

UDC 621.113.592.117

DOI <https://doi.org/10.52171/herald.395>

## **Analysis of Methods for Protecting the Working Surfaces of Disc Brakes from Moisture**

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### **Abstract**

In this article, theoretical and experimental studies of methods for protecting the working surfaces of vehicle disc-shoe brakes from moisture have been carried out. The results showed that the method for applying a coating to the disc's friction belts should be compatible with its base material, and their linear thermal expansion rates should be approximately identical to prevent coating failure; a system for removing moisture from the friction belts, based on the effect of electroosmosis, was proposed, allowing moisture to move into the cooler; to limit the replenishment of water entering through the microprotrusion channels from the matte surfaces of the rotating disc, an annular recess for water collection should be provided at the boundary between matte and polished surfaces; and an additional recommendation for testing wet friction pairs of vehicle disc-shoe brakes should be incorporated into Regulation №13 of the UN Economic Commission for Europe (UNECE).

**Keywords:** disc-shoe brake, friction pair, disc friction belt, surface protection methods, moisture removal, electroosmotic effect.

**Submitted** 05 January 2025

**Published** 16 March 2026

### **For citation:**

A.M. Semenyi

[Analysis of Methods for Protecting the Working Surfaces of Disc Brakes from Moisture]

Herald of the Azerbaijan Engineering Academy, 2026, vol. 18 (1), pp. 31-39

ISSN (p): 2076-0515, ISSN (e): 2789-8245

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## **Diskli əyləclərin işçi səthlərinin rütubətdən qorunması üsullarının analizi**

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### **Xülasə**

Məqalədə nəqliyyat vasitələrinin diskli-kündəli əyləclərinin işçi səthlərinin rütubətdən qorunması üsullarının nəzəri və eksperimental tədqiqinin nəticələri təqdim edilib. Aşağıdakı nəticələr əldə edilib: diskin sürtünmə zolaqlarına örtüyün tətbiqi üsulu elə seçilməlidir ki, o, əsas materialla uyğun olsun və onların xətti istilik genişlənmə sürətləri örtüyün dağılmasının qarşısını almaq məqsədilə kvazi-eynilik səviyyədə olsun; elektroosmos effekti əsasında işləyən, rütubətin təsiri altında soyuducuya yönləndirilməsini təmin edən diskli-kündəli əyləcin sürtünmə zolaqlarından nəmin uzaqlaşdırılması üçün sistem təklif edilib; fırlanan diskin tutqun səthlərindən mikroçixıntı kanalları vasitəsilə daxil olan suyun yenidən dolmasını məhdudlaşdırmaq üçün tutqun və parlaq səthlərin sərhədində suyun toplanması məqsədilə halqavari oyuq nəzərdə tutulmalıdır; BMT-nin Avropa üzrə İqtisadi Komissiyasının (UNECE) 13 sayılı Qaydasına nəqliyyat vasitələrinin diskli-kündəli əyləclərinin yaş sürtünmə cütlərinin sınaqları ilə bağlı əlavə tövsiyənin daxil edilməsi məqsədəuyğundur.

**Açar sözlər:** diskli-kündəli əyləc, sürtünmə cütü, diskin sürtünmə zolağı, səthlərin qorunması üsulları, rütubətin uzaqlaşdırılması, elektroosmotik effekt.

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## **Анализ методов защиты рабочих поверхностей дисковых тормозов от влаги**

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### **Аннотация**

В статье представлены результаты теоретического и экспериментального исследования методов защиты рабочих поверхностей дисково-паучковых тормозов транспортных средств от влаги. Получены следующие результаты: выбор метода нанесения покрытия на пояса трения диска производится таким образом, чтобы он был совместим с его основным материалом, а их скорость линейного теплового расширения была квазидинамической для предотвращения разрушения покрытия; предложена система для удаления влаги с поясов трения дисково-колодочного тормоза работающая на эффекте электроосмоса, когда под действием его сил влага перемещается в охладитель; для ограничения подпитки водой, поступающей по каналам микровыступов из матовых поверхностей вращающего диска, на границе между матовой и полированными поверхностями необходимо предусмотреть кольцевую выемку для сбора воды; необходимо ввести в правило №13 Европейской Экономической Комиссии при ООН дополнительную рекомендацию об испытаниях мокрых пар трения дисково-колодочных тормозов транспортных средств.

**Ключевые слова:** дисково-колодочный тормоз, пара трения, пояс трения диска, методы защиты поверхностей, удаление влаги, электроосмотический эффект.

## Introduction

Until now, the field of carbon brake discs has used one or another type of reinforcement, invariably carbon fibers in one form or another, such as fabric, chopped fiber, woven materials, etc. The main purpose of such fibers is to impart high mechanical properties to the discs, such as strength and stiffness, so that they can withstand the dynamic loads that occur during braking under prevailing operating conditions. Such applications are typically, but not exclusively, the automotive and aerospace industries, for example, for use in the braking systems of high-performance cars, sports cars, etc. The manufacture of laminated brake discs containing layers of carbon fabric or fibers is commonly referred to in the art as a carbon/carbon (C/C) composite. (The term "carbon" is used in a general sense and can mean both amorphous carbon and crystalline graphite.) In addition, brake discs are manufactured using a bulk carbon layer, such as bulk graphite, to reduce the manufacturing time and cost of the C/C composite laminate. Certainly, brake discs also use combinations of C/C composite materials and three-dimensional graphite layers. Furthermore, discs are made from carbon blanks impregnated with materials other than carbon, such as silicon. Such discs are sometimes called "carbon-ceramic." During operation, the brake friction surfaces can heat up to temperatures exceeding 1000°C, which impacts their performance. Such high temperatures lead to oxidation of the disc friction zone (the oxidation threshold of carbon is approximately 1010°C) and, consequently, increased wear of the brake friction surfaces.

Surface wetting is highly dependent on contamination. In disc brakes, when the friction pairs are wetted with water, hydrophilicity can

be artificially increased by increasing the specific load, surface temperature, and filtration rate. As the specific load increases, the surface tension of the water layer increases due to water leakage into the matte disc surface, reducing the selective wetting angle.

During electrothermomechanical frictional interaction, the friction zone of the disc heats up, and wetting its surface is accompanied by the release of heat. The greater the total heat of the water, the more hydrophilic the friction surface with its microprotrusions.

## Literature review and current state of the art

Numerous studies [1-7] have shown that wettability depends significantly on the viscosity of the coolant, as well as on the thermodynamic properties of the surface (heat-conducting or heat-insulated) on which it falls. These factors influence the intensity of heat exchange processes associated with the wettability of surfaces made of various materials. A series of experiments were conducted during the study. In the first experiment, the intensities of heat transfer during boiling water on a surface covered with a lavsan mesh and on a lavsan mesh were compared. The lavsan mesh covering the surface was impregnated with paraffin (wetting angle  $\theta = 105^\circ$ ), and a layer of silver ( $\theta = 63^\circ$ ) was sprayed onto the lavsan mesh itself. In the second experiment, experimental data were compared on coatings made of perforated fluoroplastic film with a hole diameter of 0.45 mm,  $\theta = 112^\circ$ , and the same film subjected to a special chemical treatment with a sodium-naphthalene complex to impart good wettability ( $\theta < 90^\circ$ ). The results of heat transfer measurements, presented in  $\alpha$ - $q$  coordinates, showed that within the measurement error in all experiments the points at  $q = \text{idem}$  are reproduced. According to the author [2], the wetting angle has very

little effect on heat transfer during water boiling on surfaces with perforated coatings. A hypothesis has been proposed to explain the experimental results. All the polymer coatings studied have low thermal conductivity, i.e., they are heat insulators.

Due to this property, there is a redistribution of specific heat fluxes over the heating surface and their concentration in those places where there are holes in the coating. The heat flux density in each hole of the perforated film is higher than the average calculated over the entire surface.

Due to the concentration of heat flux in the area of the holes, stable nucleate boiling at reduced pressures begins at significantly lower thermal loads averaged over the surface than in the absence of a perforated film. According to the author [2], the measurements he performed, as well as other literary sources, confirm the above assumption.

The thickness of the oil film in plain bearings was studied using the random variables method, without accounting for heat exchange with the environment [1]. The criterial equations for determining the oil film thickness were obtained on the basis of the initial equations for the contact-hydraulic wetting system "shaft - plain bearing" taking into account the boundary

conditions and uniqueness conditions, as well as generalized characteristics in the form of similarity criteria according to the second similarity theorem.

However, this method is not suitable for calculating the thickness of the water film located on the friction belt of a rotating vertical disk for the following reasons. The dynamic viscosity of oil is approximately 8-10 times greater than that of water; the mating surfaces do not roll, but slide relative to each other; the contact of the rubbing surfaces is not a point or linear contact; the  $Bi$  criterion was not taken into account in the calculations [1], characterizing the intensity of heat transfer through the thickness of the disk.

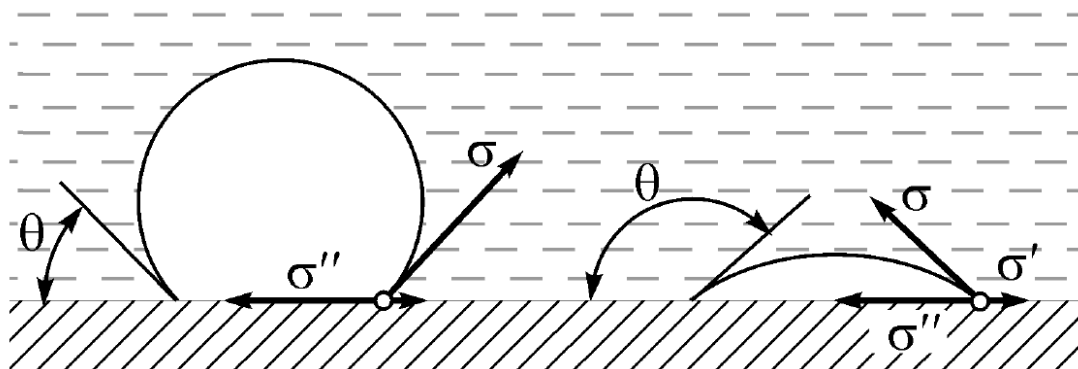
In [2], an equation was obtained for calculating the work of forming a bubble of volume  $V$  with a total surface area  $A$  during the boiling of a liquid on a solid surface, part  $a$  of which is free:

$$L = -\Delta p V + \sigma(A - a) + \sigma''a - \sigma'a, \quad (1)$$

where  $p$  - pressure in the bubble  $\sigma$ ;  $\sigma'$   $\sigma''$  - surface tension between liquid and vapor; liquid and solid surface; vapor and solid surface.

When the surface is wetted at point  $B$  capillary stress occurs (Fig. 1):

$$\sigma'' = \sigma' + \sigma \cos \theta. \quad (2)$$



**Figure 1** – Surface tension forces at the phase boundary and contact angle  $\theta$  on wetted (1) and non-wetted (2) surfaces

Therefore, the work of bubble formation depends on the area ratio  $a/A$  and the contact angle. It should be noted that as the angle changes *wettability* the value of the ratio changes  $a/A$ .

Then

$$L = -\Delta p V + \sigma A \left[ 1 - \frac{a}{A} (1 - \cos \theta) \right]. \quad (3)$$

In [8], the friction belt of a disc-shoe brake is coated with a nickel layer containing dispersed ceramic particles, at least 2.0  $\mu\text{m}$  thick, which increases its corrosion resistance and minimizes fluctuations in the braking torque of the friction pairs during braking. The nickel coating is formed on the surface of the disc friction belt using a composite deposition method, in which nickel and ceramic particles are simultaneously electrodeposited onto the surface of the disc friction belts. There was no coordination between the coating applied and the material contained within the disc.

In [9], the friction belt of a disc-shoe brake is considered, in which the disc is made of a carbon composite with a protective outer layer on the friction surface. The protective outer layer is preferably made of ceramic and is selected to provide a controlled dynamic friction coefficient and high wear resistance, corresponding to the prevailing vehicle operating conditions.

This development enables the use of a wide range of carbon substrates in brakes, which optimizes the cost and improves the efficiency of brake friction pairs. The applied protective material in the friction pair will have a low dynamic coefficient of friction in the temperature range of 100-220°C.

**The purpose of the work is** to protect the surfaces of the friction belts of disc brakes from

moisture and its effective removal into the atmosphere.

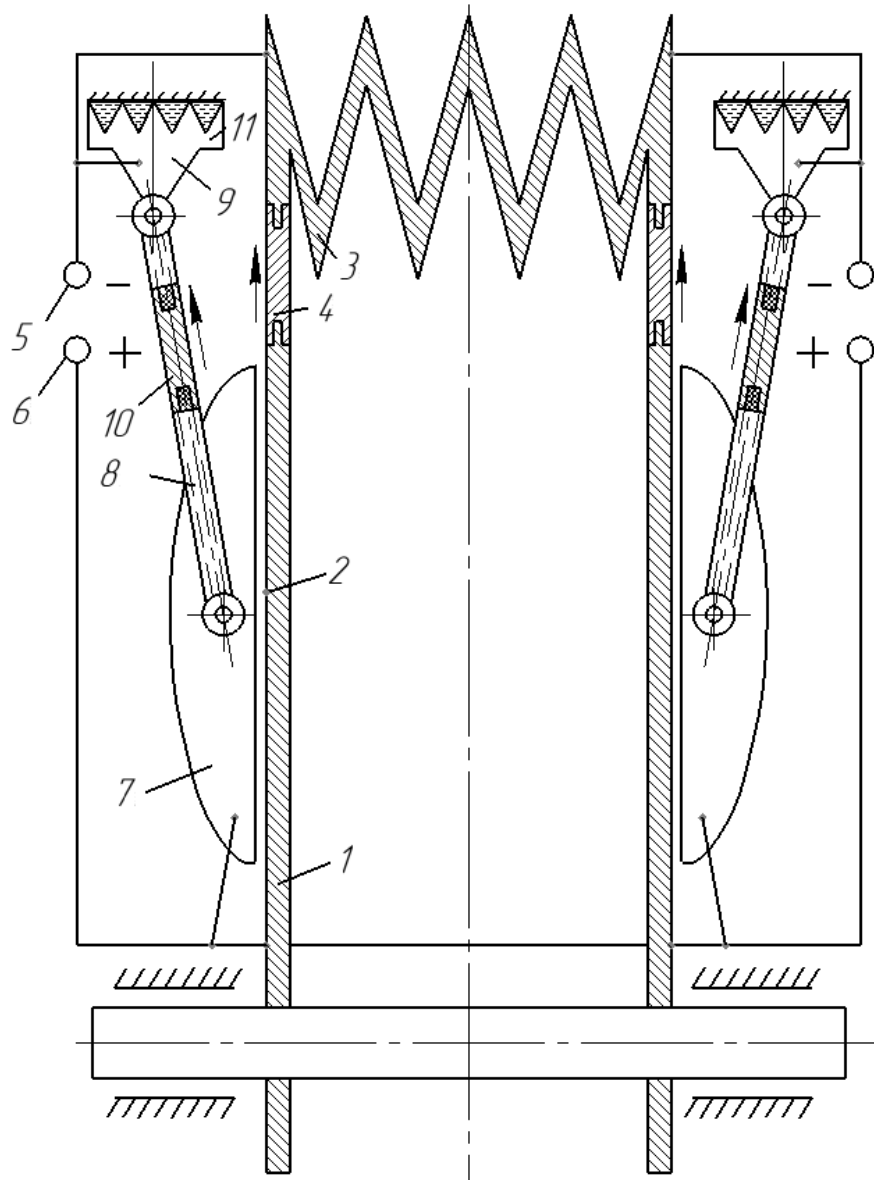
**A system for removing moisture from the friction zone of disc brakes.** The goal of this development is to increase service life and operational reliability by forcibly removing moisture from the surfaces of the disc brake disc friction zone and the friction linings of the disc brake pads.

Fig. 2 shows a cross-section of a disc-shoe brake. It comprises a housing 1 with end surfaces 2 for friction and heat generation, a finned cooler 3 having a developed heat exchange surface located on the periphery of the housing 1 and dissipating the generated heat into the atmosphere, inserts 4 made of insulating capillary-porous material in the form of rings 4 separating the cooler 3 of the brake disc from the friction surface 2, a DC voltage source with negative 5 and positive 6 poles, and brake shoes 7 attached by means of brake hangers 8 to fixed supports 9. Insulating inserts 10 made of capillary-porous material are mounted in the middle part of the brake hangers 8. Fixed supports 9 have a ribbed moisture collector 11. The cooler 3 and fixed supports 9 are connected to the negative pole 5, and the positive pole 6 is connected to surfaces 2 friction and brake pads 7. Brake pads 7, brake hangers 8 and fixed supports 9 are covered on top with a layer of capillary-porous material.

The disc brake operates as follows. When braking, the pads 7 are pressed against the friction surfaces 2, generating heat. The generated heat is dissipated into the atmosphere using a finned cooler 3. During rain or in damp, wet weather, the brake pads are switched on current source, the voltage from which is supplied from the negative pole 5 to the cooler 3 and the fixed support 9, and from the positive pole 6 to the pads 7 and the friction surface 9 2. In this case,

the process of electroosmosis takes place and, under the action of electroosmotic forces, moisture from the friction surface 2 moves into the

cooler, and from the brake pads 7 to the fixed support 9 on the moisture collector 11, where it is collected and dissipated into the atmosphere.



**Figure 2** – Disc-shoe brake with a system for removing moisture from the end surfaces: 1 - brake disc housing; 2 - disc friction surface; 3 - cooler; 4 - rings; 5, 6 - negative and positive poles of the electrical circuit; 7 - brake pads; 8 - suspension; 9 - fixed supports; 10 - inserts; 11 - moisture collector

Let's move directly to materials for protecting the surface of brake discs from moisture.

**Materials for protecting disc surfaces from moisture.** Analysis of materials with a ceramic or silicon carbide matrix revealed the following. The introduction of abrasive additives

in the form of powders and fibers into the friction lining composition is used for both metal-ceramic and composite materials with polymer and carbon matrices, but this does not make them purely ceramic. Therefore, only friction linings made from composite materials with a

ceramic matrix can legitimately be called ceramic.

The advantages of composite materials with a ceramic matrix obtained using PIP technology are the ability to control the structure and composition of the resulting compositions, the absence of thermal and chemical degradation of reinforcing and carbon fibers and powder additives during the pyrolysis of the silicon-containing binder.

Products obtained by the above methods have a range of improved performance characteristics, such as a high and stable dynamic friction coefficient, its independence from the flash point at the contact spots of microprotrusions and weather conditions, high wear-corrosion and heat resistance, resistance to thermal shock, and low density.

Another option for improving the performance of brake components made from the proposed materials is the development of gradient and layered friction materials, which combine highly wear-resistant surface layers with high impact toughness in the inner layers. However, it should be noted that the presence of wear-resistant surface layers is more typical for CMC brake discs, as they are the most expensive component designed for long-term use in the braking system, while the friction linings are consumables.

In this case, it is necessary to take into account the data in Table.

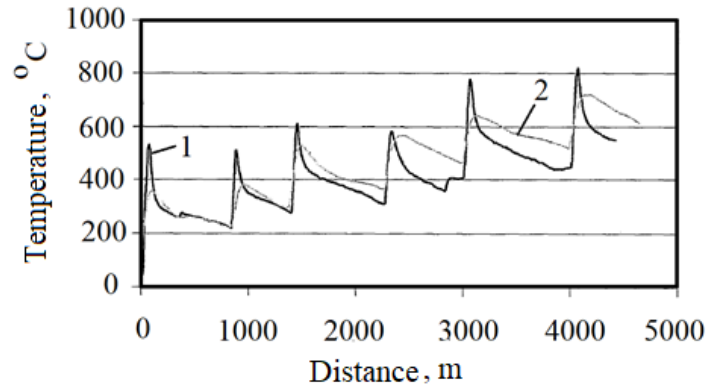
As shown in Table, the elemental composition of materials in friction pairs, related to their wear, performs different functional purposes.

**Table** – The influence on the wear of the working surfaces of friction pairs depending on the elemental composition of their materials

Element	Effect on wear of working surfaces:	
	<i>overlays</i>	<i>metal element</i>
With st.	reduces (improves thermal stability, promotes the formation of a lubricating layer)	reduces (the dynamic coefficient of friction by forming protective films)
S	increases (forms brittle sulfides, reduces the strength of the lining)	reduces (sulfide compounds acting as a lubricant)
Al	increases (causes increased abrasiveness)	increase (aluminum oxides increase mechanical wear)
Cu	reduces (improves thermal conductivity, reduces local overheating)	reduces (the tendency to stick and form burrs)
Fe	increases (hard particles can act as an abrasive)	increases (high content increases contact rigidity)
Si	increases (the abrasive properties of silicon compounds)	increases (silicates scratch the working surface of the pad)
Zn	reduces (has anti-corrosion properties, but high content leads to brittleness)	increases (zinc oxides form solid inclusions)
Pb	reduces (works as a solid lubricant, improves contact)	protects the surface from excessive wear)
Ni	decreases (increases the strength of the material)	increases (may cause an increase in the rigidity of local contact)

The work function of electrons and ions is of interest, since it forms the local energy level of ohmic, neutral, and blocking contacts due to the work function of electrons and ions ( $W$ ) from the "metal-polymer" of the friction pair. For ohmic contacts –  $W_M > W_P$ ; neutral

$W_M = W_P$ ; and for the blocker –  $W_M < W_P$  when the instantaneous superconductivity effect occurs. These contacts provide the interconnection of internal and external parameters in the friction pairs of braking devices.



**Figure 3** – Regularities of temperature change of friction pairs of a Formula 1 car's disc-shoe brake depending on the length of the Montreal circuit: with a standard disc (1) and with a sawn friction belt (2), interacting with friction linings made of carbon-carbon material [8]

Let's move on to the most loaded disc-shoe brakes of the so-called high-speed cars.

Analysis of the graphical patterns shown in Fig. 3 showed the following:

- the coating of the brake disc friction belt is selected in such a way that it is compatible with its base material, and their rate of linear thermal expansion is essentially quasi-identical in order to avoid delamination at the permissible temperature of the brake friction pairs; for example, a coating applied by plasma spraying from aluminum oxide  $Al_2O_3$  should be at least 0.2 mm thick;

- testing of a car with disc-shoe brakes at a typical average speed and braking torque with its new friction pair made it possible to obtain a dynamic friction coefficient of up to 0.7;

- to ensure braking efficiency, the brake friction pairs were preheated to a temperature of at least 200°C before testing.

## Discussion of Results

Theoretical and experimental studies of methods for protecting the working surfaces of vehicle disc brakes from moisture revealed the following:

- the method of applying the coating to the friction belts of the disc is selected in such a way that it is compatible with its base material, and their rate of linear thermal expansion is quasi-identical to prevent destruction of the coating;

- a system for removing moisture from the friction belts of a disc brake is proposed, operating on the effect of electroosmosis, when, under the action of its forces, moisture moves into the cooler;

- to limit the supply of water coming through the channels of the microprotrusions from the matte surfaces of the rotating disk, it is necessary to provide an annular recess for collecting water at the boundary between the matte

and polished surfaces;

- it is necessary to introduce into Regulation №13 of the UN Economic Commission for Europe an additional recommendation on testing wet friction pairs of disc-shoe brakes of vehicles.

## Conclusion

Thus, methods for protecting the friction belts of disc-shoe brakes of vehicles from moisture are proposed.

## Conflict of Interests

The author declares there is no conflict of interests related to the publication of this article.

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