longevity of the brake linings; vehicle; brake system; resource of the brake lining

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RESEARCH TO LONGEVITY BRAKE LINES ON THE EXPLOITATIONS

Summary. Brake lines are tested for strength and durability. However, tests of strength are short-term, but tests of durability are durable, since their aim is to assess the effectiveness of the brake linings during operation. Therefore, reduction of time evaluating the durability of brake linings exploitation is urgent. The article describes the results of the research on the longevity of the brake linings of different types of vehicles based on their controllable operation and the method of accelerated estimation of the longevity of brake linings based on the operation of their analogues.

ИССЛЕДОВАНИЕ ДОЛГОВЕЧНОСТИ ТОРМОЗНЫХ НАКЛАДОК В ЭКСПЛУАТАЦИИ

Аннотация. Тормозные накладки проверяют на прочность и долговечность. Но, испытания на прочность – кратковременны, а на долговечность – длительны, так как их цель заключается в оценке эффективности работы тормозных накладок в процессе эксплуатации. Поэтому сокращение времени оценки долговечности тормозных накладок в эксплуатации является актуальным. В работе приведены результаты исследований долговечности тормозных накладок различных автотранспортных средств по результатам подконтрольной эксплуатации и метод ускоренной оценки долговечности тормозных накладок по результатам эксплуатации аналога.

1. INTRODUCTION

The Department of Automobile Transport of the Volgograd State Technical University (VSTU) in cooperation with the Testing Laboratory (TL VSTU) accredited within the system of mechanical vehicles and trailers of the State Standard № РОСС RU. 0001.21МТ38 have been for several years dealing with the estimation of brake linings of *KamAZ* auto-trucks, *Ikarus* and *Mercedes Benz* buses, *Gazelle* mini-buses and *GAZ* and *VAZ* motor cars under the conditions of practical operation and maintenance according to the agreements with the Volzhsky Factory for Asbestos Technical Products.

Friction linings for brake shoes are one of the main elements of the braking system which determines the technical state of a vehicle in accordance with the safety requirements and provides efficient braking. Nowadays factories for asbestos technical products produce brake linings and shoes for different kinds of motor vehicles with different lifetime and operation modes on the road [1 - 4].

During the lead time a large number of checkups and tests of preproduction series is required, including those under real operation conditions. Besides, each type of products should comply with the requirements of the RULES EEK OON № 13, 13H, 99. Moreover, the results of their controllable operation are used by factories to manage the stability of production.

Friction linings are checked for strength and longevity [5, 6]. While checks for strength are short-term, checks for longevity are rather long-term. The compliance of brake linings with the safety requirements depending on the maintenance frequency suggested by the manufacturer is determined on the basis of their long-term investigation in real operation. This is why it is of current interest to the enterprises in this sphere to reduce the time needed for the determination of the longevity of brake linings.

2. OBJECTIVES

Each type of motor vehicle is kit up with brake linings of different shape and thickness. However, a factory produces brake linings of different types with the same raw materials, the same technology. The main material for a counterbody (i.e. a brake disk or a brake drum) is cast iron, usually of the brand СЧ24 GOST 1412-85 and hardness 187-241 HB. Evidently, in this case the values of the friction ratio in the pair "brake lining - counterbody" will be approximately equal in the brake mechanisms of different vehicles.

The motor vehicles are kit up with disk and drum working brake mechanisms. However, despite considerable differences in the construction of the brake mechanisms, they can still perform the same function that determine their operating conditions. In this case it could be assumed that during the operation of different vehicles the brake linings of monofunctional (by load) brake mechanisms experience the same specific pressures, then the wear rate of brake linings for 1 meter of braking distance would be the same, regardless of the type of vehicle. This is confirmed by the data obtained by calculating the specific pressure and a specific work of friction forces in a pair of friction (see Tab. 1) by method of Lukin, Gasparyants and Rodionov [9].

Table 1

Values of specific pressures and specific work of friction forces for different vehicles

Brand of vehicle	Specific pressure (MPa)	Specific work of friction forces (kJ/cm^2)	Δ, %
GAZ-3221	5,8	0,222	0,3
GAZ-3102	5,3	0,205	8,3
VAZ-2101, VAZ-2106	5,4	0,214	6,5
VAZ-2110	5,5	0,214	4,8
KamAZ-5320	5,6	0,153	3,1
Ikarus-280	6,4	0,147	10,3
Mercedes Benz 0 302 S	6,2	0,161	7,3

Meanwhile, the vehicle manufacturers regulate different maximum values of the frictional layer residual thickness in the maintenance documentation, which has to be taken into account during the brake lining longevity test.

Depending on the road operating conditions vehicles would have different brake modes and, consequently, different lining life [7, 8].

Thus it is necessary to work out a method which on the basis of the chosen analogue, the vehicle with the most intensive brake modes and the lining life of the vehicle analogue would enable us to predict lining life for any vehicles with brake linings from the same manufacturer and to reduce the duration of tests under real operating conditions.

3. METHODOLOGY OF CURRENT WORK

To work out the method of accelerated estimation of the brake lining longevity on the basis of their analogue's operation, the following solutions to the set problem were found and applied:

1.
The analysis of the vehicles' brake mechanism construction by the maintenance documentation provided by the manufacturer and the development of the vehicles database. The database should include the vehicles of the following brands: KamAZ, VAZ, GAZ, Ikarus, Mercedes Benz, and with the following characteristics: fully loaded mass and wheelbase of a vehicle, static radius of the wheel, a vehicle's height of centre of gravity, distance from front and back axles of a vehicle to its centre of gravity, facing area, the number of friction pairs, average radius of a brake lining.

The source data for the calculation are the fore- and rear wheels adhesion factor, initial and terminal braking velocity, the number of braking per kilometer, braking time, friction ratio within the pair "brake lining - counterbody".

In the beginning of the research special work methods for testing the longevity of brake linings under real operating conditions were developed for each type of brake linings, installed on the abovementioned vehicles. The analysis of the technical conditions for the production of brake linings has proved the identity of their materials and production technologies.

According to a well-known dependence the specific pressures p_i which work on the brake linings of the controllable vehicles have been calculated out of the adhesion conditions [9]:

$$p_i = \frac{\mathrm{M_T}(\varphi)}{\mu \cdot \mathrm{R_{cp}} \cdot \mathrm{i} \cdot \mathrm{F_н}}, \tag{1}$$

where: $M_m(\varphi)$ – a braking moment that depends on the adhesion factor (N·m); μ – friction ratio (we receive equal 0.35 [10]); R_{cp} – average radius of the brake lining location (m); i – number of friction pairs; $F_и$ – facing area (mm^2)

A braking moment has been calculated according to the following formula:

$$M_{\mathrm{T}}(\varphi) = \varphi \cdot R_z \cdot r_к\ , \tag{2}$$

where: φ - the coefficient of traction; $r_к$ – the radius of the wheel rolling (m); R_z – the reaction of the support surface on the wheel, determined taking into account the redistribution of load between the axles of the vehicle under braking (N)

$$R_Z = \frac{m_a \cdot g}{2} \cdot (1 + \frac{\varphi \cdot h_g}{L})\ , \tag{3}$$

where: m_a – vehicle weight per axle (kg); g – free fall acceleration (m/sec^2); h_g – the height of the centre of mass of vehicle (m); L – wheelbase (m)

The definition of the quantities and the legitimate value test of the specific friction work (ΔL_i) have been calculated according to the following method:

$$\Delta L_i = \frac{G \cdot (V_2^2 - V_1^2)}{2 \cdot g \cdot F_\Sigma} \le [\Delta L], \tag{4}$$

where: F_Σ – total facing area of all the braking mechanisms of the working brake system (mm^2); g – free fall acceleration (m/sec^2); V_1 – motor vehicle velocity at the initial stage of braking (m/sec); V_2 – motor vehicle velocity at the terminal stage of braking (m/sec); G – mass of the vehicle

The results of the calculations of specific pressures and their deviations (Δ) from the average value (5,78 MPa) and of specific friction work of the vehicles under experiment are presented in Tab. 2.

The deviation of the design pressure values is in the range of 10%. The value of ΔL is significantly smaller than the maximum value of $0{,}4\text{-}1{,}0 \cdot 10^{-4}$ kJ/cm^2. It enables us to insist on the fact that the lining friction material wear in the brake mechanisms under investigation occurs under the same environmental conditions.

Table 2

The results of the calculations of specific pressures and their deviations from the average value

Brand of vehicle	Average initial velocity of braking before stopping (km/h)	Specific pressure (MPa)	Specific work of friction forces (kJ/cm^2)	Δ, %
GAZ-3221	37,6	5,8	0,222	0,3
GAZ-3102	38,5	5,3	0,205	8,3
VAZ-2101, VAZ-2106	38,5	5,4	0,214	6,5
VAZ-2110	38,5	5,5	0,214	4,8
KamAZ-5320	55,6	5,6	0,153	3,1
Ikarus-280	32,2	6,4	0,147	10,3
Mercedes Benz 0 302 S	30,6	6,2	0,161	7,3

2.

Full-scale investigation of brake-release modes. Methods of defining of the motor vehicles' brake-release modes are presented in this article [11]. Determination of the average initial speed of braking and braking distance was organized by controlled operation of 15 vehicles each brand. It was an every day process for two weeks duration.

The choice of the analogue, i.e. a vehicle with the most intensive braking modes, is made with account of average velocity of initial braking using the following parameters: the number of brakings per kilometer; friction length per kilometer (see Tab. 3).

The maximal values of these parameters are found in the vehicle GAZ-3221, used as a route taxi, which has been chosen as a vehicle analogue.

Table 3

Values of braking friction length per kilometer

Brand of vehicle	Braking mechanism with maximum load	Braking length per kilometer (m)	Friction length per kilometer (m)
GAZ-3221	Front disk	117,3	42,69
GAZ-3102	Front disk	40,2	14,62
VAZ-2101, 2106	Front disk	54,1	19,67
VAZ-2110	Front disk	50,8	18,48
KamAZ-5320	Rear drum	33,2	12,09
Ikarus-280	Rear drum	75,7	27,54
Mercedes Benz 0 302 S	Rear drum	69,8	25,41

3.

The development of a mathematical model of repair-free lining life of the analogue vehicle. The model was developed on the basis of measurements of the residual thickness of the analogue's friction layer. The calculation of the analogue's lining life is made on the basis of the limiting state, i.e. the minimal thickness of the friction layer.

According to the wear process theory, "time - wear rate" relationship was approximated on the stage of the fixed process by a sample straight-line equation [12]:

$$y_x = -0{,}67 \cdot x + 12{,}24, \tag{5}$$

where: x – kilometrage (thousand km.), y_x – average residual thickness of a friction layer (mm)

The graphic interpretation of change in residual thickness of the analogue's friction layer depending on the kilometerage is presented in Fig. 1, using the regression equation (5).

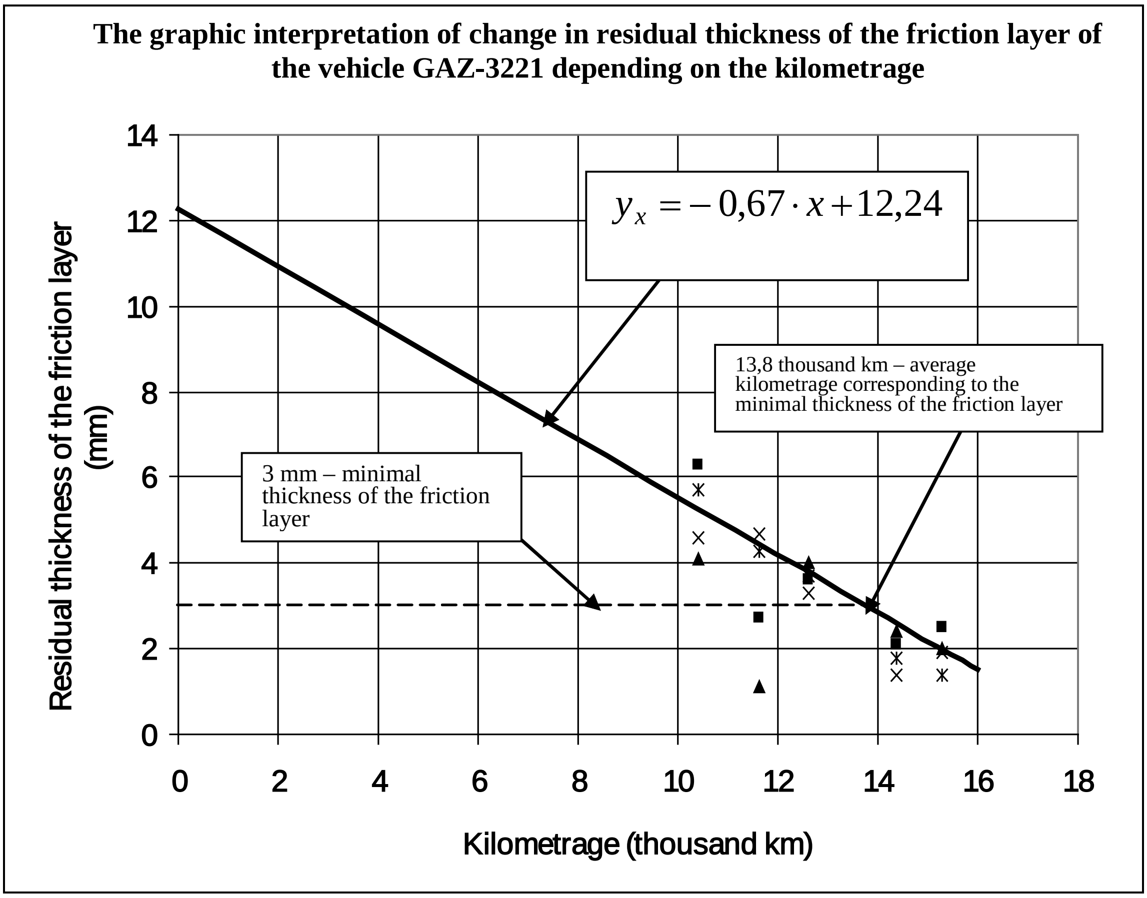

Fig. 1. The graphic interpretation of change in residual thickness of the friction layer of the vehicle GAZ-3221 depending on the kilometerage

Рис. 1. Графическая интерпретация изменения остаточной толщины фрикционного слоя автомобиля ГАЗ-3221 в зависимости от пробега

On the basis of the developed mathematical model the average analogue's lining life is calculated.

4.

The development of an equation for prediction of lining life. The estimate of an average lining life of the vehicles under investigation with account of the braking distance per kilometer and the limited value of the thickness of friction layer is made by the formula:

$$T_{cp} = T_a \cdot K_s \cdot K_h, \quad (6)$$

where: T_{cp} – average lining life of the vehicle under investigation; T_a – average lining life of the analogue; K_s – index equal to the ratio of the linings' friction length by braking per kilometer of the analogue to that of the vehicle under investigation; K_h – index equal to the ratio of the lining's working layer thickness in the vehicle under investigation to that of the analogue

The method of accelerated estimation of the brake lining longevity on the basis of their analogue's operation includes the following stages:

1. Specific pressure balance check and calculation of the linings' specific friction force per accepted value.
2. Identification of a motor vehicle's brake-release modes and choice of a vehicle with the most intensive braking (of the analogue) judging by the braking distance per kilometer.
3. Estimation of the linings' wear rate per kilometer of the braking distance of the analogue.

4. Estimation of the analogue's lining life on the basis of the limiting state, i.e. the minimal thickness of the friction layer.
5. Prediction of the average and gamma-percentile lining life (*Here:* only linings produced by the same manufacturer are under consideration) with account of the particular vehicle's braking distance per kilometer and its limiting state of residual thickness of the linings' friction layer.

4. RESULTS

The method of accelerated estimation of the brake lining longevity on the basis of their analogue's operation allowed us to make necessary calculations. The results of the calculations average lining life of the analogue, average lining life (math model) and average lining life of the vehicle under investigation are presented in Tab. 4. The calculated values are in the range of the resource defined by the results of the controlled operation.

Table 4

Average lining life of vehicles

Brand of vehicles	K_s	K_h	Average lining life of the analogue, (thousand km)	Average lining life (math model), (thousand km)	Average lining life of the vehicle under investigation, (thousand km)	Confidence limits, (thousand km)	
						Lower	Upper
GAZ-3221	1	1	13,8	12,5	13,8	13,1	14,5
VAZ-2110, 2115	2,24	1	30,9	34,0	24,5	13,7	35,3
KamAZ-5320	3,36	1,33	61,7	70,7	76,0	54,0	98,0
Ikarus-280	1,99	1,33	36,5	59,9	54,5	34,8	74,2
Mercedes Benz 0 302 S	1,60	1,11	24,5	39,3	33,8	19,6	48,0
MAZ-64229	2,85	1,11	43,7	53,5	64,2	36,5	91,9

The suggested method can be of interest to both manufacturers of brake linings and to the enterprises that use vehicles. This method was applied to vehicles of the following brands: KamAZ, MAZ, Ikarus, VAZ, GAZ, Mercedes Benz.

The method of accelerated estimation of the brake lining longevity on the basis of their analogue's operation enables us to predict average and gamma-percentile lining life of vehicles and to reduce the duration of longevity tests of the linings of different types produced by the same manufacturer. Moreover, the method allows to learn the residual thickness of a lining's friction layer without disassembling the brake mechanisms and reduces labour intensiveness and costs for maintenance. This method has been implemented within the production process of LLC "VolTax" and JSC "VATI" to service their vehicles.

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