APPLICATION OF SELECTED FREQUENCY CHARACTERISTICS OF VIBRATION SIGNAL FOR THE EVALUATION OF THE BRAKING PROCESS FOR RAILWAY DISC BRAKE

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Summary

The article presents a new method for the evaluation of the braking process through analysis of the braking vibration during braking to stop with a permanent the analysis of temporal signals of vibration acceleration in the frequency domain. The problem of research assembled in the article was determined by estimating the braking process one value of the diagnostic parameter of the vibration signal generated by the disc braking level set during braking.

Keywords: railway disc brake, coefficient of friction, RMS parameter of vibration accelerations

ZASTOSOWANIE WYBRANYCH CHARAKTERYSTYK WIDMOWYCH SYGNAŁU DRGANIOWEGO DO OCENY PROCESU HAMOWANIA KOLEJOWEGO HAMULCA TARCZOWEGO

Streszczenie

Artykuł przedstawia autorską metodę oceny procesu hamowania poprzez analizę drgań układu hamulcowego w czasie hamowań zatrzymujących dokonując analizy czasowych sygnałów przyspieszeń drgań w dziedzinie częstotliwości. Problem badawczy podejmowany w artykule określony został poprzez ocenę procesu hamowania jedną wartością parametru diagnostycznego drgań generowanych przez układ hamulca tarczowego w czasie hamowania.

Słowa kluczowe: kolejowy hamulec tarczowy, współczynnik tarcia, amplituda skuteczna przyspieszeń drgań

1. INTRODUCTION

Because of numerous advantages in comparison to a traditional air block brake, disc brakes, are more and more often utilized in passenger carriages and other railway vehicles.

In rail vehicle, because of constantly rising ride speed and to obtain required braking distance, disc brakes are used as primary brake. Additionally, according to UIC 546, speed of passenger trains of over 160km/h triggers application of disc brake. Stable and constant - in the whole speed range- average coefficient of friction μ, with the value: μ=0,35 is a basic advantage of disc brake systems [5]. Few disadvantages of disc brake include a lack of possibility of controlling the condition of the friction set: brake and pad in the whole operation time. It is particularly observable in rail cars, where disc brakes are mounted on the axle of the axle set between the wheels (figure 1a)) [2]. To check the wear of friction pads and brake discs it is necessary to apply specialistic station e.g. inspection channel to carry out inspections, and to carry out replacement of friction parts in case they reach their terminal wear [6].

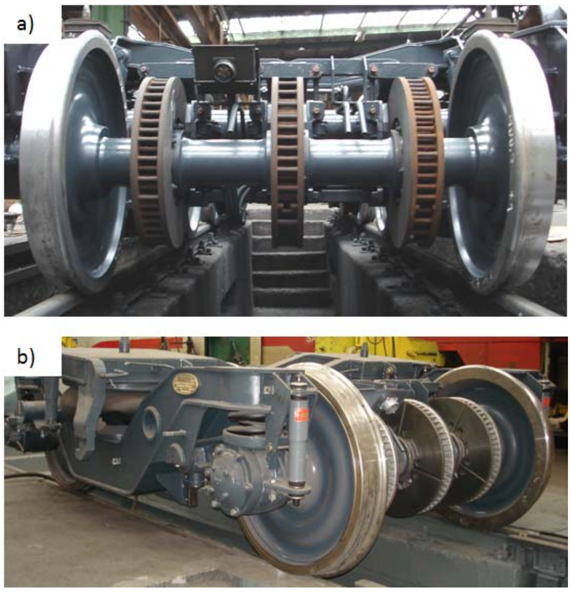

Fig. 1. View of passenger car with disc brake system: a) view of three brake discs mounted on axle passenger car) view of bogie 25AN

Selection of friction materials of type disk and pad directly affects the braking process. Work instability arises between the occurrence of vibrations on friction element, which affects the lower efficiency of the braking process. In practice, this means that, during braking the vehicles currently alternative at a time of friction resistance may cause uneven braking process.

In other works [12, 13], the possibility of the use of vibration diagnostics of the braking system. The effects of these changes in accordance with the work may be revealed in the form of a self-excited vibration. As a result, the growth of vibration friction pad causes changes in the activity of the temporary coefficient of friction during braking, as braking to stop and braking with the constant power. This will be presented in the next part of the article. Conversely, another issue of vibration braking systems presented was, among others, in the works [1, 14, 15].

The purpose of this research is to apply vibration signal of pad calipers to assess the braking process for railway disc brake, during braking.

2. METHODOLOGY AND RESEARCH OBJECT

The research was carried out at internal station for tests of railway brakes. A brake disc type 590×110 with ventilation vanes and three sets of pads type 175 FR20H.2 made by Frenoplast constitute the research object. One set was new - 35mm thick and two sets were worn to thickness of 25mm and 15mm. A reasearch program 2B1 (II) according to instructions of UIC 541-3 was applied.

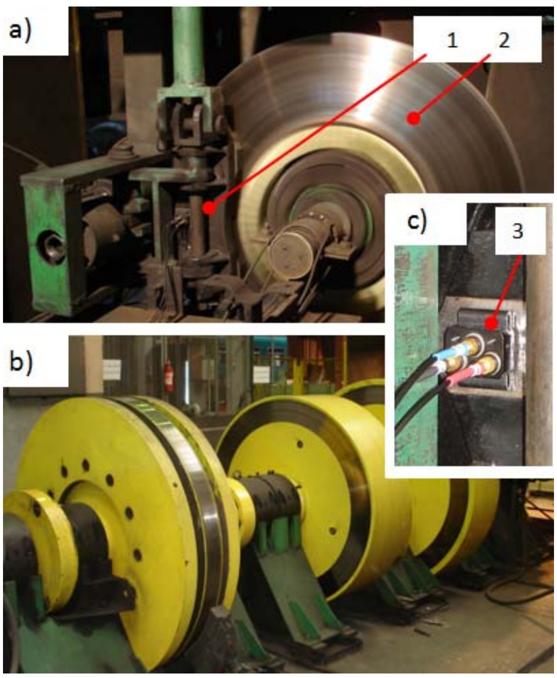

Fig. 2. Interial station for tests of railway brakes: a) view of level set of railway disc brake, b) view of masses using to brake simulated load to passenger car, c) accelerometer B&K 4504A; 1- calliper with brake pads, 2- disc brake type 590×110, 3- accelerometer

The braking was carried out from several of speed: 50, 80, 120, 160 and 200km/h. During the research pad's pressures to disc N of 25kN was realized as well as braking masses per one disc of M=5.7T and during braking to stop [8].

This research was carried out in accordance with principles of active experiment [3]. After carrying out a series of brakings the friction pads were changed and values of instantenuous vibration accelerations were registered.

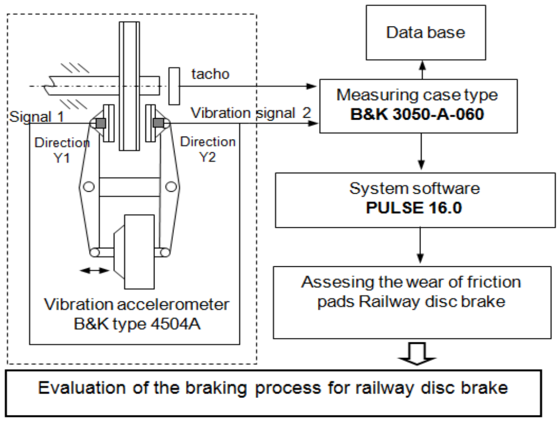

Fig. 3. Measurement set of vibrations generated by caliper with pads

Vibration converters were mounted on pad calipers with a mounting metal tile, which is presented in Fig. 2a and 2b. During the research signals of vibration accelerations were registered in three reciprocally orthogonal directions. To acquire vibration signal a measuring system consisting of piezoelectric vibration accelerations converter and measuring case type B&K 3050-A-060 with system software PULSE 16.0 was used. Fig. 3 presents the view of the measurement set.

3. RESEARCH RESULTS

The purpose of spectrum analysis of signals of vibration accelerations was to determine frequency bands connected with change of pad's thickness during operation of braking system..

Figure 4 show an exemplary signal of instantaneous values of vibration accelerations of caliper and pad registered in direction Y_1 (orthogonal to the disc) during station research.

To diagnose the wear of friction pads and evaluation of braking process of railway brake the following dimensional point parameter RMS amplitude, described with dependence (1):

$$A_{RMS} = \sqrt{\frac{1}{T}\int_0^T [s(t)]^2 \, dt} \qquad (1)$$

where:

T – average time [s],

$s(t)$ – instantaneous value of vibration accelerations, in [m/s^2].

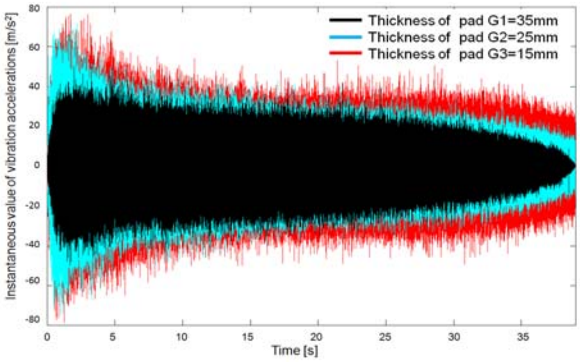

Fig. 4. Signal of vibration accelerations registered on pad caliper in direction Y_1 for different thickness of pads during braking to stop (Speed at beginning of braking v=120km/h)

Before calculating point parameters from signals of vibration accelerations in program Matlab 2012, a preliminary processing of signal in time domain was carried out. The reason of this processing was to select from the whole registered signal a part connected only with braking process. This process was also carried out to obtain required dynamics of changes essential for diagnostic purposes. Defining dependence of friction pad's thickness on selected point parameters was carried out through determining dynamics of changes for a certain parameter, which is presented in dependence (2) [3]:

$$D = 20\lg\left(\frac{A_2}{A_1}\right) \tag{2}$$

where:

- A_1 – the value of point parameter determined for pad G_3 or G_2, in [m/s^2],
- A_2 – the value of point parameter determined for pad G_1, in [m/s^2].

Table 1 Measurement results for braking to sop

Measurement of vibrations in direction $\mathbf{Y_1}$					
Frequency	Value of point parameters m/s^2			Dynamics of changes dB	
	Pad 35mm	Pad 25mm	Pad 15mm	G2/G1	G3/G1
Speed at the beginning of braking v=120km/h					
1950-2000	0,33	0,46	0,61	2,79	5,20
2450-2500	0,29	0,48	0,64	4,40	7,00
Speed at the beginning of braking v=160km/h					
1950-2000	0,39	0,59	0,88	3,69	7,08
2050-2100	0,46	0,75	0,89	4,33	5,81
2450-2500	0,38	0,54	0,99	3,05	8,34
Speed at the beginning of braking v=200km/h					
1950-2000	0,78	1,35	1,64	4,62	6,27
3400-3450	0,38	0,66	0,98	4,79	8,19
5050-5100	0,49	0,63	1,02	2,20	6,41
5300-5350	0,35	0,39	0,75	1,04	6,65

The analysis of results of vibration tests showed that obtaining dependence of friction pads' thickness on the value of point parameters is possible by measuring vibration in directions Y_1 and Y_2 on a accelerometer mounted from the side of brake cylinder's case and brake cylinder's piston rod.

During station research, dynamics of changes of analyzed values of RMS point parameter according to dependence (2) was defined, which is presented in table 1. On this basis it was found out that all value of point parameters of vibration accelerations shows good sensitivity towards change of pad's thickness at vibration measurement in directions Y_1.

The research conducted at internal station for tests of railway brakes showed that the wear of the friction pads, in addition to growth, the instantaneous values of the accelerations of vibrations, also reduce the value of the instantaneous and average coefficient of friction (dependence (3) and (4). The decrease in friction factor, especially when braking with high speed (over 160 km/h) may affect thermal processes and the phenomenon of formation of a layer of a „third" contact cover disk, obtained from products of wear friction pairs described in works [4, 5, 7].

$$\mu_a = \frac{F_t}{F_b} \tag{3}$$

$$\mu_m = \frac{1}{s_2}\int_0^{s_2} \mu \cdot ds \tag{4}$$

where:

- F_t – instantaneous force is tangent to the radius of the braking r,
- F_b – total instantaneous force of the pressure on brake disc,
- s_2 – road braking from speed v to stop,
- μ_a – instantaneous coefficient of friction,
- μ_m – average coefficient of friction.

Figure 5, 6 and 7 presents exemplary amplitude spectra of vibration accelerations for various pad's thicknesses received during braking to stop from speed at the beginning v=120, 160 and 200km/h. Spectrum received on measurement of vibrations in direction perpendicular to friction surface of the disc (direction Y). The figure 5, 6 and 7 presents exemplary amplitude spectra of vibration accelerations of the use of band-pass filter. Then for all the analyzed speed brake checked whether it is possible to find common frequency band in which there is a relationship linear RMS amplitude of this band from wear of the friction pads.The scope of the filter has been set to 1950-2000Hz, because in this area there is a dependency of amplitude of vibration accelerations on thickness of friction pads.

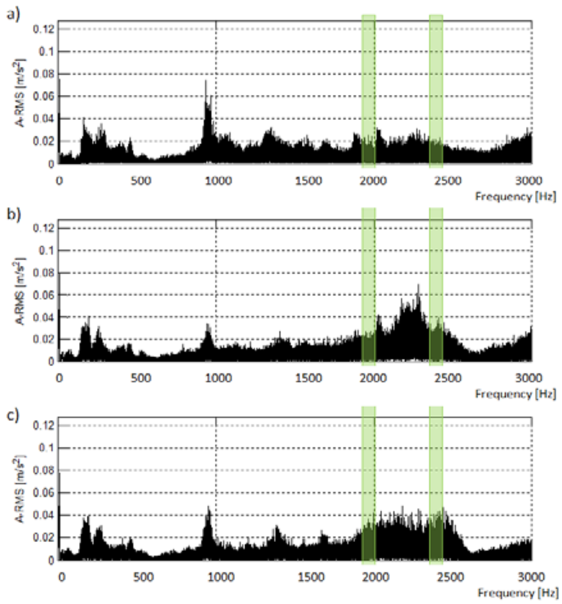

Fig. 5. Dependence of amplitude of vibration accelerations on frequencies for different pad's thicknesses during braking from speed of 120km/h in direction *Y1*: a) pad's thickness G1=35mm, b) pad's thickness G2=25mm, c) pad's thickness G3=15mm

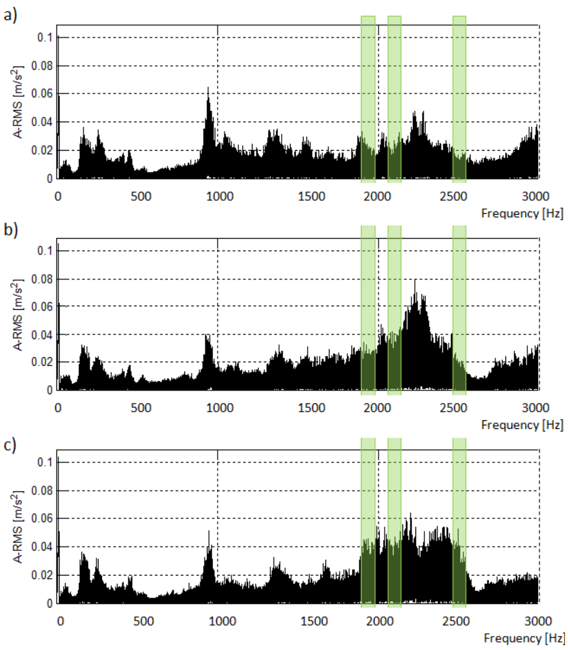

Fig. 6. Dependence of amplitude of vibration accelerations on frequencies for different pad's thicknesses during braking from speed of 160km/h in direction *Y1*: a) pad's thickness G1=35mm, b) pad's thickness G2=25mm, c) pad's thickness G3=15mm

Braking time to analyze in the field amplitudes was common for all brakings with new and wear friction pads. (one periods of time 39 seconds).

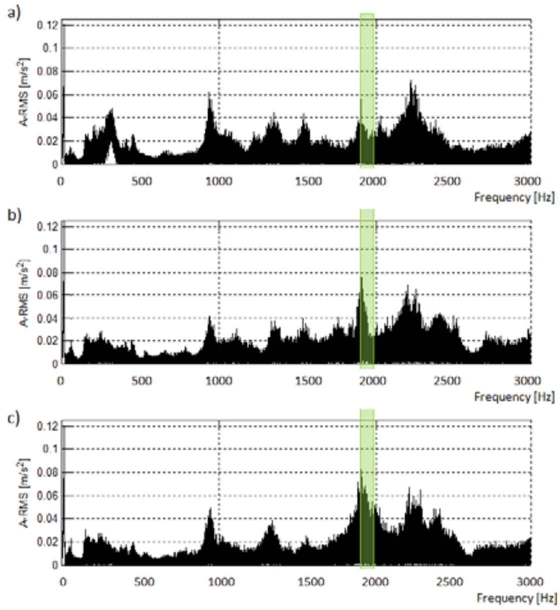

Fig. 7. Dependence of amplitude of vibration accelerations on frequencies for different pad's thicknesses during braking from speed of 200km/h in direction *Y1*: a) pad's thickness G1=35mm, b) pad's thickness G2=25mm, c) pad's thickness G3=15mm

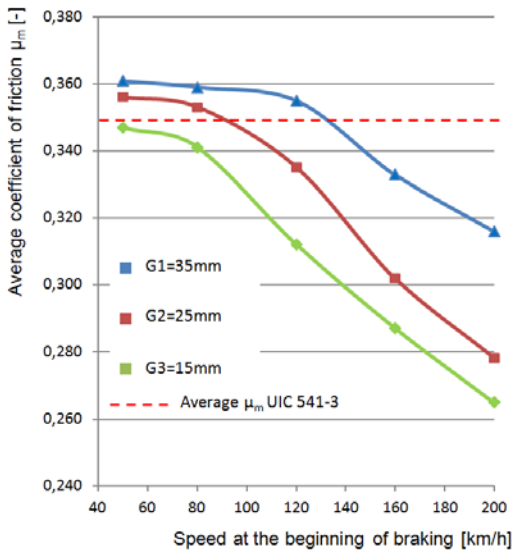

Fig. 8. Dependence average coefficient of friction of speed at the beginning of braking for three thickness of friction pads

Figure 8 present dependence average coefficient of friction of speed at the beginning of braking for three thickness of friction pads (speed at the beginning of brake v=50, 80, 120, 160 and 200km/h).

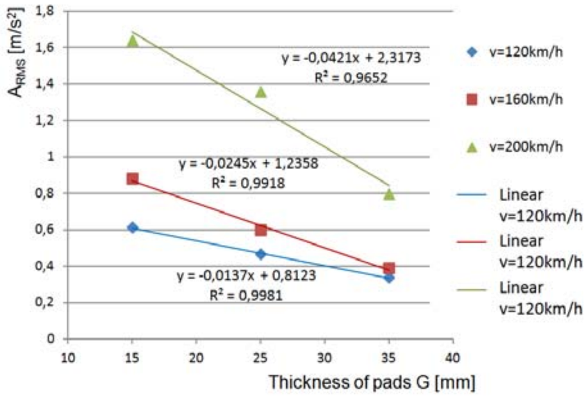

Fig. 9. Dependence of pad's thickness in function of point parameters (A_{RMS} value) of vibrations accelerations for measurement in the Y_1 direction for speed at the beginning of braking v=120, 160 and 200km/h

Figure 9 present dependence of RMS value form frequency band 1950-2000Hz of friction pad's thickness (wear or friction pads).

Figure 10 present dependence of friction pad's thickness of disc brake G on RMS value point parameter of vibration accelerations. For RMS value from selected frequency band, also obtained from measurement in direction Y_1 by using linear approximating functions described with dependences (8-10) for three speeds at the beginning of braking, the following equations defining friction pads' thickness were introduced:

$$G_{(v=120)} = -72{,}7 \cdot A_{RMS(v=120,\,1950-2000)} + 59{,}1 \qquad (8)$$

$$G_{(v=160)} = -40{,}4 \cdot A_{RMS(v=160,\,1950-2000)} + 50{,}2 \qquad (9)$$

$$G_{(v=200)} = -22{,}9 \cdot A_{RMS(v=200,\,1950-2000)} + 53{,}9 \qquad (10)$$

where:

G – thickness of pad [mm],
$A_{(..)}$ – point parameters RMS value of vibration accelerations [m/s^2].

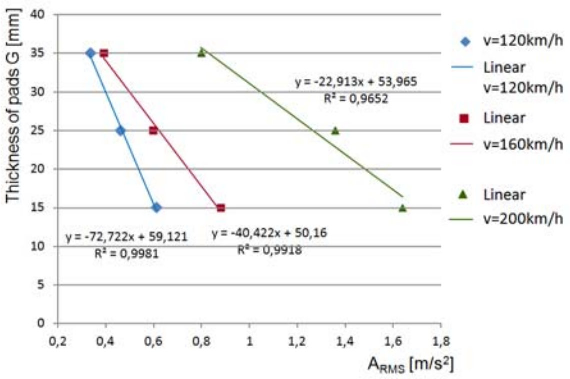

Fig. 10. Dependence of pad's thickness in function of point parameters (A_{RMS} value) of vibrations accelerations for measurement in the Y_1 direction for speed at the beginning of braking v=120, 160 and 200km/h

Figure 11 presents dependence of average coefficient of friction of thickness pad for three speed at the beginning of braking. In all case, using linear approximating functions.

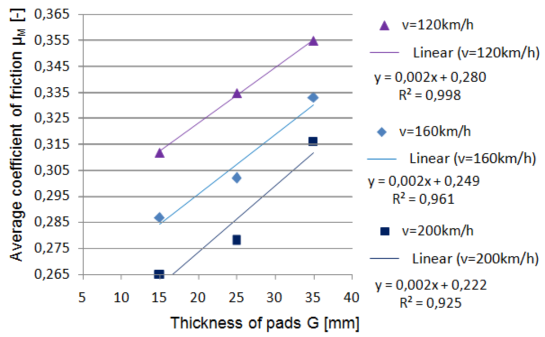

Fig. 11. Dependence of average coefficient of friction μ_m of thickness pads G for three speed at the beginning of braking v=120, 160 and 200km/h

Using approximating functions RMS value from frequency band 1950-2000Hz of wear friction pad and approximating function thickness of pads of average coefficient of friction, the following equations defining average coefficient of friction were introduced:

$$\mu_{m,(v=120)} = -0{,}153 \cdot A_{RMS\,(v=120,1950-2000)} + 0{,}404 \qquad (20)$$

$$\mu_{m,(v=160)} = -0{,}097 \cdot A_{RMS\,(v=160,1950-2000)} + 0{,}369 \qquad (21)$$

$$\mu_{m,(v=200)} = -0{,}059 \cdot A_{RMS\,(v=200,1950-2000)} + 0{,}362 \qquad (22)$$

where:

μ_m – average coefficient of friction [-],
$A_{(..)}$ – point parameters RMS value of vibration accelerations [m/s^2].

Table 2 Error in % in the application models in estimating linear regression average coefficient of friction for braking to stop using RMS value accelerations caliper with pads vibration from frequency band 1950-2000Hz

For point parameter A_{RMS}			
Speed at the beginning of braking [km/h]	For brake pad G_1= 35[mm]	For brake pad G_2=25 [mm]	For brake pad G_3=15 [mm]
v=120	0,7	0,5	0,4
v=160	0,5	2,9	1,2
v=200	0,3	1,4	0,1

The analysis of results of research in amplitude domain showed that on the basis of the analysed in this article point parameters it is possible to diagnose the wear of friction pads and next to evaluation of the braking process for railway disc brake. The dynamics of changes of RMS values of vibration accelerations for pads: G_1, G_2 and G_3 can be found in the range between 2,8 and 7dB for RMS for direction Y_1 measurement of vibrations on railway disc brake. Table 2 present error in % in the application models in estimating linear regression average coefficient of friction.

4. CONCLUSION

The reseach at internal station for tests of railway brakes showed that it is possible to diagnose the wear of friction pads and next to evaluation of the braking process for railway disc brake, by using analysis of the values of the vibration acceleration caliper by defining in frequency domain.

Analysis of caliper vibrations in frequency domain enables to diagnose the wear of friction pads in band: 1950-2000Hz during braking to stop. Research showned that the vibration accelerometer can be installed on both caliper pads of disc brake level set.

During verification of regression diagnostic models determined on the basis of point parameter RMS value of signals coming from pad caliper, differences in determining pads' thickness did not exceed 1% for all analysis point parameters for speed at the beginning of braking v=120km/h, did not exceed 3% for v=160km/h and 1,5% for v=200km/h. The combination of two types of dependence, first wear of friction pads values from point parameter RMS from frequency band 1950-2000Hz of accelerations of vibrations and a second average coefficient of friction of the thickness of brake pads (wear), allowed us to derive the dependence of the average friction coefficient values from point parameter for different speed at the beginning of braking. The reseach at internal station for tests of railway brakes showed it is difficult to determine a frequency band for low speed braking, so the change in the spectrum depending on wear.

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