

Influence of the Mutual Overlapping Coefficient on the Process of a Disc Brake Squealing during Braking

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Received July 14, 2020; revised October 15, 2020; accepted November 5, 2020

Abstract—This article presents the results of an experimental study of the impact of the mutual overlapping coefficient on the probability of a disc brake squealing under braking at the moment before the complete stop of a rolling stock. The studies are carried out on an original test bench, which reproduced the real conditions of the interaction of the working elements of the friction unit of a disc brake according to the criteria of mass-dimensional and load-speed characteristics, as well as the operating temperature. The charts and spectrograms of noise are given that illustrate the influence of the mutual overlapping coefficient of the disc brake on the process of squealing during braking. It is shown that the greatest probability (in the range of 90 to 95%) of the brakes squealing is observed when the values of the mutual overlapping coefficient are 0.33 and 0.66. When the mutual overlapping coefficient is 0.98 the brakes do not squeal at all. Practical recommendations are given to eliminate the squealing of disc brakes before a rolling stock comes to a complete stop by increasing the mutual overlapping coefficient to values close to 1.0.

Keywords: disc brake, squealing of brakes, mutual overlapping coefficient, brake pad, brake shoe, brake disc, friction force and coefficient, frictional properties, probability

DOI: 10.3103/S1068366621010062

INTRODUCTION

Friction (disc and shoe) brakes are widely used in modern rolling stock, due to the simplicity of their design, relatively low cost, reliability, and braking efficiency [1–3].

Despite the many decades that friction disc and shoe brakes have been used, they still have some disadvantages, including the squealing of brakes, one of the most significant disadvantages, which manifests itself at the moment preceding a train coming to a complete stop [4, 5].

The squealing of brakes should be viewed as a technical deficiency with environmental, economic, and social consequences. This is due to the fact that the squealing of brakes occurs in the frequency range most sensitive to human perception, and measures to prevent or at least localize the effect of brakes from squealing are calculated in multimillion-dollar, unproductive financial costs.

Eliminating the squealing of brakes as an independent factor does not lead to unequivocally positive results, since squealing is a manifestation (consequence) of the conditions of the interaction and frictional properties of the friction unit, which (properties), in turn, are formed under the influence of phys-

ical and mechanical properties of materials from which the working elements of the friction unit of the disc brake are made, as well as the mass-dimensional and load-speed characteristics of their interaction [8].

According to the research, the squealing of brakes depends on the frictional properties of the working elements of the friction unit of the disc brake and the conditions of their interaction [4, 5].

All other things being equal, the intensity of frictional processes in the contact area of the working elements of the friction unit of the disc brake is due to the mutual overlapping coefficient K_{mo} (hereinafter, K_{mo} coefficient) [6].

Therefore, other things being equal, the K_{mo} coefficient predetermines the level of the stress-strain state of the contact area of the friction unit's elements of the disc brake and, as a consequence, the frictional properties of the disc brake as a whole and the ability of the latter to generate squealing during braking.

The aim of this paper is to study the causal relationship between the overlapping coefficient, the frictional properties of the friction unit, and the likelihood of a disc brake squealing during braking.

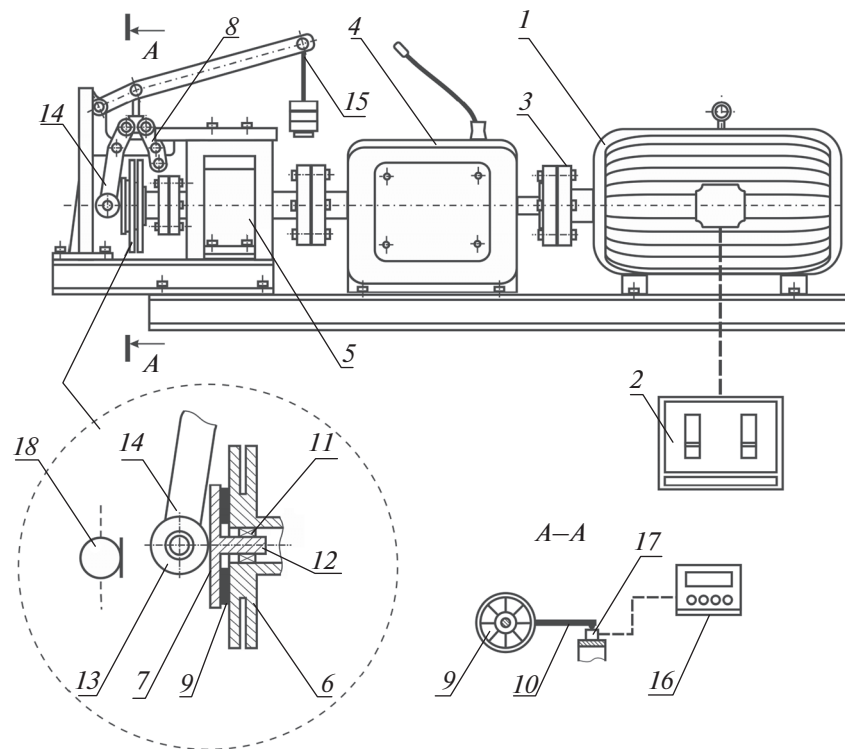


Fig. 1. Stand for studying the impact of K_{mo} on the process of a disc brake squealing during braking: (1) asynchronous electric motor; (2) control unit; (3) elastic coupling; (4) gearbox; (5) bearing system; (6) brake disc; (7) brake pad; (8) stopper; (9) brake pads; (10) bracket for measuring the friction force; (11) bearing; (12) shaft; (13) bearing; (14) lever; (15) loading mechanism; (16) measuring unit; (17) sensor for measuring friction force; (18) microphone.

MATERIALS AND METHODS

The experiments were carried out on a full-scale stand [7], the schematic diagram of which is shown in Fig. 1. The stand allows us to reproduce the real conditions of the interaction of the working elements of a disc brake according to the criteria of the load-speed and mass-dimensional characteristics, as well as the operating temperature, which is the necessary and sufficient condition for obtaining adequate results when conducting experiments on the stand [8].

An innovative feature of the stand lies in the design of the brake shoe, which has a round shape, which makes it possible to place the brake pads of the given area and shape on it, and also allows us to create combinations of several friction materials.

As a result, it becomes possible to vary the K_{mo} coefficient of the disc brakes in a wide range from 0.33 to 0.98. This is achieved by changing the number of brake pads placed on the brake shoe, provided that their location is symmetrical.

The design of the brake shoe minimizes the time and labor intensity of replacing the brake pads, as well as changing the K_{mo} coefficient. The brake shoe is at the same time an element that is directly used to measure the friction force using the strain gauge method.

On the stand, it seems possible to create the frequency of the revolutions of the brake disc of $n = 360, 640,$ and 1007 rpm, which by recalculation corresponds to the linear speed of a rail carriage of 74, 133, and 208 km/h.

The friction unit is designed on the stand in such a way that the heat dissipating area of the brake disc does not change by more than 20% for any value of the overlapping coefficient K_{mo} , which reduces the influence of temperature on the frictional characteristics of the disc brake.

The idea of the experiments was to determine the causal relationship between the K_{mo} coefficient, the frictional properties of the friction unit, and the probability P of squealing in the overrun mode of the stand (the state of the stand in the period between the removal of the torque and until it stops completely in the deceleration mode). The friction coefficient μ is taken as the resulting characteristic of the frictional properties of the friction unit of the disc brake.

The experiments were performed according to the following algorithm:

- the specified K_{mo} coefficient was set and the number of revolutions of the brake disc n ;
- the electric motor was turned on;

Table 1. Experimental conditions

No.	Parameter	Quantitative assessment
1.	Initial temperature of the brake disc t , °C	19
2.	Mutual overlapping coefficient K_{mo}	0.33; 0.66; 0.98
3.	Pressing force of brake pads F , kN	1.5; 2.0; 2.5; 3.0
4.	Rotation rate of disc brake n , rpm	1007
5.	Brake pad material	UT 22-B
6.	Brake disc material	Steel 35 SG/Steel 35 SG
7.	Electric motor power N , kW	75.0
8.	Number of measurements	20

—the given force F was created by pressing the brake pads against the brake disc;

—the brake disc's temperature was stabilized;

—the friction force was measured;

—the noise spectrogram was recorded in the over-run mode of the stand.

Based on the measurements, the dependences of the probability P of the brakes squealing on the mutual overlapping coefficient K_{mo} and the coefficient of friction μ of the disc brake were constructed.

During the experiments, the following characteristics were controlled:

—overlapping coefficient K_{mo} ;

—friction force F_{fr} ;

—pressing force F of the brake pads to the brake disc;

—speed n of the brake disc;

—temperature in the area of the contact between the brake pads and brake disc.

The influence of K_{mo} on the thermal state of the brake disc was estimated by the value of the temperature stabilization for the specific conditions of the interaction of the working elements of the friction unit. The parameters characterizing the experimental conditions are summarized in Table 1.

The relationship of the K_{mo} coefficient with the frictional properties of the friction unit of the disc brake and the likelihood of squealing was established based on the recording of cases of squealing and the recording of noise spectrograms.

RESULTS AND DISCUSSION

The experimental results are shown in Figs. 2 and 3. Analysis of the results showed that the K_{mo} coefficient, other things being equal (F , n), has a dominant effect on the formation of the frictional properties of the friction unit and its ability to generate squealing during braking in the moment preceding the complete cessation of movement of the brake pads relative to the brake disc.

With an increase in the K_{mo} coefficient from 0.33 to 0.98, there was a tendency towards an increase in temperature and an increase in the coefficient of friction μ .

With the values of the mutual overlapping coefficient $K_{mo} = 0.33$ and 0.66, the probability of the brakes squealing was 90–95%. With the K_{mo} coefficient = 0.98, no case of brakes squealing was recorded for the series of 20 experiments (Fig. 2).

The strong probability of the brakes squealing when the values of the K_{mo} coefficient of 0.33 and 0.66 and its absence when the K_{mo} coefficient is 0.98 can be explained based on the analysis of the conditions for the formation of the stress-strain state of the surface of friction elements during the interaction of the force.

According to the works [9, 10], with the interaction of the force of the brake disc and brake pads at low values of K_{mo} , alternating stresses are realized on their

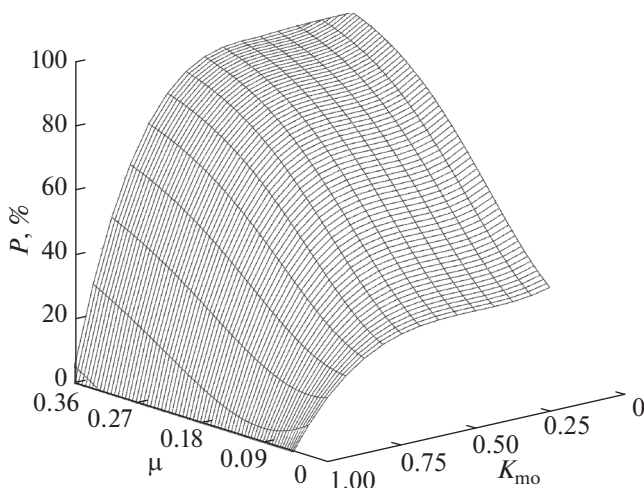


Fig. 2. Impact of the mutual overlapping coefficient and the coefficient of friction on the probability of the brake squealing before stopping: P , the probability of squealing during braking; K_{mo} , mutual overlapping coefficient; μ , the coefficient of friction.

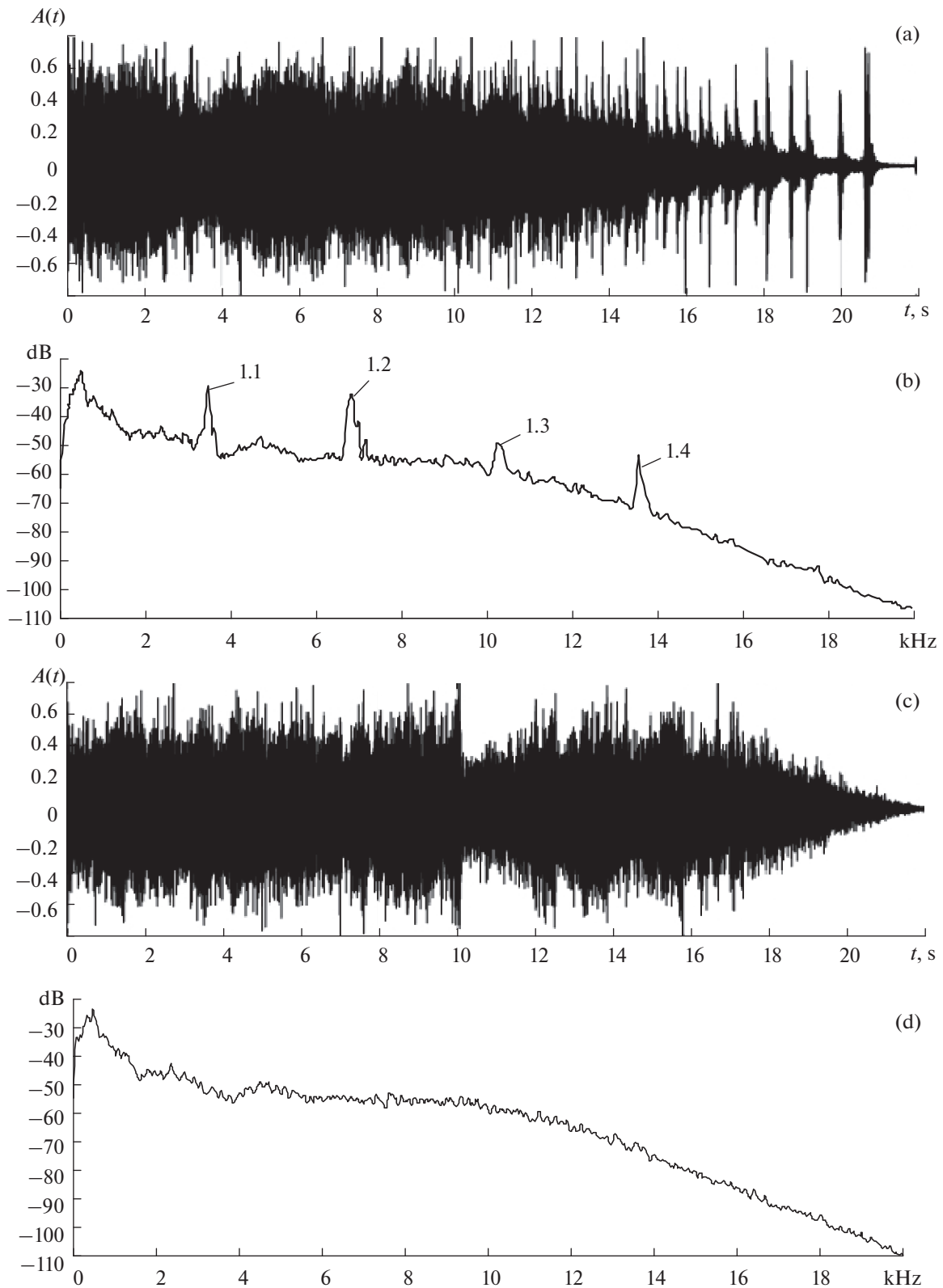


Fig. 3. Spectrograms of the noise generated by the elements of the disc brake and the stand in the braking mode before the complete stop of the relative movement of the brake disc and brake pads. $K_{mo} = 0.33$ (a, b), $K_{mo} = 0.98$ (c, d); 1.1; 1.2; 1.3; 1.4 are the frequencies of the brakes squealing.

surface. Compression stresses are realized in the oncoming part of the brake disc surface and tensile stresses are realized in the part moving away.

Cyclic elastic deformation of the surface microgeometry and its subsequent elastic recovery is the dominant mechanism for the emergence of sound waves, which are manifested in the form of squealing. In the case of a disc brake, the resulting microvibrations, during the elastic restoration of the rough layer, are spread over the entire surface of the brake disc, which enhances the sound intensity.

The mechanism of the interaction of the surface layer of the brake disc with the brake pad when the K_{mo} coefficient approaches 1.0 is significantly different from the one described above. With such values of the K_{mo} coefficient, the possibility of the cyclic alternating deformation of the brake disc surface and elastic restoration of the surface roughness are excluded. As a result, the mechanism of the elastic free recovery of the rough layer of the surface of the brake disc is eliminated, which prevents the occurrence of sound waves that appear in the form of the squealing of brakes and which are characteristic of a classic disc brake.

In addition, at K_{mo} close to 1.0, the brake pad simultaneously interacts with the entire working surface of the brake disc and has a damping effect on the process of sound waves in the rough surface layer of the brake disc. As a result, the squealing of the brakes is completely absent.

Figure 3 shows the spectrograms of noise, which illustrate the process of the brakes squealing during braking. The noise spectrograms for $K_{mo} = 0.33$ (b) and $K_{mo} = 0.98$ (d) show that the general noise background is identical in the distribution of sound waves over frequencies, which confirms the correctness of the experiments.

From the spectrograms it follows that the squealing of the brakes is in the frequency range that is most sensitive for humans (1.0 kHz or higher). The characteristic squealing of the brakes is seen in the spectrogram of the noise emitted at $K_{mo} = 0.33$ by the working elements of the stand (b). The sound harmonics of the squealing process stands out against the general background noise.

According to the experimental results obtained, the probability of squealing increases with an increase in the friction coefficient μ of the disc brake, which is consistent with the conclusions made in [4, 5]. When the K_{mo} coefficient is 0.98 this regularity is violated (the high friction coefficient corresponds to the absence of squealing of the brakes).

In the case of a classic disc brake ($K_{mo} = 0.23$), with an increase in the friction coefficient μ , the surface deformation is intensified, which leads to an increase in the level of alternating stresses on the surface of the brake disc. As a result, a more intense elastic recovery

of the deformed surface and the generation of sound waves are observed.

At K_{mo} close to 1.0, the pressure in the contact area of the working elements of the disc brake decreases and the level of deformation of the rough surface layer of the brake disc decreases and, most importantly, there are no alternating deformations of the surface of the disc brake.

As a result, the dominant mechanism of the emergence of the squealing of the brakes is blocked and the stage of the intensive elastic restoration of the surface, on which the sound waves are generated in the form of squealing, is excluded.

From this it follows that when analyzing the causes of the squealing of the brakes, it is necessary, together with other influencing factors, to take into account the K_{mo} coefficient.

The study performed allowed us to obtain results from which it follows that the K_{mo} coefficient increasing to values close to 1.0 in promising disc brake designs promotes an increase in the coefficient of friction μ (for friction pairs in which the coefficient of friction increases with temperature) and effectively suppresses (dampens) the high-frequency oscillations of the surface of the brake disc, which ensures the complete elimination of the squealing of brakes when braking.

CONCLUSIONS

(1) The mutual overlapping coefficient K_{mo} , other things being equal, has a dominant effect on the formation of the frictional properties of the friction unit of a disc brake and its ability to emit squealing during braking at the moment preceding the complete cessation of movement of the brake pads relative to the brake disc.

(2) The greatest probability (90 to 95%) of brakes squealing is observed at values of the mutual overlapping coefficient K_{mo} of 0.33 and 0.66. With the overlapping coefficient K_{mo} of 0.98, there is no squealing of the brakes.

(3) An increase in the overlapping coefficient K_{mo} of the brake disc and brake pads to values close to 1.0 will eliminate the squealing of a disc brake before stopping and increase its friction coefficient μ (for friction pairs in which the coefficient of friction μ increases with temperature).

NOTATION

K_{mo}	coefficient of mutual overlapping
F	the force of pressing the brake pads to the brake disc
F_{fr}	friction force
n	rotation frequency of disc brake

μ coefficient of friction
 P probability

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