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Application of different types of motor-axle bearings of locomotive wheel-motor units in the Far North

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ABSTRACT Improvements in locomotive wheel-motor unit (WMU) design over the last decade have been made in terms of the transition to rolling motor-axle bearings (MAB) instead of plain bearings, which was the basis for the proposed study. The study is aimed to provide a theoretical estimation of power losses in different types of locomotive WMU MAB and its validation depending on heating temperature and bearing specifications. The study is aimed to determine power losses in MABs using new approaches to their determination.

New methods of determining the power losses in the plain and rolling MABs of locomotive WMUs are suggested.

These methods allow calculating the values of power losses depending on the specifications of MAB and its heating temperature. Depending on the bearing heating temperature, recommendations are provided with regard to operating conditions of a particular type of locomotive WMU bearing. It is recommended to operate motor-axle plain bearings in the temperature range of 10 to 20 °C, and rolling bearings from 20 °C and above.

The suggested methodologies for calculating power losses of locomotive WMU MABs can be used to determine the energy efficiency of a given drive type, taking into account the type of the grease, its temperature, design features and operating conditions. The obtained results can serve as recommendations for the selection of the type of MAB.

KEYWORDS: motor-axle bearing; axial oil; dynamic viscosity; friction coefficient; traction rolling stock; plain bearing; rolling bearing; power loss; and wheel-motor unit

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Научная статья

Применение различных типов моторно-осевых подшипников колесо-моторных блоков локомотивов в районах Крайнего Севера

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АННОТАЦИЯ Совершенствование конструкции колесо-моторного блока (КМБ) локомотива в последние десять лет осуществлялось в части перехода на моторно-осевые подшипники (МОП) качения вместо подшипников скольжения, что стало основанием для предлагаемого исследования. Цель исследования — теоретическая оценка уровня потерь мощности в различных типах МОП КМБ локомотивов и ее апробация в зависимости от температуры нагрева и технических характеристик подшипников. Задачи исследования — определение потерь мощности в МОП с использованием новых подходов к их установлению.

Предлагаются новые методики определения потерь мощности в МОП скольжения и качения КМБ локомотивов.

Данные методики позволяют рассчитывать величины потерь мощности в зависимости от технических характеристик МОП и его температуры нагрева. В зависимости от температуры нагрева подшипника приводятся рекомендации по условиям эксплуатации конкретного типа подшипника КМБ локомотива. Моторно-осевые подшипники скольжения рекомендуется эксплуатировать в диапазоне температур от 10 до 20 °C, подшипники качения от 20 °C и выше.

Предложенные методики расчета потерь мощности МОП КМБ локомотивов могут быть использованы для установления энергетической эффективности данного типа привода, принимая во внимание тип смазочного материала, его температуру, конструктивные особенности и условия его эксплуатации. Полученные результаты могут послужить рекомендациями по выбору типа МОП.

КЛЮЧЕВЫЕ СЛОВА: моторно-осевой подшипник; осевое масло; динамическая вязкость; коэффициент трения; тяговый подвижной состав; подшипник скольжения; подшипник качения; потери мощности; колесо-моторный блок

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INTRODUCTION

Improvements in wheel-motor unit (WMU) design in terms of motor-axle bearings (MAB) in the last ten years have been associated with a transition to rolling bearings [1]. Differences in design and operating principle between plain and rolling bearings place different demands on the lubricant used and the performance of the bearings[1].

Operation of locomotives in the Far North in winter in terms of high negative temperatures affects physical and chemical properties of the grease [2–5]. In this regard, the question of energy efficiency of different types of locomotive WMU MABs in the Far North regions of Russia is relevant.

The purpose of this paper is to provide a theoretical evaluation of power loss level in plain and rolling MABs of locomotive WMU and its validation depending on heating temperature and bearing specifications.

MATERIALS AND METHODS

Calculation methodology for power losses in plain MABs

The methodology for calculating power losses in plain MABs of locomotive WMU with axle-suspension was presented earlier [6]. The friction coefficient *f* in plain bearings changes with increasing speed according to a rather complex characteristic described by the Hersey-Stribeck diagram[2], shown in *Fig. 1* [7, 8].

The angular rates of transition from dry friction ω_{WS1} to semi-liquid friction and from semi-liquid friction to liquid friction ω_{WS2} can be determined from the following ratios [6, 9]

$$\omega_{WS1} = \frac{4}{3 \cdot 10^8} \frac{F_{r\,MAB}}{c \cdot \mu \cdot d_{MAB}^2 \cdot l_{MAB}}; \tag{1}$$

$$\omega_{WS2} = \frac{F_{r\,MAB}}{l_{MAB} \cdot d_{MAB}^3} \frac{\Delta^2}{\mu \cdot [S_0]}, \tag{2}$$

where $F_{r\,MAB}$ is radial load on the MAB, N; l_{MAB} is MAB insert length, m; d_{MAB} is diameter of MAB shaft journals, m; $[S_0]$ is dimensionless Sommerfeld number.

According to the works [6–8] in the dry friction range the coefficient of friction f_{0-1} may be taken as equal to 0.12.

In the area of liquid friction (section 2–3 in *Fig. 1*), in accordance with the works[3] [6] the friction coefficient f_L in plain MAB is

$$f_L = 3.7339 \frac{d_{MAB}^{0.731}\, l_{MAB}^{0.577}\, \mu^{0.577}}{\Delta^{0.154} F_{r\,MAB}^{0.577}} \omega_{WS}^{0.577}, \tag{3}$$

where Δ is diametrical clearance in the bearing.

[1] Anisimov I.G., Badyshtova K.M., Bnatov S.A. et al. Fuels, lubricants, technical liquids. Product range and application: Handbook. Moscow, Tekhinform, 1999;596. (In Russ.).

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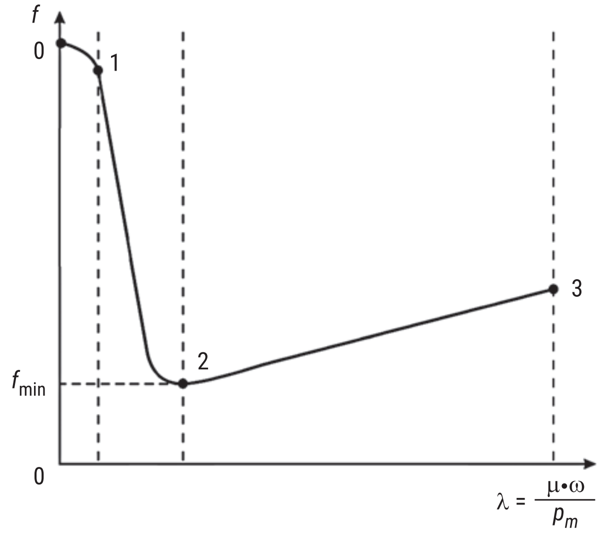

Fig. 1. Guersey – Striebeck diagram:
μ — dynamic viscosity of the grease (Pa · s); ω — angular speed of rotation of the shaft (in our case, the wheelset ω_{WS}, rad/s); p_m — average specific bearing load, Pa

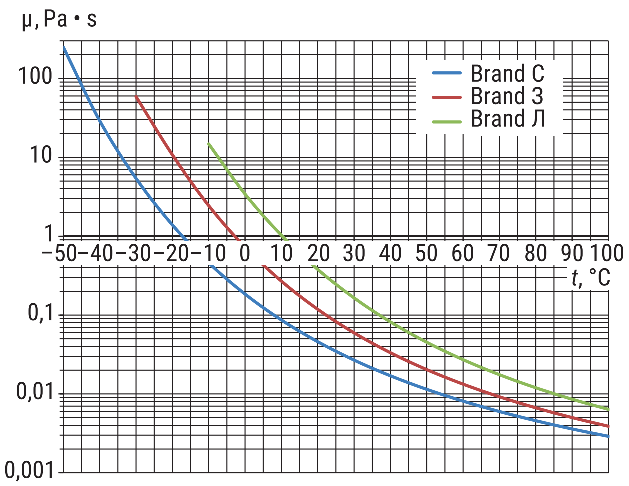

Fig. 2. The results of determining the dynamic viscosity of different brands of axial oils depending on temperature

In the area of semi-liquid friction, the friction coefficient f_{SL} is determined by

$$f_{SL} = \frac{f_1(\omega_{WS2} - \omega_{WS}) + f_2(\omega_{WS} - \omega_{WS1})}{\omega_{WS2} - \omega_{WS1}}. \quad (4)$$

The power loss capacity of the plain MAB is calculated according to the following relationship

$$\Delta P_{MAB} = F_{r\,MAB} d_{MAB} f \omega_{WS}. \quad (5)$$

As can be seen from the above dependencies, the friction coefficient and power loss capacity of the MAB is influenced by the dynamic oil viscosity μ and the diameter gap Δ.

The dynamic oil viscosity μ depends mainly on the type of oil used and its temperature. The main requirements for physical and chemical characteristics of the oil in plain MABs of locomotives are defined according to GOST 610-2017.

The dependence of the dynamic viscosity of these oils on the ambient temperature was determined analytically have been determined in the work[3], as shown in *Fig. 2*.

Calculation methodology for power losses in rolling MABs

Friction loss capacity of the rolling MABs is determined by

$$\Delta P_{MAB} = \sum_{i=1}^{2} \Delta M_{MAB\,i}\, \omega_{WS}, \quad (6)$$

where $\Delta M_{MAB\,i}$ is friction loss moment in one of the rolling bearings.

According to the publication[2], friction torque in the rolling bearing can be calculated according to the following relationship

$$\Delta M_{MAB} = \Delta M_{MAB0} + \Delta M_{MAB1}, \quad (7)$$

where ΔM_{MAB0} is friction loss torque depending on bearing type; ΔM_{MAB1} is friction loss torque depending on bearing load.

Considering the lubrication conditions, one of the dependencies is used at $\nu\omega_{WS} \geq 209$

$$\Delta M_{MAB0} = 10^{-7} f_0 \left(\nu \frac{30}{\pi}\right)^{2/3} D_{0MAB}^3 (\omega_{WS})^{2/3}; \quad (8)$$

at $\nu\omega_{WS} < 209$

$$\Delta M_{MAB0} = 160 \cdot 10^{-7} f_0 D_0^3, \quad (9)$$

where f_0 is coefficient depending on bearing type and lubrication conditions; ν is kinematic viscosity of the grease, mm²/s; D_0 is average bearing diameter.

In equations (8) and (9) the torque value is obtained in Nmm.

Spherical roller double row bearing 23048/W33 and radial single row bearing 20-7032148 are used as rolling MABs on locomotives[4] [2, 9, 10].

We will find the average diameter of the rolling MAB according to the equation

$$D_{0MAB} = \frac{1}{2}(d_{MAB} + D_{MAB}), \quad (10)$$

where d_{MAB} is bearing inner diameter; D_{MAB} is bearing outer diameter.

[4] 2TE25KM mainline freight double section diesel locomotive. Operation manual. Part 1. Technical description. MC BMBP, CJSC, 2015;153. (In Russ.).

Substituting the bearing dimensions into equation (10), we will obtain:

$$D_{0\mathrm{MAB}} = 0{,}5 \cdot (240 + 360) = 300 \text{ mm}.$$

According to the paper[3], for a spherical roller double row angular contact bearing the coefficient f_0 is 4 to 6 and for a single row radial roller bearing the coefficient f_0 is 6 to 12.

Friction loss torque depending on bearing load ΔM_{MAB1}, is determined on the basis of the ratio[3]

$$\Delta M_{\mathrm{MAB1}} = f_1(g_1 P)D_0, \tag{11}$$

where f_1 is coefficient depending on bearing type and degree of loading; g_1 is coefficient depending on the ratio between the radial and axial loads borne by the bearing.

Coefficient f_1, included in the equation (11), according to the data[3] can be taken as equal to f_1 = 0.0005 for the rolling MABs used.

The coefficient depending on the ratio of the radial load to the axial load taken by the bearing is determined by the ratio

$$g_1 = P_1 F_r, \tag{12}$$

where F_r is radial load on the bearing.

The radial load on the rolling MAB is taken as equal to the radial load on the plain MAB.

Consequently, the values of the torque components ΔM_{MAB1} on both supports will be equal and calculated according to the following relationship

$$\Delta M_{\mathrm{MAB1}} = f_1 F_{r\,\mathrm{MAB}} D_{0\mathrm{MAB}}. \tag{13}$$

Substituting these results into the equation (6), we will obtain the following relationship for determining power loss in a rolling MAB: at $\nu\omega_{\mathrm{WS}} \geq 209$

$$\Delta P_{\mathrm{MAB}} = \\ = \left[\begin{aligned} &0.1\left(f_0' + f_0''\right)\left(\nu\frac{30}{\pi}\right) D_{0\mathrm{MAB}}^3 \left(\omega_{\mathrm{WS}}\right)^{2/3} + \\ &+2 f_1 F_{r\mathrm{MAB}} D_{0\mathrm{MAB}} \end{aligned}\right]\omega_{\mathrm{WS}}, \tag{14}$$

at $\nu\omega_{\mathrm{WS}} < 209$

$$\Delta P_{\mathrm{MAB}} = \left[\begin{aligned} &16\left(f_0' + f_0''\right) D_{0\mathrm{MAB}}^3 + \\ &+ 2 f_1 F_{r\mathrm{MAB}} D_{0\mathrm{MAB}} \end{aligned}\right]\omega_{\mathrm{WS}}. \tag{15}$$

Given the design features of WMU with rolling bearings [10], the coefficients f_0' and f_0'' mean that their values are different for the bearing supports.

The characteristics presented (14), (15) show that the change in power loss capacity in a particular rolling MAB depends on the angular rotation speed of the wheelset ω_{WS} and kinematic viscosity of the mineral oil.

As an example, let's take LOCOLIT rolling bearing grease by "TITAN-SM", LLC. This type of grease is used in the range of operating temperatures from –50 to +150 °C.

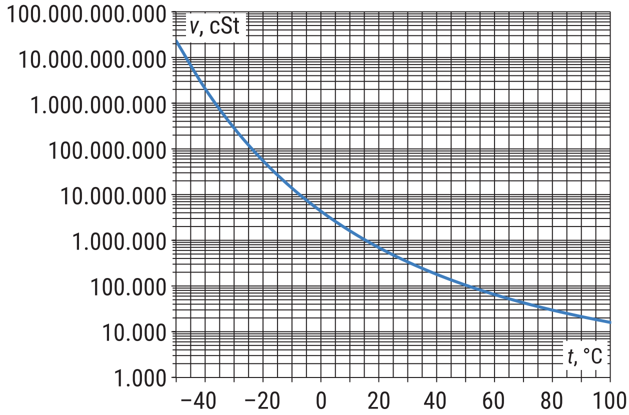

Fig. 3. Kinematic viscosity of LOCOLIT grease for rolling bearings as a function of temperature

The values of the kinematic viscosity at different temperatures are determined according to Walter's empirical formula [9]

$$\lg(\lg(\nu_t + c)) = a + b\lg(T); \tag{16}$$

where ν_t is kinematic viscosity of the liquid at a given temperature, cSt; a, b, c are coefficients which are constant for a given liquid type; T is liquid temperature, °K.

Using dependence (16), kinematic viscosity values in the range of operating temperatures from –50 to +100 °C were determined (*Fig. 3*).

RESULTS OF THE STUDY

Calculation of power losses in different types of locomotive WMU MABs

WMU plain MABs used on diesel locomotives 2TE116, 2TE116U and 2TE25KM (with motor-axle plain bearings) have the following main dimensions:

- l_{MAB} — MAB insert working length — 0.262 m;
- d_{MAB} — shaft journal diameter — 0.215 m.

Given the unladen weight of the WMU of 5.8 t [11], the radial load per bearing can be taken as equal

$$F_{r\,\mathrm{MAB}} = \frac{1}{2} \cdot 5.8 \cdot 10^3 \cdot 9.81 = 28\,450 \text{ H}.$$

Using dependencies (1)–(5) and the values of the dynamic viscosity μ of the axial oils according to GOST 610-2017, the results of the calculation of the power loss in plain MAB using C grade oil at –10; 0; 10; 20 °C and various values of the diameter clearance are proposed Δ.

Specifications of rolling bearings of locally produced WMUs used in TEM18DM, 2TE116U, 2TE25KM locomotives are presented above. Using dependencies (14) and (15), let's determine power losses in rolling MABs at different heating temperatures. Calculation results are given in *Fig. 8*.

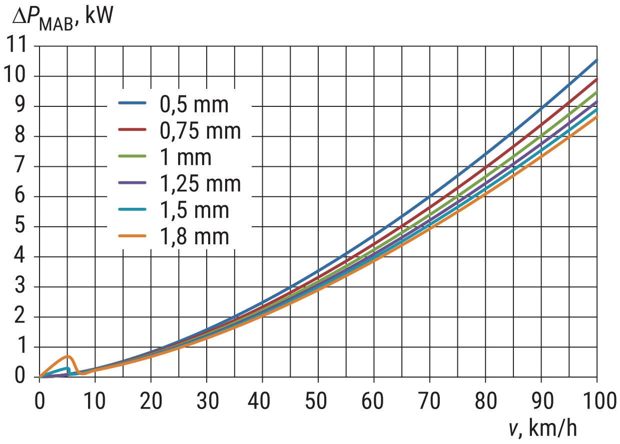

Fig. 4. Change in power loss in plain MAB at different values of diameter clearance and temperature –10 °C

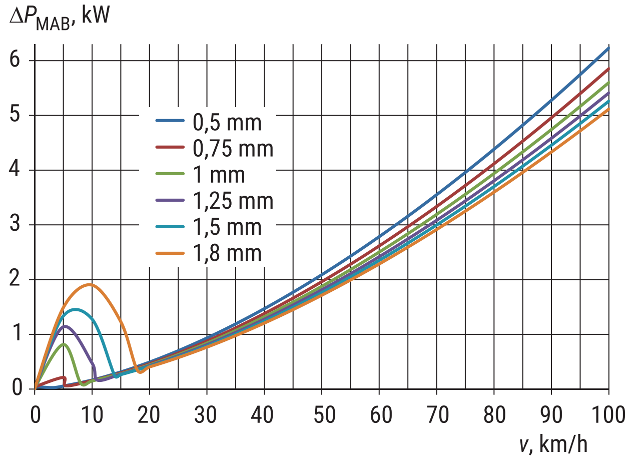

Fig. 5. Change in power loss in plain MAB at different values of diameter clearance and temperature of 0 °C

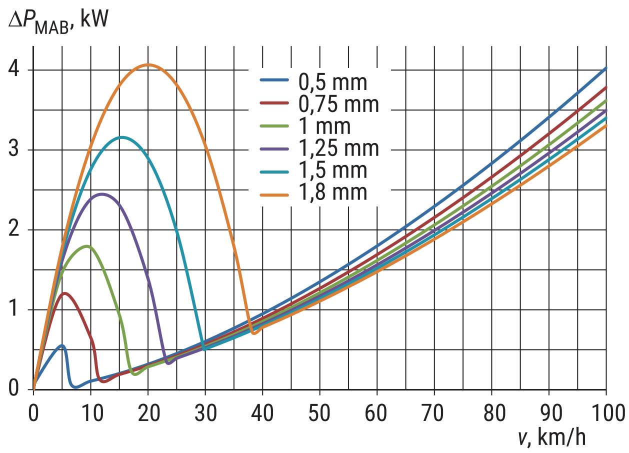

Fig. 6. Change in power loss in plain MAB at different values of diameter clearance and temperature of 10 °C

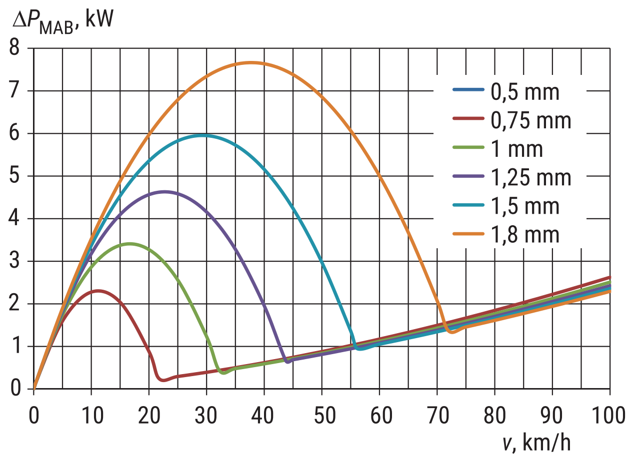

Fig. 7. Change in power loss in plain MAB at different values of diameter clearance and temperature of 20 °C

Power loss analysis of motor-axle bearings

Calculation results for plain MABs show that power losses vary widely, are increased at increase of sub-zero temperature and can reach 10–17 kW in the speed range of 75–90 km/h (*Fig. 4*). *Fig. 6, 7* show power losses at heating temperatures 10; 20 °C, where stepwise increase of power losses in a range of speeds 0–70 km/h it is observed, thus the higher temperature of heating the wider range of speeds is. The calculation of the energy efficiency of plain bearings (*Fig. 4–7*) confirms the influence of the diameter clearance Δ and heating temperature on the power loss [12].

A determination of the power loss of a rolling MAB as a function of the heating temperature is shown in *Fig. 8*. In the speed range of 20 to 40 km/h, the losses are up to 20 kW at different temperatures. At a heating temperature of –10 °C after 40 km/h, the power loss is increased significantly.

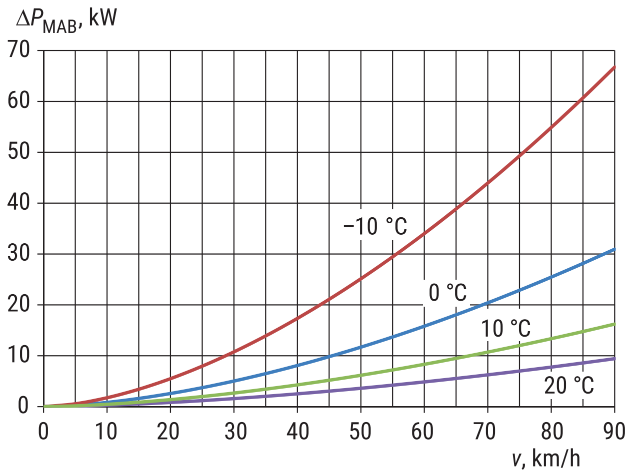

Fig. 8. Change in power loss in rolling MABs at different heating temperatures

CONCLUSION AND DISCUSSION

The following conclusions can be drawn from the above:

- The dependencies shown in *Fig. 4–7* allow concluding that the most effective operation of plain bearings must be carried out with the minimum diameter clearance permitted by the standard technical documentation and heating temperature range from 10 to 20 °C;
- An increase in the heating temperature of the plain bearing leads to a reduction of power loss in a wide speed range, as shown in *Fig. 4–7*;
- Calculation results for rolling MABs showed, that increasing heating temperature reduces power losses, thus operation of these bearings is most favourable at low speeds and positive heating temperature from 10 to 20 °C;
- The use of plain MABs improves the energy efficiency of WMU compared to rolling bearings when operating in the temperature range from 0 to 10 °C.

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This article is a prerequisite for further research into different types of WMU MABs in terms of their thermal balance issues.

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