EVALUATION OF THE WEAR OF FRICTION PADS RAILWAY DISC BRAKE USING SELECTED PONT PARAMETERS OF VIBRATIONS SIGNAL GENERATED BY THE DISC BRAKE

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Summary

The article presents a new method for diagnosis of the wear of friction pads through analysis of the braking vibration during braking with the constant braking power and during braking to stop by making the analysis of signals in the amplitude domain. At the time of research there are vibration acceleration generated by the caliper with brake pads during braking.

Keywords: railway disc brake, diagnostics of brake, amplitude characteristics

OCENA ZUŻYCIA OKŁADZIN CIERNYCH KOLEJOWEGO HAMULCA TARCZOWEGO NA PRZYKŁADZIE WYBRANYCH CHARAKTERYSTYK AMPLITUDOWYCH SYGNAŁU DRGANIOWEGO GENEROWANEGO PRZEZ HAMULEC

Streszczenie

Artykuł przedstawia autorską metodę diagnozowania zużycia okładzin ciernych poprzez analizę drgań układu hamulcowego na przykładzie hamowania na spadku jak i hamowania zatrzymującego, dokonując analizy sygnałów w dziedzinie amplitud. W czasie badań rejestrowano przyspieszenia drgań generowane przez obsady hamulcowe z okładzinami w czasie hamowania.

Słowa kluczowe: kolejowy hamulec tarczowy, diagnostyka hamulca, charakterystyki amplitudowe

1. INTRODUCTION

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. 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 [5]. 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 [8].

In rail technique, rail track stations are used to diagnose the wear of friction pad. At these stations friction set consisting of disc brake and friction pad is photograhed during train ride. However is not a very precise metho because, on the basis of registered pictures the thickness of frction pads of disc brake is only assessed. When pads' thickness amounts to approx. 10mm tram driver receives information that terminal acceptable wear of pads on a certain axle of axle set has been reached. Rail track stations to diagnose the wear of friction pads are used by German, British and French railways.

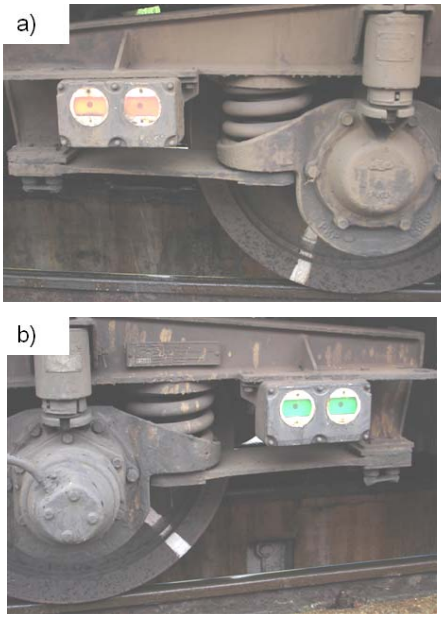

Fig. 1. System signaling braking process and easing process in passenger car typu Bmnopux:
a) brake turned on, b) excluded brake

In railway vehicles, systems signaling braking process and easing process, visible for the service from the inside and outside of the vehicle, are the most often applied (Fig. 1) [7]. Those systems enable to check during train ride in which car braking system is bloked. Nevertheless, rail technique lacks an objective method of quantitive assessment of the wear of friction pads [3].

The purpose of this research is to apply vibration signal of pad calipers to assess the wear of friction pads of 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.

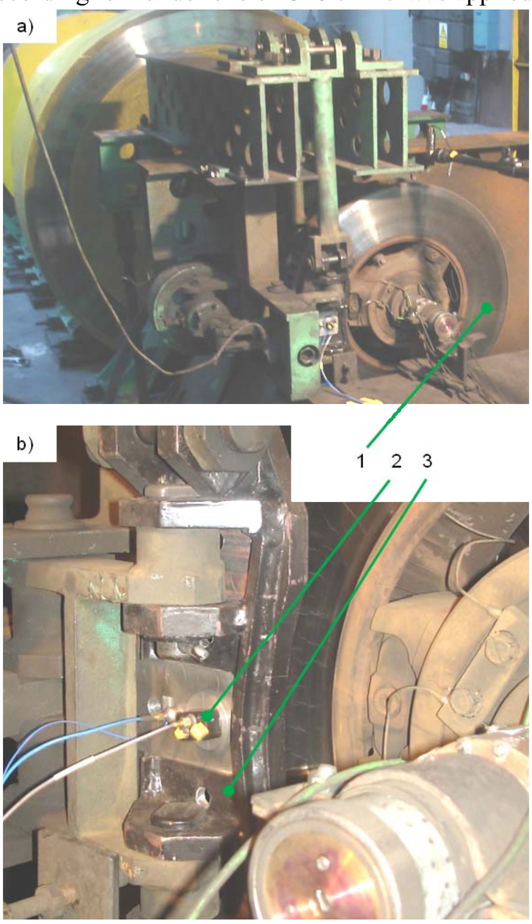

Fig. 2. Interial station for tests of railway brakes: a) view of level set of railway disc brake, b) pad caliper with accelerometer; 1- disc brake type 590×110, 2- accelerometer, 3- calliper with pad

The braking was carried out from speed of 80km/h and it was the braking with the constant braking power P=45kW. 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 [6].

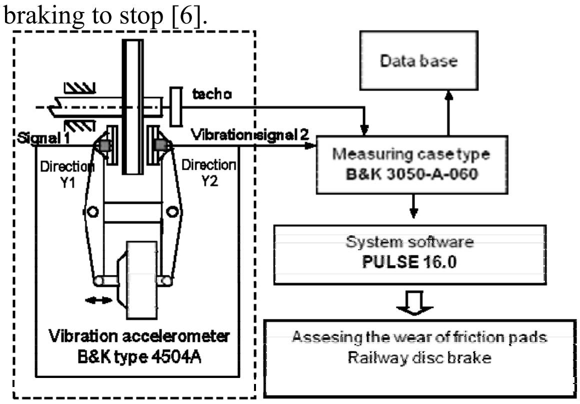

Fig. 3. Measurement set of vibrations generated by caliper with pads [

This research was carried out in accordance with principles of active experiment [4]. After carrying out a series of brakings the friction pads were changed and values of instantenuous vibration accelerations were registered.

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 [10]. 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 [1, 2].

3. RESEARCH RESULTS

In domain of amplitudes, the most common are the point parameters [9], which are used to describe displacement signals, speed signals and signals of vibration accelerations. Characterizing vibration signal with one number is an advantage of point parameters, thanks to which it is easy to define changes in vibroacoustic signal resulting from changes in technical condition of the tested object.

To diagnose the wear of friction pads of railway brake the following dimensional point parameters are applied:

1) RMS amplitude, described with dependence:

$$A_{RMS} = \sqrt{\frac{1}{T}\int_{0}^{T}[s(t)]^2\,dt} \qquad (1)$$

where:

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

2) average amplitude, described with dependence:

$$A_{AVERAGE} = \frac{1}{T}\int_{0}^{t}|s(t)|dt \qquad (2)$$

3) square amplitude, describe with dependence:

$$A_{SQUARE} = \left[\frac{1}{T} \int_0^T |s(t)|^{\frac{1}{2}} dt \right]^2 \qquad (3)$$

4) peak amplitude, described with equation:

$$A_{PEAK} = \left[\frac{1}{T} \int_0^T |s(t)|^{\infty} dt \right]^{\frac{1}{n}} \quad dla \quad n \to \infty \qquad (4)$$

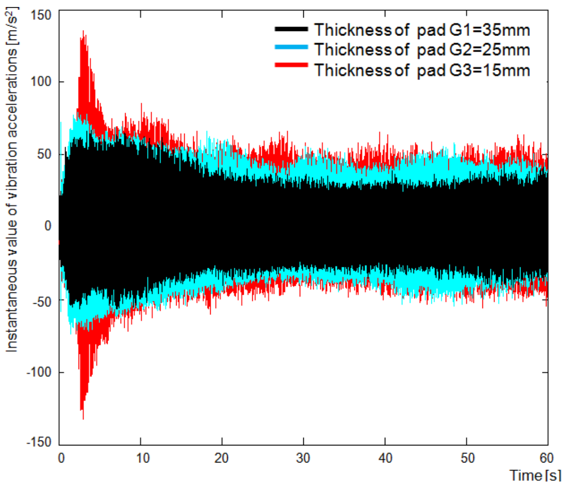

Fig. 4. Signal of vibration accelerations registered on pad caliper in direction Y_1 for different thickness of pads during braking with the constant braking power

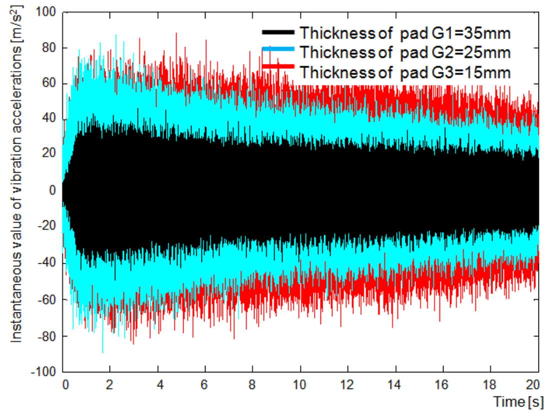

Fig. 5. Signal of vibration accelerations registered on pad caliper in direction Y_1 for different thickness of pads during braking to stop (Speed at beginning of braking v=80km/h)

Before calculating point parameters from signals of vibration accelerations in program Matlab 7.0, 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) [4]:

$$D = 20 \lg \left(\frac{A_2}{A_1} \right) \qquad (5)$$

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].

Figure 4 and 5 shows 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.

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.

Table 1 measurement results for braking with the constant braking power

Point parameter	Value of point parameters m/s^2			Dynamics of changes dB	
	Pad 35mm	Pad 25mm	Pad 15mm	G2/G1	G3/G1
Measurement of vibrations in direction $\mathbf{Y_1}$					
A_{RMS}	6,419	12,416	14,504	5,730	7,080
$A_{AVERAGE}$	5,108	9,904	11,535	5,750	7,075
A_{SQARE}	4,322	8,389	9,757	5,760	7,072
A_{PEAK}	33,51	63,167	91,584	5,505	8,732
Measurement of vibrations in direction $\mathbf{Y_2}$					
A_{RMS}	6,004	12,578	20,15	6,423	10,52
$A_{AVERAGE}$	4,775	10,029	16,017	6,445	10,51
A_{SQARE}	4,038	8,493	13,547	6,457	10,51
A_{PEAK}	31,46	67,758	106,88	6,662	10,62

Table 2 measurement results for braking to sop

Point parameter	Value of point parameters m/s^2			Dynamics of changes dB	
	Pad 35mm	Pad 25mm	Pad 15mm	G2/G1	G3/G1
Measurement of vibrations in direction $\mathbf{Y_1}$					
A_{RMS}	8,037	14,016	16,787	4,830	6,397
$A_{AVERAGE}$	6,312	10,989	13,328	4,815	6,491
A_{SQARE}	3,026	4,7861	5,8635	3,982	5,745
A_{PEAK}	49,17	89,949	88,270	5,244	5,080
Measurement of vibrations in direction $\mathbf{Y_2}$					
A_{RMS}	12,00	14,473	19,243	1,627	4,102
$A_{AVERAGE}$	9,424	11,310	15,160	1,584	4,129
A_{SQARE}	4,513	4,919	6,645	0,748	3,360
A_{PEAK}	74,23	92,107	129,56	1,874	4,838

During station research, dynamics of changes of analyzed values of selected point parameters according to dependence (5) was defined, which is presented in table 1 and table 2. 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 for braking to stop and direction Y_1 and Y_2 for braking with the constan braking power

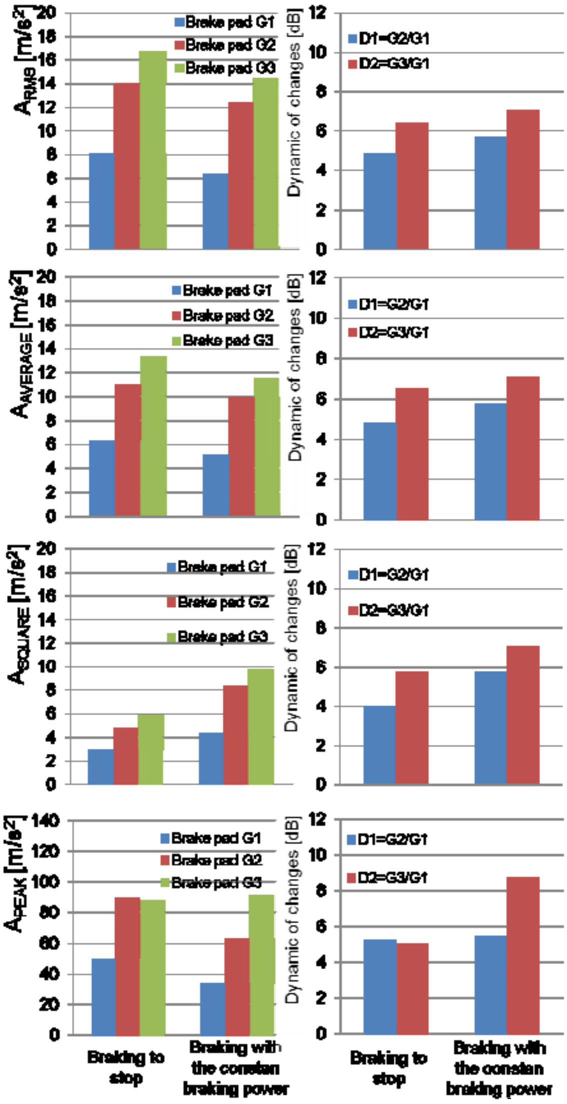

Fig. 6. Dependence value of selected point parameters and dynamic of changes vibration accelerations measurement in direction *Y1* for braking to stop and braking with the constant braking power

Figure 6 and 7 present dependence of (RMS) value, average value, square value and peak value of vibration accelerations measure in direction Y_1, Y_2 on time brakings during braking with constant power *P* and braking to stop for various values of pad wear *G* with v=80km/h.

Braking time to analyze in the field amplitudes is divided into 8 periods of time every 20 seconds to the total time of analysis t = 160s. The analysis in the field amplitudes in further braking times, does not affect the improvement of diagnostic parameter.

During station research, dynamics of changes of analyzed values of selected point parameters according to dependence (5) was defined, which is presented in table 1 and 2. Selected point paramiters were designated with the first 20 seconds for both types of braking successively applying.

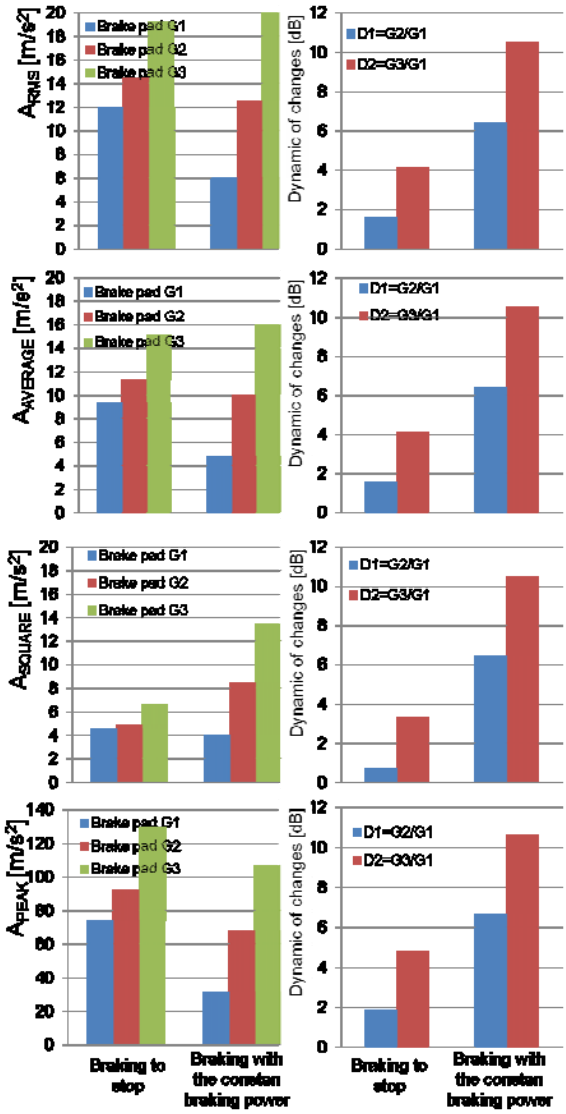

Fig. 7. Dependence value of selected point parameters and dynamic of changes vibration accelerations measurement in direction *Y2* for braking to stop and braking with the constant braking power

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 for braking to stop and Y_1 and Y_2 for braking with the constant braking power.

Figures 8 to 11 presents dependence of friction pad's thickness of disc brake *G* on selected point parameters of vibration accelerations. For RMS, Average, Square and Peak value of point parameter, also obtained from measurement in direction Y_1, Y_2 by using linear approximating functions described with dependences (6-13) for speeds at the beginning of braking v=80km/h, the following equations defining friction pads' thickness were introduced:

$$G = -2{,}1877 \cdot A_{RMS\,(Y1,\,BS)} + 53{,}32 \qquad (6)$$

$$G = -2{,}2948 \cdot A_{RMS\,(Y1,\,BP)} + 50{,}5 \qquad (7)$$

$$G = -2{,}7492 \cdot A_{AVERAGE\,(Y1,\,BS)} + 53{,}07 \qquad (8)$$

$$G = -2{,}8793 \cdot A_{AVERAGE\,(Y1,\,BP)} + 50{,}48 \qquad (9)$$

$$G = -6{,}915 \cdot A_{SQUARE\,(Y1,\,BS)} + 56{,}52 \qquad (10)$$

$$G = -3{,}4003 \cdot A_{SQUARE\,(Y1,\,BP)} + 50{,}47 \qquad (11)$$

$$G = -0{,}3469 \cdot A_{PEAK\,(Y2,\,BS)} + 59{,}22 \qquad (12)$$

$$G = -0{,}2651 \cdot A_{PEAK\,(Y2,\,BP)} + 43{,}21 \qquad (13)$$

where:

- G – thickness of pad [mm],
- $A_{(..)}$ – point parameters of vibration accelerations [m/s^2],
- BS – braking to stop,
- BP – braking with constant braking power.

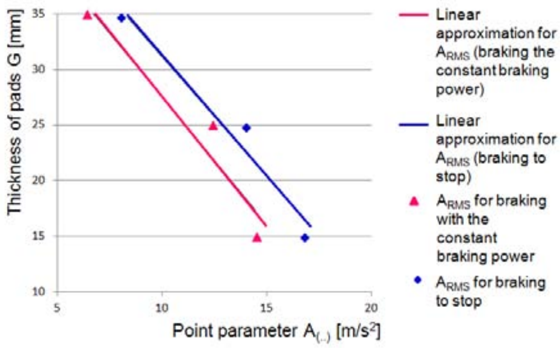

Fig. 8. Dependence of pad's thickness in function of point parameters (A_{RMS} value) of vibrations accelerations for measurement in the Y_1 direction

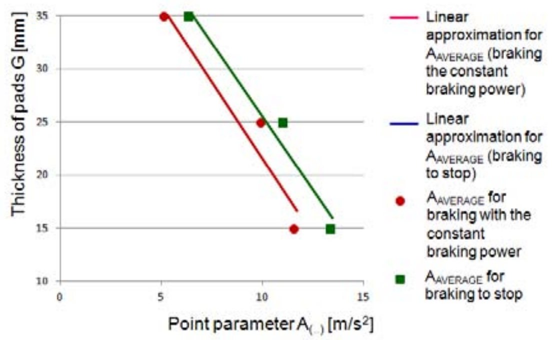

Fig. 9. Dependence of pad's thickness in function of point parameters ($A_{AVERAGE}$ value) of vibrations accelerations for measurement in the Y_1 direction

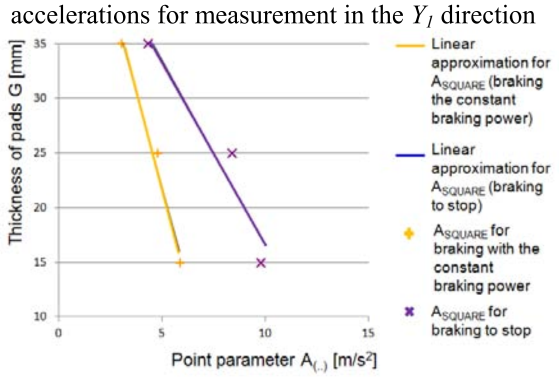

Fig. 10. Dependence of pad's thickness in function of point parameters (A_{SQUARE} value) of vibrations accelerations for measurement in the Y_1 direction

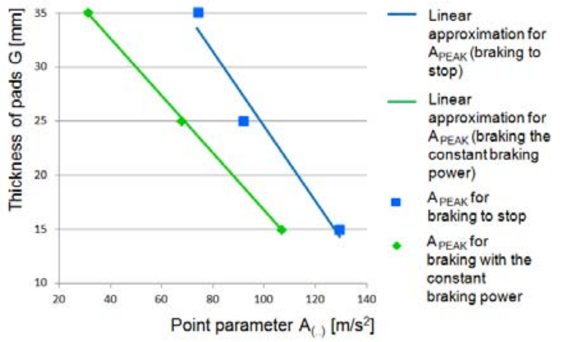

Fig. 11. Dependence of pad's thickness in function of point parameters (A_{PEAK} value) of vibrations accelerations for measurement in the Y_2 direction

The inaccuracy of the linear regression models described dependencies (6-13) present table 3 and 4.

Table 3 Error in % in the application models in estimating linear regression actual thickness of brake pad for braking with the constant braking power

Measurement of vibrations in direction Y_1			
Point parameters	For brake pad G_1= 35mm	For brake pad G_2=25 mm	For brake pad G_3=15 mm
A_{RMS}	2,16	11,96	12,89
$A_{AVERAGE}$	2,15	12,15	13,12
A_{SQARE}	2,15	12,24	13,24
Measurement of vibrations in direction Y_2			
A_{PEAK}	0,37	0,98	0,82

Table 4 Error in % in the application models in estimating linear regression actual thickness of brake pad for braking to stop

Measurement of vibrations in direction Y_1			
Point parameters	For brake pad G_1= 35mm	For brake pad G_2=25 mm	For brake pad G_3=15 mm
A_{RMS}	2,07	9,36	9,63
$A_{AVERAGE}$	2,00	8,56	8,69
A_{SQARE}	1,67	6,29	6,11
Measurement of vibrations in direction Y_2			
A_{PEAK}	4,37	8,32	4,84

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 independently during braking with constant braking power P=45kW and braking to stop. 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 6 and 8dB for direction Y_1 and 6 to 10dB for direction Y_2 measurement of vibrations on railway disc brake only during braking with the constant braking power.

4. CONCLUSION

In the diagnostics of the wear of friction pad of disc brake, point parameters obtained from amplitude flows of vibration accelerations are easier to interpret. Analyzing results in the range of applying point parameters of signals of vibration accelerations to determine friction pads' wear determinated by current pads' thickness in the moment of measurement, it can be found out that selected parameters allow to determine friction pads' thickness.

Measurement of vibration accelerations in direction Y_2 orthogonal to friction surface of the disc and mounting vibration converter from the side of brake cylinder piston rod, is characterized as the most sensitive towards direction Y_1, which is confirmed by values of coefficient of dynamics of changes defined with dependence (5). However, the direction Y_1 of vibration measurement to diagnose allows wear friction pads for both braking types analyzed. During verification of regression diagnostic models determined on the basis of point parameters of signals coming from pad caliper, differences in determining pads' thickness did not exceed 13% for all analysis point parameters for braking with the constan braking power and did not exceed 9% for braking to stop. The next stage of research will review regression diagnostic models on the other friction pads thickness.

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