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The Noise-Generating Mechanism during the Application of Disc Brakes on Rolling Stock

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Abstract—The results of a study of the noise generating mechanism during the application of disk brakes on rolling stock are presented. It is shown that one of the main sources of noise generation is the deformation of the microgeometry of the surface layer and its elastic recovery, which occurs under the influence of the interaction of the working elements of the disk brake. The influence of the ratio of the working areas of the friction elements that model the brake pad and brake disc on the noise intensity during their interaction is estimated. A design and technical method is proposed for reducing the noise level of a disk brake during braking, which consists of increasing the ratio between the working areas of the brake pad and brake disc.

Keywords: disc brake, brake disc, noise, surface microgeometry, deformation, coefficient of friction, surface profilogram, ratio of working surfaces

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INTRODUCTION

Noise during application of brakes on the rolling stock of railroads is a serious problem of disc brakes. In spite of the many decades of the use of disc brakes, this problem has not yet been rationally solved. The noise during application of brakes on rolling stock is not only of technical, but also of social relevance, because it appears in the frequency range that is most perceptible for humans. The effect of noise on humans is particularly strong before a full stop of rolling stock [1]. More than 80 million people in the European Union suffer from excessive transport noise, whose level is higher than 65 dB [2, 3].

Assuming that the population density and the density of railroads in most developed countries is high and still growing, the problem of noise during application of brakes on rolling stock is particularly acute and economically costly.

The factors that affect noise generation are numerous; they can be divided into the following categories:

—structural factors (errors during design);

—factors related to materials science (discrepancy between the characteristics of working friction materials and operation conditions and/or their incompatibility);

—process factors (errors during the development of technology or its violation during the fabrication of friction materials);

—operational factors (incorrect control of brakes, severe operation conditions, and wear of disc brake elements).

Because noise generation is the consequence of friction in the elements of the system, an integral parameter, that is, the friction coefficient, is used most often during evaluation of influencing factors [4–7]. According to the literature data, a decrease in the friction coefficient provides a decrease in the noise level during application of brakes [8].

The friction coefficient depends on molecular–mechanical processes in the contact zone, which affect it to a nearly identical extent. Consequently, molecular and mechanical processes during friction also affect noise generation during the application of brakes.

The relationship between noise generation and molecular–mechanical processes was discussed in [9, 10], where the effect of adhesion interaction on noise generation was shown. However, the effect of mechanical processes on noise generation during application of brakes, in particular, deformation of the surface microgeometry of the interacting components of disc brakes, has not yet been studied in detail.

The aim of this work was to study the mechanism of the deformation of the surface microgeometry of brake discs, which causes the main generation of noise during the application of brakes; to evaluate the effect of the ratio of working areas of friction elements that model brake pads and brake discs on the noise intensity during their interaction; and to develop design and technical measures for a decrease in the noise level during the application of brakes.

STATEMENT OF THE PROBLEM

Let us consider the loading diagram of a disc brake during application of the brake (Fig. 1).

The brake disc *1* rotates with a rotation speed ω. The brake pad *2* is attached to the brake disc *1* by a normal force *P*. As a result, compression stresses act on the brake disc surface in the (+) range, while tensile stresses occur in the (–) range, which results in cyclic deformations of the surface microgeometry. Deformation of surface microgeometry occurs in the (+) range, while its elastic recovery occurs in the (–) range.

Cyclic deformations are the cause of sound oscillations, which propagate along the entire surface of a brake disc. In this case, the surface of the brake disc, which is in the contact zone with the brake pad, emits sound waves to a lower extent because it is damped by the brake pad.

Recovery of the deformed surface microgeometry should occur when stresses in the surface layer caused by the normal pressing force *P* are less than the compression stresses of the brake disc surface in a tangential direction.

For this reason, investigation of the mechanism of deformation and recovery of the surface microgeometry, as well as the effect of the brake disc area on the noise level, are relevant problems; results on these issues are given in this paper.

MATERIALS AND METHODS

An experiment on a pilot bench [11] was carried out to determine the mechanisms of deformation of surface microgeometry, which reproduces the interaction of disc brake elements of a trolley car in real load conditions that occur during the application of a brake. The aim of this experiment was to study the features of the deformation of the surface microgeometry of a brake disc during application of a brake in the area of compression (+) and tensile (–) stresses, as well as without mechanical stress.

To measure the parameters of microgeometry under the simultaneous effects of normal and tangential forces using the bench loading system, a normal pressing force on the brake disc of 5.0 kN was generated and a tangential force of 1.5 kN was created using a jacking cylinder acting on a brake disc.

Special boxes were attached to the (+) and (–) zones of a brake disc surface and a quickly hardening plastic was placed in them. After the hardening of the plastic, the mold reproduced the brake disc surface. By analogy, the molds were obtained without mechanical stress on the brake disc.

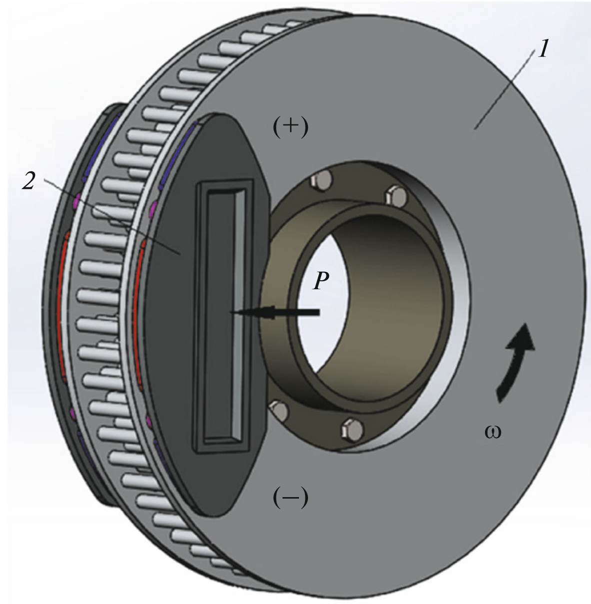

Fig. 1. The loading diagram of a disc brake during application of the brake: (*1*) brake disc; (*2*) brake pad; ω is the rotation rate of the brake disc; (+) is the region of deformation of the microgeometry; (–) is the region of elastic recovery of the microgeometry; and *P* is the pressing force of the brake pad to the brake disc.

Using these molds, roughness and corrugation parameters were recorded on a profilometer (the roughness and corrugation parameters were recorded from 20 tracks along the rotation of the brake disc).

After statistical treatment, the results of measurements are summarized in Tables 1–3. Table 1 shows the roughness and corrugation parameters recorded from the brake disc surface in the (+) range under the simultaneous effects of normal and tangential forces, while there were no normal and tangential forces in Table 2. Table 3 shows the roughness and corrugation parameters recorded from the brake disc surface in the (–) zone without mechanical stresses. Intrinsic surface profilograms in the (+) zone are given in Fig. 2.

Table 1. The surface roughness and corrugation parameters of brake discs in the (+) region under the simultaneous effects of normal and tangential forces

Parameters	MX	DX	V
R_a, μm	1.41	0.0211	8.1
$R_{\max}$, μm	5.84	0.0942	4.9
SM, μm	93.0	150.0	16.1
W_a, μm	2.32	0.0398	9.6
$W_{\max}$, μm	9.44	0.3207	6.7
W_{sm}, μm	2320.0	14232.0	5.0

Table 2. The surface roughness and corrugation parameters of a brake disc in the (+) region in the presence of normal and tangential forces

Parameters	MX	DX	V
R_a, μm	0.49	0.0039	10.0
R_{max}, μm	3.4	0.0051	3.4
SM, μm	115.0	290.0	12.9
W_a, μm	1.54	0.0139	8.9
W_{max}, μm	5.67	0.0380	4.6
W_{sm}, μm	3150.0	25020	5.3

Table 3. The surface roughness and corrugation parameters of a brake disc in the (–) region without normal and tangential forces

Parameters	MX	DX	V
R_a, μm	0.45	0.004	10.2
R_{max}, μm	3.2	0.0063	3.0
SM, μm	107.0	270.0	12.0
W_a, μm	1.50	0.0145	9.3
W_{max}, μm	5.60	0.0360	4.1
W_{sm}, μm	3090.0	24980	5.8

The area of the (+) and (–) ranges of the brake disc on which deformation and recovery of surface microgeometry occur has a direct influence on the noise level during application of a brake.

An experiment was carried out in order to evaluate the effect of the relationship between the area of these ranges and the noise level. The idea of the experiment was to determine the noise level during interaction of ring-like friction elements that were 50 mm in diameter, which modeled the brake pad and the brake disc. The experiment was carried out for ratios of the working areas of ring-like elements of 0.25, 0.50, 0.75, and 1.00 (this ratio was obtained due to the symmetric sampling of the metal on the working surface of one of the rings).

The experimental bench reproduced the conditions of interaction of the elements of a disc brake. An asynchronous electrical engine providing the rotary frequencies of 2.0, 4.0, and 6.0 rpm as a power drive. A special loading unit was designed to control these experimental conditions (Fig. 3).

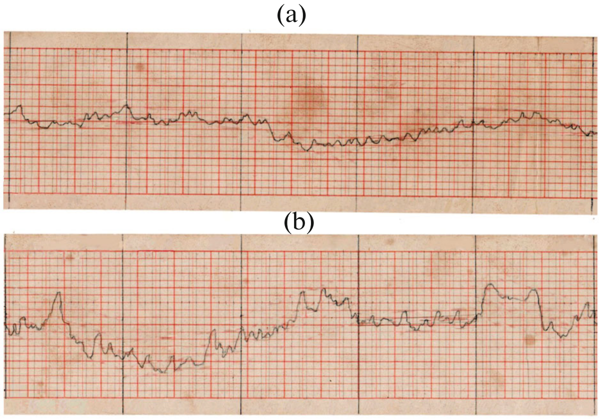

Fig. 2. Intrinsic surface profilograms recorded in the application area of compression stresses (+): (a) is the surface profilogram of a brake disc before loading and (b) the surface profilogram of a brake disc during loading with normal and tangential forces.

The degree of loading of the friction unit was chosen using calculations derived from the condition of elastic deformations of the rough layer of interacting surfaces. The rings were pressed with a force of 300–500 N. The ring loading was controlled using a spring with the specified stiffness.

The working surfaces of the test specimens were preliminarily run in before the experiment. The noise level was measured during experiments using a VShV-003-M2 noise-level meter.

During the experiments one of the rings was stationary while the other one rotated coaxially relative to it.

The results of the experiments are given in Fig. 4.

RESULTS AND DISCUSSION

The results of this study showed that interaction of a brake pad with a brake disc during application of a brake is accompanied by intense deformation of the surface microgeometry of the brake disc in the (+) range of compression stress and elastic recovery of microgeometry in the (–) range of tensile stress (Tables 1–3).

Deformation of the surface microgeometry in the (+) range is characterized by an increase in height and a decrease in the step parameters of roughness and corrugation, as well as an increase in the filling density of the surface profile on the supporting curve. These results agree qualitatively with those obtained in [12] for the evaluation of the coupling characteristics of locomotive wheels and rails.

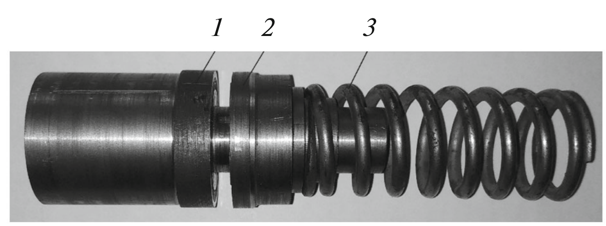

Fig. 3. Loading device: (*1*) stationary ring, (*2*) mobile ring, and (*3*) spring with specified stiffness.

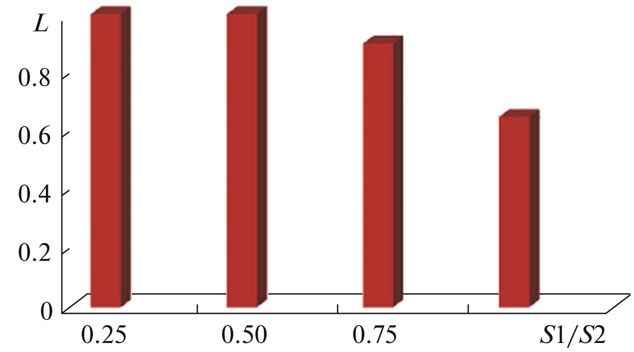

Fig. 4. The noise level diagram generated during interaction of rings with various ratios of working areas. $S1/S2$ is the ratio of the working areas of the rings and L is the relative noise level (1.0 corresponds to the highest total noise level for $S1/S2 = 0.25$).

The recovery of the microgeometry in the (–) range initiates oscillations including those in the sound frequency range on the surface of a brake disc, which can be indirectly confirmed by simple calculation on the basis of experimental parameters of microgeometry. It is easy to calculate the vibration frequency if one knows the mean roughness step and velocity of motion. One example is that elastic recovery of microgeometry at the velocity of 4 km/h and microirregularities of 90 μm would be accompanied by sound waves with a frequency of nearly 9900 Hz, which corresponds to noise characteristics under real conditions.

Recovery of the microgeometry in the (–) range initiates oscillations, which propagate along the free surface of a brake disc and are emitted. The experiment showed that a decrease in the brake disc area, which is free from the contact with the brake pad, results in a decrease in the noise level. As an example the noise levels are 1.0 : 1.0 : 0.9 : 0.65 for the ratios of the working friction areas of ring-like elements of 0.25 : 0.50 : 0.75 : 1.00.

With the change of the frequency of the relative rotation of rings (within the studied rotation frequencies), the noise level reaches a maximum at 4.0 rpm and a minimum at 6.0 rpm.

An increase in the pressing force of rings does not qualitatively affect the form of the noise level distribution for the area ratios of the rings described above.

Analysis of the results shows that an increase in the ratio of the working areas of brake pads and brake discs to a limiting value corresponding to unity is one of the methods to decrease noise during the application of brakes of rolling stock with disc brakes. In this case, sound oscillations are damped along the entire brake disc area, which acts as a membrane to emit sound waves.

CONLCUSIONS

(1) It has been shown that damping of the surface microgeometry of a brake disc in the region that precedes its main contact with a brake pad and elastic recovery of the microgeometry in the range where the brake disc surface leaves the mutual contact zone with a brake pad is one of the main components of the mechanism of noise generation during application of the brakes of rolling stock of railroads with disc brakes.

(2) The noise level has been experimentally determined during interaction of ring-like elements, which model a brake pad and a brake disc and have ratios of the working friction area of 0.25, 0.50, 0.75, and 1.00, which is 1.0 : 1.0 : 0.9 : 0.65.

(3) With changes of the relative rotation frequency of the rings (within the rotation frequencies under study), the noise levels reached a maximum at 4 rpm and a minimum at 6 rpm. An increase in the pressing force of the rings did not qualitatively affect the form of the noise level distribution for the ratios of the working areas of the rings described above.

(4) A decrease in the noise level during application of the brakes of rolling stock with disc brakes is possible via an increase in the ratio of the working areas of brake pads and brake discs to a limiting value corresponding to unity using design and technical methods. This can provide a decrease in the noise level of nearly 30%.

DESIGNATIONS

R_a	is the combined surface roughness
$R_{\max}$	is the maximum surface roughness
SM	is the roughness step
W_a	is the mean deviation of corrugation waves
$W_{\max}$	is the maximum height of corrugation waves
W_{sm}	is the corrugation wave step
MX	is expectancy
DX	is dispersion
V	is the coefficient of variation, %

REFERENCES

1. Giannini, O., Akay, A., and Massi, F., Experimental analysis of brake squeal noise on a laboratory brake setup, *J. Sound Vib.*, 2006, vol. 292, no. 1, pp. 1–20.
2. Sladkowski, A., Gaska, D., Haniszewski, T., and Margielewicz, J., Aktywna wibroizolacja drgań mechanicznych pasażerskiego wagonu kolejowego, *Zesz. Nauk. Politech. Slask., Transp.*, 2015, vol. 87, no. 1929, pp. 63–71.
3. Minenko, E. and Kuramshin, D., *Otsenka transportnogo shuma i metody ego snizheniya* (Evaluation of Transport Noise and Its Reduction Methods), Moscow: LAP LAMBERT Academic, 2014.

4. Kragel'skii, I.V. and Gitis, N.V., *Friktsionnye avtokolebaniya* (Friction-Induced Self-Oscillations), Moscow: Nauka, 1987.

5. *Spravochnik po tribotekhnike. Tom 1. Teoreticheskie osnovy* (Handbook on Triboengineering, Vol. 1: Theoretical Foundations), Khebda, M. and Chichinadze, A.V., Eds., Moscow: Mashinostroenie, 1989.

6. Garkunov, D.N., *Tribotekhnika* (Triboengineering), Moscow: Mashinostroenie, 1985.

7. Braun, E.D., Bushe, N.A., and buyanovskii, I.A., *Osnovy tribologii* (Fundamentals of Tribology), Chichinadze, A.V., Ed., Moscow: Nauka i Tekhnika, 1995.

8. Bergman, F., Eriksson, M., and Jacobson, S., Influence of disc topography on generation of brake squeal, *Wear*, 1999, vols. 225–229, pp. 621–628.

9. Chen, G.X. and Zhou, Z.R., Correlation of a negative friction–velocity slope with squeal generation under reciprocating sliding conditions, *Wear*, 2003, vol. 255, pp. 376–384.

10. Guangxiong, C., Zhongrong, Z., Kapsa, P., and Vincent, L., Effect of surface topography on formation of squeal under reciprocating sliding, *Wear*, 2002, vol. 253, pp. 411–423.

11. Osenin, Yu.Yu., Sosnov, I.I., Sergienko, O.V., and Bugaenko, V.V., The stand for the testing of disk of high-speed break for the railways, *Visn. Skhidnoukr. Nats. Univ. im. V. Dalya*, 2013, no. 2, pp. 2, 99–103.

12. Mikhin, N.M. and Osenin, Yu.I., The influence of the stress state of the contact area of solids on the parameters of surface roughness and waviness, *Probl. Tertya Znoshuvannya*, 1988, no. 34, pp. 46–54.

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