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Disc Brake with Two Thermally Insulated Friction Units with Different Frictional Properties

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Abstract—The study considers the principles of creating a disc brake, promoting consistently high friction in a wide range of brake temperatures. The selection of friction materials for thermally insulated friction units is carried out according to the principle of mutual compensation of the negative properties of one friction unit due to the positive properties of another one. For example, for a cast iron–35GS steel disc brake, when heated to 300°C, the friction coefficient changes from 0.38 to 0.17, while for a carbon–35GS steel disc brake, the reverse effect of a coefficient variation from 0.17 to 0.58 is observed. A combination of the given tribological systems provides an acceptably high friction coefficient in the entire brake temperature range. A disc brake with two heat-insulated friction units makes it possible to improve the rolling stock braking efficiency. The cost of the new disc brake (compared to a disc brake based on a composite carbon–carbon friction material) is expected to be lower by about 30%.

Keywords: disc brake, thermal insulation, brake disc, brake pad, friction unit, friction coefficient, friction force, friction temperature, braking

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INTRODUCTION

An increase in braking energy is one of the main trends in the development of ground rail and road transport, due to the increase in speed and the need to improve the level of vehicle safety [1–3].

Currently, the development of new friction materials with improved performance properties is the main direction for improving disc brakes, but development is a long and costly process and does not guarantee achievement of the initially specified disk brake friction characteristics [4–7].

In this regard, it is relevant to search for new approaches to improve disk brake efficiency, reliability, and durability, which could give tangible results in solving this urgent scientific and technical problem already in the short term [8–12].

As one of these new directions, it should be noted the achievement of the specified operational properties of disc brakes by using several friction materials (three or more) in the friction unit [13]. The implementation of this direction does not require significant capital investments and is an alternative to the creation of new friction materials.

However, a simple combination of several friction materials in one friction unit does not provide sufficient braking efficiency, since the brake disc, which is a common friction element for them and has, as a rule, high thermal conductivity, leads to the same temperature regime of interaction for all friction materials involved in braking. As a result, it is not possible to achieve the optimal temperature regime of operation, as well as the maximum friction coefficient for each friction pair, which is the reason for the insufficiently high efficiency of this method.

Objective—To experimentally confirm the effectiveness of a new disc brake based on two thermally insulated friction units that have different frictional properties.

MATERIALS AND METHODS

Figure 1 shows a diagram of a disc brake with two thermally insulated friction units *A* and *B*, which have different frictional properties [14]. Discs *1* and *2* are thermally insulated from each other due to thermal insulating element *5*. Each of the discs has the ability to interact with brake pads *3* and *4*. Disc *1* and pad *3* form friction unit *A*, disk *2* and pad *4* form friction unit *B*.

The main principle of selecting friction materials for friction units *A* and *B* of the disc brake is that due to the frictional properties of one friction pair operating, for example, in friction unit *A*, it would be possible to compensate for the disadvantages of the fric-

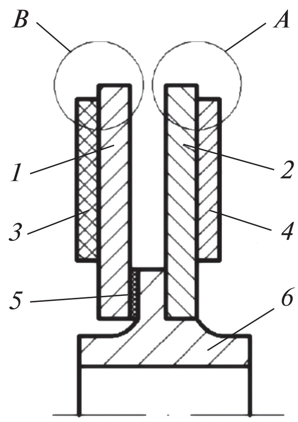

Fig. 1. Schematic diagram of the disc brake with two thermally insulated friction units with different frictional properties: (*A*) 1st friction unit; (*B*) 2nd friction unit; (*1*, *2*) brake discs; (*3*, *4*) brake pads; (*5*) thermal insulating element; (*6*) hub.

tional properties of the second friction pair operating in friction unit *B*.

Examples of such friction materials are carbon and cast iron. Carbon has a high coefficient of friction in the temperature range of 300–1000°C, but at lower temperatures the friction characteristics are reduced to an unacceptable level, which is a disadvantage. Cast iron has a high friction coefficient in the initial temperature range, and with a further increase in temperature, its frictional properties weaken.

With this in mind, carbon is located in friction unit *A*, where it works in tandem with 35GS steel, which is used to manufacture brake discs. Cast iron is placed in friction unit *B* in which it also works in tandem with 35GS steel. Since friction units *A* and *B* are thermally isolated from each other, therefore, each of them operates in a separate temperature regime, due to its natural properties, compatibility of materials, and the level of energy supplied, which contributes to an increase in braking efficiency [12, 13].

The novelty of the problem statement implied the creation of a friction machine constructively providing thermal insulation of double-disc brake friction units with different frictional properties. The effectiveness of the proposed principles for creating a new disc brake was tested experimentally on a specially designed friction machine (Fig. 2) [15].

Rings *12* and *13*, when interacting, perform brake disc functions. The rings are fixed on table *3* using permanent magnets *4* and *5*, which are placed in the recesses made on table *3*.

This solution made it possible to compensate for the thermal expansion of the rings when they are heated from an external heat source. Heat-insulating material *16* is laid between the permanent magnets and the rings. The set temperature for rings *12* and *13* was achieved due to external heat sources (gas burners), since the realized braking energy did not allow heating the friction units to the required level.

The experiments were performed in accordance with the following algorithm:

(A) Friction elements *14* and *15* were installed on rings *12* and *13* and fixed relative to the loading system. The materials of friction elements *14* and *15* are taken in accordance with Table 1.

(B) The electric motor was turned on.

(C) Normal loading of friction elements was created by normal forces $F_1 = F_2 = 6$ N (Fig. 2).

(D) Rings *12* and *13* were heated by gas burners to the temperatures specified in Table 1. The intensity of

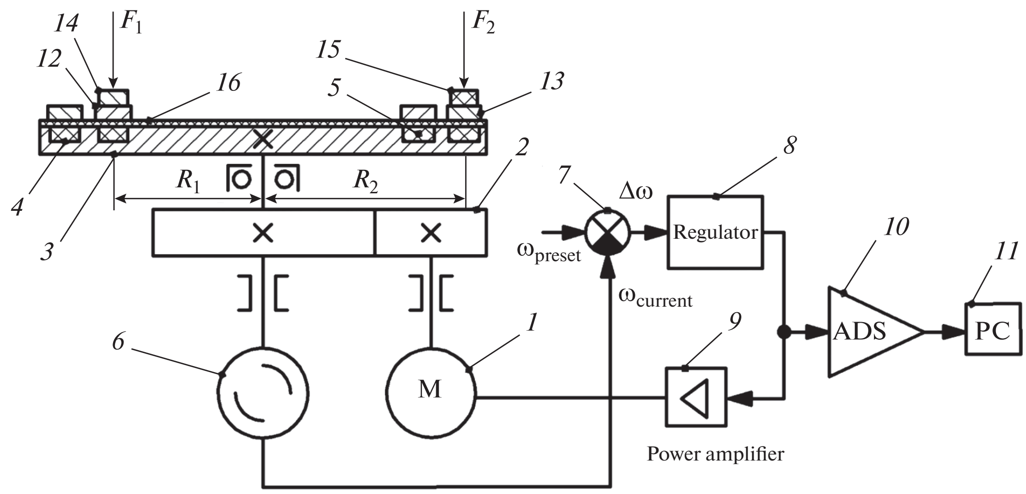

Fig. 2. Structural diagram of the friction test machine for studying interaction of the disc brake working elements with two thermally insulated friction units with different frictional properties: (*1*) electric motor; (*2*) gear box; (*3*) table; (*4*, *5*) magnets; (*6*) drive; (*7*) discriminator; (*8*) regulator; (*9*) amplifier; (*10*) analog-to-digital converter; (*11*) computer; (*12*, *13*) rings; (*14*, *15*) brake pads; (*16*) thermal insulating element.

Table 1. Experimental conditions

No.	Friction unit *A*	Friction unit *A* temperature, °C	Friction unit *B*	Friction unit *B* temperature, °C
1	Cast iron–steel	20–200	Cast iron–steel	20–200
2	Carbon–steel	20–400	Carbon–steel	20–400
3	Carbon–steel	20–400	Cast iron–steel	20–200

each of the burners was set such that the temperature level according to Table 1 was simultaneously reached.

(E) During the heating process, the operating parameters of the friction machine were recorded.

With allowance for the design features of the stand, friction force F_{fr} was determined by expression:

$$F_{fr} = \frac{M_{engine} j_{rd} \eta_{rd} - M_{idl}}{R}. \quad (1)$$

where M_{engine} is the torque; j_{rd} is the gearbox ratio; η_{rd} is the reduction gear efficiency; M_{idl} is the static moment of idling losses (determined experimentally); and R is the average radius of the friction force application.

The friction coefficient was calculated as the ratio of friction force F_{fr} to normal load F_1.

In accordance with the above algorithm, the experiments were performed for the friction units and operating temperatures presented in Table 1.

Due to the fact that for series of measurement No. 3 there was no integral operating temperature of the tribosystem (for friction units *A* and *B*, the temperature regime is individual), all graphs were plotted as a function of heating time *t*, which was the same for all measurements, and for measurements No. 1 and 2 was identical to the generated temperature.

The experiments included three series of measurements for the conditions of interaction of the friction elements, summarized in Table 1.

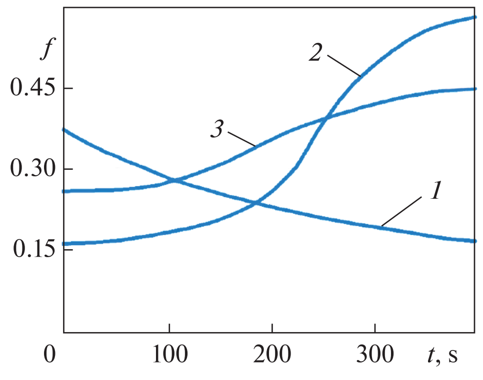

Fig. 3. Dependance of friction factor *f* on heating time *t*: (*1*) traditional disc brake (cast iron–35GS steel friction pairs); (*2*) conventional disc brake (the carbon–35GS steel friction pairs); (*3*) disc brake with thermally insulated friction units (cast iron–35GS steel and carbon–35GS steel friction pairs).

The 1st and 2nd second series of measurements simulated the interaction scheme of a traditional disc brake, with the only difference that in the first case, cast iron was chosen as the brake pad material, and in the second, a carbon-based material was chosen. Taking this into account, in each of the two series of measurements, the interaction temperature in friction units *A* and *B* was the same.

The third series of measurements simulated the interaction conditions under which friction units *A* and *B* were thermally isolated from each other and had different frictional properties.

RESULTS AND DISCUSSION

The experimental results are shown in Fig. 3.

It follows from the results that for the scheme of interaction of working elements corresponding to a traditional disc brake, the friction coefficient, depending on the heating time of rings *12* and *13*, friction pairs of cast iron–35GS steel (curve *1*), operating simultaneously in friction units *A* and *B* decreased at the same temperature.

For the same scheme of a traditional disc brake, when the friction pairs carbon–35GS steel (curve *2*) in friction units *A* and *B* at the same temperature regime, the friction coefficient tended to increase. Moreover, for the first approximately 30% of the heating time of rings *12* and *13*, the friction coefficient increased slightly and had an insufficient value for effective braking.

Under the conditions of thermal insulation of friction units *A* and *B* for the combination of friction materials in friction unit *A* carbon–35GS steel and in friction unit *B* cast iron–35GS steel (curve *3*), an acceptable level of friction coefficient was provided in the entire range of heating of rings *12* and *13*. In this case, the friction coefficient varied from 0.27 to 0.43.

The friction materials that were used in the experiments (carbon, cast iron, and 35GS steel) are not recommended for the final formation of friction units, but only serve as an example of the possibilities of a promising disc brake with thermally insulated friction units having different friction properties.

Bearing in mind that there is half as much expensive carbon-based friction material used in the disc brake design, therefore, the total cost of the disc brake based on the proposed principles will be at least 30% less compared to a similar carbon-based one.

The implementation of the proposed principle of a new disc brake will provide a given characteristic of the friction coefficient on the braking time, as well as on the temperature in the contact area.

CONCLUSIONS

(A) The schematic diagram of the disc brake with two thermally insulated friction units with different friction properties is proposed. As a result, the operation of friction materials is ensured under conditions of natural temperature for each pair of friction, due to their natural properties, compatibility, and the supplied level of braking energy.

(B) The main principle of selection of friction materials for thermally insulated disc brake friction units is to improve the properties of friction materials of one friction pair due to the properties of another friction pair operating in the second friction unit. The implementation of this principle will provide the specified friction characteristics of the disc brake based on currently existing friction materials and eliminates the need to create new ones.

(C) In the example of thermally insulated friction units of the carbon–35GS steel and cast iron–35GS steel disc brakes, it is shown that the proposed principle is effective and ensures the elimination of the disadvantage of the carbon–35GS steel friction unit associated with a low friction coefficient in the initial period of friction heating and provides an acceptable level of friction coefficient over the entire temperature range.

NOTATION

F_1 and F_2	is the normal force
F_{fr}	is the friction force
M_{engine}	is the torque
j_{rd}	is the gearbox ratio
η_{rd}	is the reduction gear efficiency
M_{idl}	is the static moment of idle losses
R	is the average radius of the friction force application
f	is the friction coefficient
t	is the heating time

REFERENCES

1. Ehlers, H.-R. et al., Potential and limits of opportunities of the block brake, *Glasers Ann.,* 2002, nos. 6–7, pp. 290–300.
2. Myshkin, N.K., Grigoriev, A.Y., Kavaliova, I.N., et al., Contact interaction in precision tribosystems, *J. Frict. Wear,* 2020, vol. 41, no. 3, pp. 191–197.
3. Seelam, A.B., Hussain, N.A.Z., and Krishanmurthy, S.H., Design and analysis of disc brake system in high speed vehicles, *Int. J. Simul. Multidisci. Des. Optim.,* 2021, no. 12, p. 19. https://doi.org/10.1051/smdo/2021019
4. Chan, D. and Stachowiak, G.W., Review of automotive brake friction materials, *Proc. Inst. Mech. Eng., Part D,* 2004, vol. 218, no. 9, pp. 953–966. https://doi.org/10.1243/0954407041856773
5. Shpenev, A.G., Influence of thermoelastic instability on the wear of composite brake discs, *J. Frict. Wear,* 2021, vol. 42, no. 1, pp. 52–62. https://doi.org/10.32864/0202-4977-2021-42-1-52-62
6. El-Tayeb, N.S.M. and Liew, K.W., On the dry and wet sliding performance of potentially new frictional brake pad materials for automotive industry, *Wear,* 2009, vol. 266, no. 1, pp. 275–287. https://doi.org/10.1016/j.wear.2008.07.003
7. Peng, T., Yan, Q., Li, G., et al., The braking behaviors of Cu-based metallic brake pad for high-speed train under different initial braking speed, *Tribol. Lett.,* 2017, vol. 65, no. 4, p. 135. https://doi.org/10.1007/s11249-017-0914-9
8. Kindrachuk, M., Volchenko, D., Balitskii, A., Abramek, K.F., Volchenko, M., Balitskii, O., Skrypnyk, V., Zhuravlev, D., Yurchuk, A., and Kolesnikov, V., Wear resistance of spark ignition engine piston rings in hydrogen-containing environments, *Energies,* 2021, vol. 14, no. 16, p. 4801. https://doi.org/10.3390/en14164801
9. Myshkin, N.K., Zhang, G., Gutsev, D.M., Grigoriev, F.A., and Wang, W., Characteristics of peek-based nanocomposites in friction on steel, *J. Frict. Wear,* 2021, vol. 42, no. 3, pp. 350–357. https://doi.org/10.32864/0202-4977-2021-42-3-350-357
10. Balyts'kyi, O.I., Kolesnikov, V.O., and Eliasz, J., Study of the wear resistance of high-nitrogen steels under dry sliding friction, *Mater. Sci.,* 2013, vol. 48, no. 5, pp. 642–646. https://doi.org/10.1007/s11003-013-9549
11. Balyts'kyi, O.I., Kolesnikov, V.O., and Kawiak, P., Tribotechnical properties of austenitic manganese steels and cast-irons under sliding friction conditions, *Mater. Sci.,* 2005, vol. 41, no. 5, pp. 624–630.
12. Mithlesh, S., Zubair, A.T., Mohit, B., Kotte, V., Kumar, K.P., Kurakula, V.S., and Singh, M., Improvement in performance of vented disc brake by geometrical modification of rotor, *Mater. Today: Proc.,* 2021. https://doi.org/10.1016/j.matpr.2021.05.006
13. Osenin, Yu.Yu., Douma, M.Al-M., Osenin, Yu.I., Sergienko, O.V., Sosnov, I.I., and Chesnokov, A.V., Providing the stability of the coefficient of friction of a vehicle disk brake under extreme operating conditions, *J. Frict. Wear,* 2016, vol. 37, no. 3, pp. 230–236.
14. Osenin, Yu.I., Kryvosheya, D.S., Kryvosheya, Yu.V., and Osenina, N.Yu., Disc brakes, Ukr. Patent 148210, *Byull. Izobret.,* 2021, no. 29.
15. Osenin, Yu.I., Malahov, O.V., Malahova, V.V., Krivosheya, Ju.V., and Antoshkina, L.I., Friction machine, Ukr. Patent 137412, *Byull. Izobret.,* 2019, no. 20.

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