable operation of the braking system. The temperature in the friction elements contact has a significant effect on braking efficiency. Temperature in the contact zone considerably increases during operation of brake elements. In case of prolonged braking, this occurs wear increasing and early crack forming. The tests carried out in laboratory conditions by using the friction machine and the test bench [4, 5, 6, 7, 9] showed that the initial contact temperature rise results in increasing of the friction coefficient. The critical temperature depends on the contacting bodies' materials and structure, the environmental air temperature and other factors. When it is reached, a severe decrease of friction coefficient occurs. This adversely affects braking properties of the rolling stock. The designers and operators face the challenge of developing new construction of brake elements that will allow controlling the temperature in the contact, keeping the optimum friction coefficient and providing higher wear resistance of friction surfaces.

### 2 Analysis of the friction elements temperature stabilization methods

One of the factors which significantly affects safety of railway vehicles operations is the interaction of elements in the brake system, which ensures the braking process implementation reliability. In rail transport, a significant part of the accidents is caused by the structural defects of the rolling stock, occurred as a result of problems with its brake equipment. Nowadays, the most common construction to ensure stable operation of brake elements are using ventilated discs. The main advantage of this design is that disc cooling surface works when braking up to certain speed. But the significant disadvantage is that train movement resistance is increased because of ventilation

effect also when discs does not need to be cooled. According to the preliminary calculations and studies [11] dealing with disc brake resistance, the train power may be reduced by 2.3 – 4.2 % depending on the speed and length of the rolling stock as well as by number of disks situated on the wheelset. Therefore in case of use such disk brake structure, it may be helpful to use construction elements to prevent the air flow in the brake discs ventilation channels when vehicle running.

In operational practices as well as in scientific research works of leading scientists dealing with new construction of brake elements, ways for cooling and friction contact temperature stabilizing this options are investigated:

- forced air flow supply in the friction elements contact [5, 10];
- forced air supply, the temperature of which is regulated depending on conditions and modes of operation;
- using of pads with porophore inserts with forced air supply, the temperature of air is regulated [12];
- using of pads with cooling ribs [14];
- application of brake pads with outer surface covered with heat dissipating material;
- supply of friction activators in the friction elements contact zone.

To stabilize temperature in the contact, authors propose to use progressive braking shoe. Outer surface of them contains channels filled with phase transition material. When the pads are heated up to the critical temperature the phase transition material changes its state from solid to liquid. Thereby cooling of the pads is provided and braking force realization reserve is increased.

### 3 The expert evaluation

Brake equipment is a complex technical system. The quality of its work is determined by criteria such a functionality [4, 5], reliability, cost, energy, resources, time, technical, social, environmental, etc. Creating the braking elements is a multi-criterial, statistical, non-deterministic decision task. It is necessary to choose from among of perspective constructive variants, the most applicable one. The decision-making theory is in general used to select the best option (alternative) from all possible, with respect to given optimality criterion in conditions of some uncertainty that requires the specification of the situation, resulting to new formulations of the decision-making problem as well as to the variety and solution methods improvement. The expert evaluations method was used for issues analysis shown in this paper.

Especially useful is using information obtained from experts because of its completeness, consolidation and analyticity. Special logical and mathematical methods of processing results based on system expertise are used. This allows drawing conclusions about experts' practical results survey usefulness in real dispersion with relative error values from 1% to 20% and accuracy from 60% to 95% [1, 15]. This method is the most effective one and allows to get adequate results.

### 4 Results of the research

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Expert evaluation method allows operate with insufficiently formalized and structured tasks, which don't have clearly defined algorithms, properties, and relations. Usage simplicity of the expert evaluations method as well as its flexibility and ability to obtain the necessary information are essential qualities, why this method was used for options evaluation in brake system improvement by stabilizing the temperature in contact. The group of experts include scientist, engineering-technical workers

from universities, depots, as well as manufacturers dealing with rolling stock elements production. Evaluation factors of innovative methods for increase rolling stock brake systems efficiency are following:

- security;
- stable friction characteristics (friction coefficient according temperature);
- wear resistance;
- braking noise level;
- cost of construction and operation;
- environmental factor.

#### Problem statement of expert evaluation are:

1. The object of study is the braking system.
2. The number of options offered to the experts is  $n$ .
3. In the assessment of the options  $m$  experts are involved.
4. Each expert has his own rank, which is determined by the level of competence and sources of argument evaluation.
5. Each expert makes a qualitative assessment of the proposed options.
6. All options for improvements to the brake elements should be distributed according their importance.

#### Innovative methods for modern brake systems efficiency increase are the following:

IM1 – forced air flow supply in the friction elements contact;

IM2 – forced air supply, the temperature of which is regulated depending on conditions and modes of operation;

IM3 – using pads with porophore inserts;

IM4 – using pads with cooling ribs;

IM5 – application of brake pads with outer surface covered with heat dissipating material;

IM6 – friction activators supply to the friction elements contact zone;

IM7 – application of brake elements with phase transition inserts in their construction features.

Examination results processing procedure is based on the following algorithm. The first stage in pre - examination results processing is verbal variables translation into quantitative assessment and expert opinions conformity degree determination, i.e. the Spearman method correlation rank calculation [16].

Obligatory condition for application rank correlation methods for ranked data is that number of ranks must be equal to number of study methods. This means the sum of ranks number must be equal to

$$\sum_{i=1}^n x_i = \frac{1}{2} n(n+1). \quad (1)$$

At the second stage the experts' evaluation is conducted. Subsequently, at third stage, the processing of experts' evaluation results is implemented. The software module in Microsoft Excel was developed for this purpose (Fig. 1).

Evaluation of innovative methods of modern rolling stock brake systems efficiency increase														
<b>Input values:</b>														
1 Number of experts					m= 11									
2 Number of methods					n= 7									
Methods	Expert											Output parameters		
	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	$\sum X_{im}$	Rank	Si
IM1	5	6	5	5	4	5	6	4	5	5	4	54	0,15	100
IM2	7	7	6	6	6	6	7	7	7	6	7	73	0,21	841
IM3	4	4	4	4	4	5	5	4	4	5	4	47	0,13	9
IM4	3	3	4	3	3	2	3	4	3	4	3	35	0,10	81
IM5	4	5	3	5	4	5	4	6	4	3	4	47	0,13	9
IM6	2	4	3	2	3	4	4	3	3	4	4	36	0,10	64
IM7	5	5	6	6	6	5	5	6	6	5	6	61	0,17	289
												353	1,00	
<b>Output values:</b>														
Sum of squares of differences (deviations)					S= 1393									
The concordance coefficient					W= 0,41									
The criterion $\chi^2$					$\chi^2 = 27,14$									

**Fig. 1** Software module "Evaluation of innovative methods of modern rolling stock brake systems efficiency increase" window

According to each of the  $j$  experts ( $j = 1-m$ ) evaluation, certain method  $i$  ( $i = 1-n$ ) has the influence of different degree to the object of study. Regarding the degree of influence determined by the expert, the ranking of methods  $x_{ji}$  is conducted.

In this case, consistency of expert opinion is determined using the coefficient of concordance  $W$ , which is the total of the rank correlation coefficient for a group of  $m$  experts. To calculate the concordance coefficient values, first sum of the scores (grades) for each method given by all experts is found:

$$Z = \sum_{ij=1}^m x_{ij}. \quad (2)$$

Subsequently, the sum of differences (deviations) squares is calculated by the formula:

$$S = \sum_{i=1}^n \left\{ Z - \frac{1}{2} m(n+1) \right\}^2. \quad (3)$$

Evidently, the value of  $S$  has a maximum value in case when all experts give the same assessments.

The concordance coefficient is usually obtained by the formula proposed by Kendall [8, 13]:

$$W = \frac{12S}{m^2(n^2 - n)}; \quad (4)$$

where  $m$  is experts' quantity and  $n$  is methods quantity. This coefficient can vary from 0 to 1. If  $W$  is equal to one, it means all experts gave the same evaluations to the particular method. When it is equal to zero, it means relations between the evaluations obtained from various experts are absent.

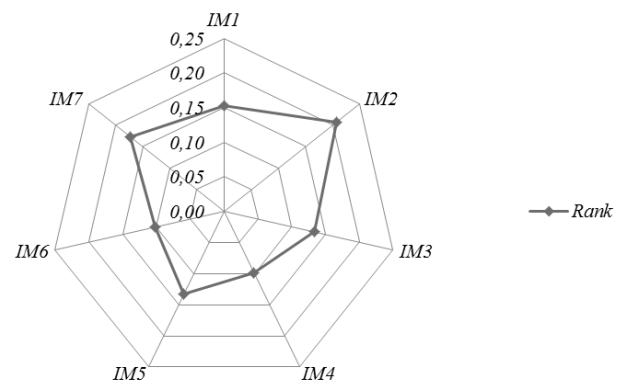
To assess the significance of concordance coefficient  $W$  the  $\chi^2$  distribution with  $\vartheta = n - 1$  degrees of freedom is used:

$$\chi^2 = Wm(n-1). \quad (5)$$

In order to make sure that no reduction of methods is

random, the  $\chi^2$  criterion should be applied. It tests the hypothesis of unequal distribution of methods against the alternative hypothesis of their equal distribution [3]. In our case  $\chi_p^2 = 0.41 \cdot 11 \cdot (7 - 1) = 27$  (see. Fig. 1). Expected criterion value is compared with tabulated values of the Pearson distribution. For the assumed degrees of freedom  $\nu = 7 - 1 = 6$  and significance level ( $\alpha = 0,05$ ) tabular value is  $\chi_m^2 = 12.59$ . As  $\chi_p^2 = 27 \geq \chi_m^2 = 12.59$ , the experts' opinions are considered to be agreed.

As soon convinced of the experts is consistent, we build a chart of ranks. Obtained rank diagram is shown in Fig. 2. The effectiveness of the proposed methods is evaluated by sum of grades: the large is sum of particular ranks method, the more efficient operating of brake system due stabilizing friction elements temperature can be obtain.



**Fig. 2** Ranking results of the innovative methods for modern rolling stock brake systems efficiency increase

## 5 Conclusion

As a result of an expert research, the evaluation of innovative methods for increase efficiency of brake systems for modern rolling stock was done. It is found out, that the most appropriate method for improving braking performance is the air flow supply with adjustable temperature depending on the braking and operation conditions. This method received the highest rank of 0.21. However,

other methods can be also considered appropriate, because differences in estimates are insignificant. According to the experts' opinions, the smallest effects to the temperature stabilization have pads with cooling ribs (the sum of the ranks is 0.1). But, this innovative solution will work effectively together with another methods, such as cold air flow supply. The ribbed surfaces will enhance cooling and improve airflow to the friction surface. Additional elements installation on the discs and pads for increasing airflow to the contact zone is also possible. According to ranking, use of pads with phase transition materials has significant impact. It allows remove heat from the contact instantly. Application of porophore inserts in the pads construction also allows cool the contact by formation of cooling gas during braking. Using heat-dissipating materials in the construction of brake systems is also progressive technical solution, which allows to create steadily outflow of heat from the friction surfaces. Supplying additional air flow to the heat-dissipating material allows to achieve higher temperature stabilization efficiency.

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