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Research on the influence of rolling element geometry on the wear resistance of drilling equipment bearings

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Abstract

The article presents the results of experimental studies of the influence of the geometric parameters of rollers and raceways on the resistance of roller bearings to rolling element rotation and jamming. Failure of bearing assemblies due to roller rotation is a common cause of emergency equipment shutdown, which is accompanied by expensive repairs. The aim of the work was to determine the optimal ratio of roller length to its diameter (l/d) and the influence of raceway diameter (D) on critical wear, which leads to loss of roller stability. The research methodology was based on mathematical experimental design with variation of parameters l, d and D in laboratory conditions when simulating misalignment of the bearing assembly. An empirical relationship was established that quantitatively describes the relationship between roller geometry, raceway diameter and critical wear. The results showed that increasing l/d increases the resistance of the rollers to turning, while an excessive increase in D contributes to the growth of backlash and distortions. The most effective configuration was found to be the one with the maximum length and minimum diameter of the roller at a small value of D. The results obtained can be used for the design improvement of bearing assemblies, in particular in drilling equipment, in order to increase the resource and reliability of their operation.

Keywords: roller bearings, rolling elements, wear resistance, drilling equipment, geometry optimization, roller skew, critical wear

Introduction

Roller bearings are an integral part of many mechanisms and machines, in particular in heavy machinery, metallurgy, automotive and drilling equipment. One of the common problems in their operation is the seizure of the bearing, which often causes the failure of the entire assembly. One of the critical scenarios is the reversal of the rolling elements, which is accompanied by a complete stop of the moving elements of the bearing. As a result, there is intensive wear of the raceways, the appearance of chips, cracks and even destruction of the working elements that are in contact with the rolling element.

Fig. 1 Appearance of worn rollers of the bearing assembly after operation

Particularly dangerous are cases when fragments of the bearing remain inside the mechanism. This can lead to secondary damage: damage to gears, shaft jamming, failure of gearboxes, the need to completely stop the equipment for dismantling.

During the operation of roller bearings, the main supporting element: the large-diameter rollers, bears the greatest load. This is especially true for bearings operating under high pressure or shock loads.

The main reason for the failure of a bearing assembly is the gradual wear of the rolling elements and raceways. As it is used: the diameter of the rollers decreases due to micro-cutting or fatigue fracture; the raceways (inner and outer) lose their geometric accuracy and hardness; the total weakening of the contact between the elements leads to an increase in the gaps. The critical point is when the free space in the assembly becomes sufficient for the rollers to turn under the influence of frictional forces and vibrations. This leads to jamming, temperature increase, loss of lubrication and subsequent destruction of the assembly.

When the wear level in a bearing assembly reaches a critical level, there is a risk of the rolling elements turning, which in turn can cause sudden jamming. This leads to an emergency stop of the equipment, breakage of structural elements and expensive repairs. Despite a large number of studies, there is still no consensus on the determining factor that most affects the bearing life. Various authors give preference to: the influence of dynamic loads, temperature conditions, fit stiffness, surface microgeometry, methods of thermal and chemical-thermal treatment of raceways.

This indicates the complexity of the task and the multifactorial nature of wear, which requires a comprehensive approach to improving the design and manufacturing technology of bearings. Based on studies of the kinematics of rolling element motion, the rotation of rollers in a bearing assembly a phenomenon that precedes jamming and complete failure of the assembly can be caused by a complex of factors. The main ones are:

1. Uneven load distributionon the rolling element along the length of the running track. This may be the result of misalignment, manufacturing inaccuracy or deformation of the housing.

2. Increase in the inter-roller clearance, which occurs due to wear of the rolling elements along the diameter. After the roller leaves the loaded zone, the clearance increases, which creates conditions for destabilization of its orientation.

3. Wear on the ends of the rollers and the sides of the running tracks, which weakens the guiding function of the structure.

4. Difference in angular velocities (or other moving part) and individual rollers. With significant wear or misalignment of the roller, the ends of the rollers may be subject to pinching, especially in the unloaded area.

5. Degradation of raceway geometry due to fatigue or abrasive wear. This leads to loss of stability of the rolling element trajectory.

These factors do not act in isolation; the mutual amplification of the negative impact leads to an avalanche-like deterioration of the unit's performance: first, micro-slippage occurs, then oscillations and reversals of the rollers, and ultimately complete destruction.

In general, failure of the friction unit in a roller bearing is caused by the total wear of the friction pair of rolling elements (rollers) and raceways. When, as a result of operational wear, a sufficient gap, i.e. free space in the contact, appears, the roller loses stability and can turn under the influence of forces arising between it and the sides of the track. This becomes the initial stage of jamming.

Prevent the rollers from turningpossibly in several ways, covering both constructive and tribological solutions:

1. Minimizing wear and tear by: optimizing load and speed modes; selecting appropriate materials and heat treatment; using wear-resistant coatings; improving the lubrication system.

2. Bearing geometry optimization, in particular the ratio of the roller length to its diameter. Proper design of the shape of the rolling elements and raceways contributes to better roller stability in contact.

All these measures are interrelated and effective only in combination with compliance with technological tolerances, manufacturing accuracy, high-quality assembly, and proper operating conditions.

Both tribological and design support for reliable operation of roller bearings are urgent tasks of modern mechanical engineering. Within the framework of this work, the main attention is paid to the design aspect, which consists in choosing the optimal geometric parameters of rolling elements.

Review and analysis of literary sources

The problem of increasing the wear resistance and durability of roller bearings is the subject of numerous studies. The scientific literature considers a wide variety of aspects: from the influence of operating conditions, friction materials and type of lubricant, to the design features of bearings and surface hardening methods.

In [1], it is shown that the service life of the roller bit mainly depends on the bearing. In order to find out the cause and mechanism of bearing failure, the mechanics and microstructure of the failed roller bit bearings are analyzed. The results show that the bearing failure mainly includes wear (including adhesive and abrasive wear), plastic deformation, cracks, fractures and burns. The main causes of these failures are: abrasive substances and temperature rise caused by chips and lubrication failure; stress concentration, shock and vibration due to uneven loading and fit clearance; and initial cracks or defects due to unqualified surface treatment.

References [2-4] provide an overview of bearing materials, bearing ratings, and studies of failed bearings. Rolling bearings are designed for rolling contact rather than sliding contact; friction effects, although low, are not negligible, and lubrication is important. The papers list typical characteristics and causes of several types of failure, describing wear failure, fretting failure, corrosion failure, plastic flow failure, rolling fatigue failure, and damage failure. The effect of roller profile was analyzed in [5[to determine the actual load-life relationship for modified roller profiles. For rollers without crowns (linear contact), the load-life degree is p = 4, which is consistent with the Lundberg-Palmgren value, but crowning reduces the degree p.

In [6], a multi-objective optimization method was proposed to improve the fatigue, wear, and thermal failure performance of roller bearings. The objective functions considered are: dynamic capacity (Cd), which is related to fatigue life, elastohydrodynamic minimum film thickness (hmin), which is related to wear life, and maximum bearing temperature (Tmax), which is related to lubricant life. This paper presents a nonlinear constrained optimization problem with three objectives with eleven design variables and twenty-eight constraints. These objectives were optimized separately (i.e., single-objective optimization) and simultaneously (i.e., multi-objective optimization) using a multi-objective evolutionary procedure called elitist non-dominated sorting genetic algorithm. In [7] it is stated that the optimization of the internal geometry of rolling bearings for specific applications is still a subject of research. Furthermore, in recent years, new rolling bearings have been developed based on existing geometries, which are still being developed. Many recent studies have focused on optimizing the contact between the roller end and the raceway rib surface. In contrast, this work focuses on the development of a new type of rolling bearing based on the existing CRO, but where the rib contact is no longer required. First of all, the geometric parameters defining the internal geometry of rolling bearings, more precisely the contact between the roller and the raceways, were investigated. In addition, several patents defining new rolling bearing geometries were analyzed. Thus, optimization of the geometric parameters of the rollers is one of the key areas for increasing the reliability of bearing assemblies operating under high loads and complex kinematic regimes. The authors note that as the length of the roller increases relative to the diameter, its diagonal also increases. Accordingly, in order for the roller to turn, significantly more wear of the end surfaces of the roller and the sides of the running track is required. This complicates the conditions for the occurrence of the rolling element turn and increases the stability of the bearing assembly.

Optimal l/d ratio of roller in cone bits.In the design of large-diameter three-cone drill bits, roller supports (bearings) are traditionally used instead of plain bearings. The domestic standard recommended taking the ratio of the length of the roller to its diameter (l/d) at approximately 1.5–2 (about 1.7–2.0). For American drill bits, it is characteristic to use even more "elongated" rollers - with a ratio of l/d even higher than 2, which approaches the area of needle bearings. In particular, needle bearings are roller bearings in which the length of the rollers exceeds the diameter by at least three times (l/d = 3…10). Thus, in American designs, the rollers of the bearings are often longer and thinner than was accepted according to Soviet standards.

Justification of the increased l/d ratio. The main reason for increasing l/d of rollers is to increase load capacity and wear resistance. A longer roller with the same diameter has a larger contact area with the raceways, which allows the load to be distributed over a larger surface. US engineers, seeking to increase the service life, made the rollers more elongated in order to place more rolling elements of smaller diameter in one row. This allows to reduce contact stresses and better withstand high radial loads.

In addition, modern designs use special measures to ensure the reliable operation of thin long rollers. For example, most modern cylindrical roller bearings have barrel-shaped (convex) rollers to prevent load concentration at the edges and premature failure from misalignment. The convex profile compensates for bending and small misalignments of the roller under load, distributing the stress more evenly along its length. Such solutions allow the use of increased l/d without a catastrophic increase in contact wear.

Limitations and disadvantages of overextended rollers. Despite the above advantages, an excessive increase in l/d can also have negative consequences. Long and thin rollers are more sensitive to manufacturing inaccuracies, deformations and misalignments. With a large l/d ratio, even a small angular misalignment of the roller in the bearing causes misalignment and uneven contact: the load is concentrated on the edges of the roller, which causes intense wear, heating and the risk of chipping of the tracks. Thus, excessively "needle" rollers can work worse without special design measures. It has also been observed that needle bearings are less suitable for high rotational speeds - their long thin rollers cause more friction and an increase in temperature, limiting the maximum speed. Standard needle bearings also have a limited permissible concentricity.

It is because of these factors that Soviet standards limited l/d to ≈1.5–2 as a compromise between engine life and bearing reliability. American manufacturers, while introducing higher ratios, simultaneously improved the design of the bearing assembly – they used sealing and continuous lubrication, precision tolerances, convex rollers, and even combined bearing schemes. Such engineering solutions allow for increased rigidity and uniformity of support operation even with longer rollers. A number of scientific and technical studies were aimed at determining the optimal l/d ratio. In particular, in tests with the participation of Ukrainian specialists, the geometry of the rollers was varied in laboratory conditions (diameter ~10–15 mm, different track lengths ~8–30 mm) at a load of 2000–3000 N and rotation ~150 rpm. The results showed that the optimal l/d ratio is about 1.0–1.5, i.e. somewhat less than that provided for by the standards (~1.7–2). The researchers note that at l/d≈1.0–1.5 the best balance between low contact stresses and resistance to roller misalignment is ensured. Further increase in the roller length beyond the optimum does not give a significant gain in load capacity, but leads to increased friction and the risk of overheating/wearing of the roller edges. Thus, too high an l/d parameter can even reduce the bearing life if it is not structurally compensated.

Traditional standards were drawn up with a certain margin and allowed l/d≈2 precisely to maximize the load capacity. However, modern analysis shows that slightly smaller values contribute to greater reliability. American manufacturers, having experimentally increased l/d, were faced with the need to solve the problems of overheating of bearings. Therefore, in the designs of leading companies (Smith, Hughes/Baker, etc.) sealed bearing units with forced lubrication, heat-resistant materials and profiled rollers were introduced in order to realize the advantages of large l/d without premature failure of the unit. The recommended ratio of roller length to diameter in cone bits (≈1.5–2) has historically been chosen as a compromise between increasing the bearing load capacity and maintaining its reliability. Increasing l/d above 2 (practice in some Western designs) allows for more thin rollers to be placed and reduces the specific pressure, but requires more advanced implementation - high-precision tolerances, high-quality lubrication and constructive measures against skewing (for example, barrel-shaped rollers). Without these measures, excessively long rollers can overheat from friction and fail faster. Experimental data confirm that the optimum l/d lies within ~1.2±0.3, at which the bearing serves the longest. Thus, it was not for nothing that Soviet standards limited l/d to ~2: this value is close to the upper limit of the rational range. American engineers, going beyond this limit, gained a gain in load capacity at the cost of complicating the design of the bearing assembly. From the point of view of modern science, further increase in l/d gives decreasing returns and requires compensation for negative effects, while moderate l/d ≈1.3–1.5 seems to be the most balanced for roller bearings of tapered drill bits.

Research objective and problem statement

As noted earlier, the main causes of roller rotation in a bearing assembly are wear of the rolling elements and misalignment of the roller, which occurs due to uneven load distribution and increased axial/radial backlash due to degradation of the contact surfaces. In this regard, an urgent scientific and applied problem is to determine the critical conditions under which the roller turns, which leads to jamming of the assembly and failure of the assembly. The purpose of this workthere are:

1. Establishing the optimal ratio of the roller length to its diameter (l/d), which ensures resistance to turning under the influence of operational loads.

2. Detecting the effect of the diameter of the treadmills (D)on the probability of rolling body reversal.

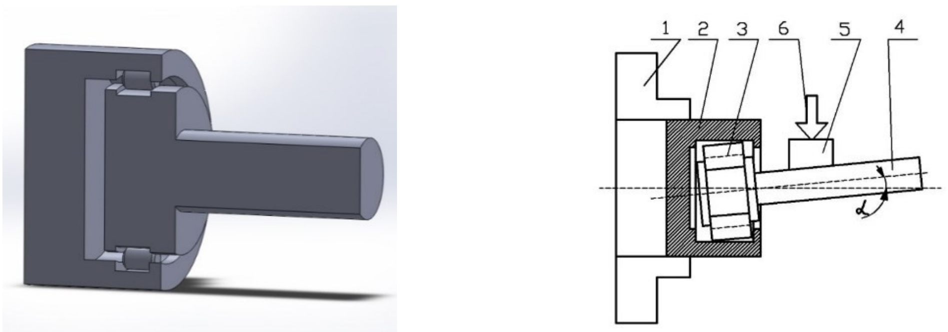
3. Construction of a mathematical model that will allow quantitatively assessing the limit values of wear that lead to loss of roller stability and jamming of the assembly.

The research aims to establish a mathematical relationship between the total wear of the contact pair (roller - running track), the roller geometry (l/d), and the design parameters of the assembly, in particular the running track diameter (D). The resulting model will allow predicting the durability of the roller bearing based on its geometric parameters, initial tolerances, and wear intensity.

Experimental research methodology

During rotation, the bearing roller is constantly pressed against the peripheral shoulder of the outer ring, which leads to one-sided wear, the appearance of local gaps and a gradual increase in backlash in the support assembly. This phenomenon is the main cause of the rotation of the rollers and, as a result, misalignment, which only increases with operation. To simulate the real operating conditions of the bearing assembly in a laboratory environment, in particular to simulate the misalignment of the inner ring relative to the outer ring, an artificial angle α = 1…2° was set during the study. This allowed for a sufficiently accurate simulation of the geometric destabilization of the assembly, which occurs as a result of operational wear and causes the rollers to turn.

Fig. 2a and 2b present a general diagram of a laboratory setup for tribological research of friction pairs, which was used to study the influence of skew and load on the resistance of a roller to turning.



a b

Fig. 2. Scheme of tribological studies of friction pairs

As part of the study, the criterion for evaluating the results was the moment of the roller's turning, which occurred as a result of operational wear of the contact pair. The experiment was considered completed at the moment of fixing the roller's turning, after which precise measurements of the wear of the rolling elements and contact surfaces of the running tracks were carried out.

To identify the influence of design parameters on the development of wear and reversal, the mathematical design of experiments was used, which allowed to reduce the number of tests and at the same time provide statistically significant results.

Based on the preliminary analysis, an experimental plan was drawn up (Table 1) with variations in the main geometric parameters:

- roller diameter d = 10…20 mm;
- roller length l = 10…30 mm, which allows us to investigate the influence of the l/d ratio in the range from 1.0 to 3.0;
- treadmill diameter D = 100 and 200 mm— two levels of modeling of nodes with different dimensional bases.

Each combination of parameters was considered under constant conditions of load (2000…3000 N), rotation frequency (150 rpm), lubricant and ambient temperature. The experiment was carried out with fixing the time to the roller reversal and the wear values after stopping the test.

Table 1

Mathematical plan

Experiment No.	Factors			Roller length, l, mm	Roller diameter, d, mm	Diameter of the outer running track, D, mm
	A	B	C			
1	-1	-1	-1	10	10	100
2	1	-1	-1	30	10	100
3	-1	1	-1	10	20	100
4	1	1	-1	30	20	100
5	-1	-1	1	10	10	200
6	1	-1	1	30	10	200
7	-1	1	1	10	20	200
8	1	1	1	30	20	200

Research results and their discussion

To ensure the reliability of the results and the statistical stability of the estimates, each experimental point was carried out three times. Based on the results of the three repeated tests, the average value of the assessment criterion was determined - that is, the average moment of the roller's turn or the average amount of wear.

The results obtained were analyzed using mathematical statistics methods, after which generalized graphical relationships were constructed, reflecting the influence of the studied factors on the roller's resistance to turning.

In Fig. 3 presents a typical dependence of the critical wear value on the geometric parameters of the roller (l/d) and the diameter of the running track (D). The graph allows you to visually assess the influence of the main design parameters on the performance of the roller support and outline the areas of greatest sensitivity to wear.

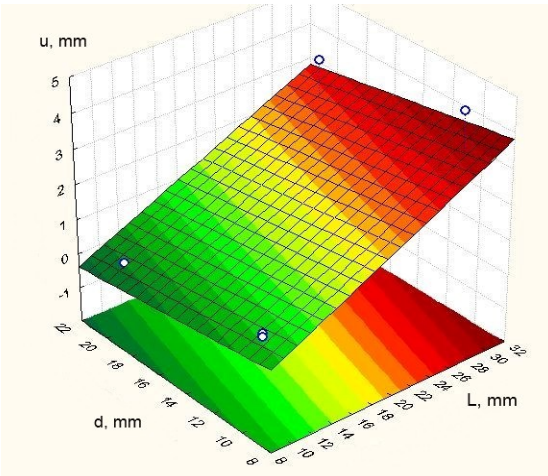


Fig. 3. Dependence of the critical value of roller wear, which leads to its reversal, on the geometric parameters: roller length l and its diameter d at variable values of the running track diameter D.

The color scale shows the zones of permissible (green), limiting (yellow) and emergency (red) wear. The graph shows that with the same roller diameter, increasing its length (i.e. increasing l/d) significantly reduces the probability of turning - the area of permissible wear increases. Increasing the diameter of the running track D also has a positive effect on the resistance of the assembly to jamming.

Comparison with previous studies

The obtained experimental results are in good agreement with the conclusions of previous authors [1, 5, 6], who indicated the importance of the structural ratio l/d (length to roller diameter) as one of the key factors determining the resistance of the roller bearing to jamming.

The authors [1] theoretically substantiated, that increasing the length of the roller at a constant diameter reduces the probability of turning, since this requires more wear of the end surfaces and shoulders of the running track. It was also noted in [6] that American bits use an increased l/d value, which contributes to durability, although there was no quantitative justification for this choice.

Within the framework of this work, this assumption has been confirmed experimentally.The constructed dependence surface (Fig. 3) clearly demonstrates that:

- with increasing l/d ratio, critical wear, which leads to roller reversal, increases;
- The larger diameter of the raceway D also has a positive effect on the stability of the bearing assembly, reducing the likelihood of misalignment and backlash.

Thus, the previously put forward hypotheses have been experimentally confirmed, and the ranges of parameters that ensure optimal operation of the roller support have been quantitatively specified. This has important practical significance for the constructive improvement of the bits, increasing their resource and reducing the accident rate during deep drilling.

Mathematical dependence of critical roller wear

Based on the results of experimental studies, an empirical dependence of the critical value of linear wear of the roller, at which its reversal in the bearing assembly occurs, was established. The dependence takes into account the influence of the main geometric parameters - the roller length l, the diameter d and the diameter of the outer raceway D:

$$I=0.29\cdot l-0.093\cdot d-0.001\cdot l\cdot d-0.0009\cdot D\cdot l+0.0003\cdot D\cdot d-0.54 \quad (1)$$

where: I is the wear value at which the roller turned, mm;

l is the roller length, mm;

d is the roller diameter, mm;

D is the diameter of the outer running track, mm.

Analysis of the results shows that the greatest influence on the occurrence of a U-turn is the length of the roller. This is clearly visible both in the results of the experimental processing and in the coefficients of equation (1), where:

- the effect of the roller length is 0.29·l,
- influence of roller diameter — 0.093·d

That is, with increasing roller length l, the critical wear that is allowed to occur before the moment of turning increases much faster than with a change in diameter d. This statement is also illustrated graphically in Fig. 3, which shows the dependence of the wear value on l and d. The graph shows that increasing roller length significantly increases the bearing's resistance to turning, in contrast to diameter, the influence of which is less pronounced.

Assessment of the accuracy of the model and the influence of the l/d ratio on the resource of the unit. Comparison of the calculated and experimental data showed that the discrepancy between the results obtained using the proposed mathematical model (1) and the actual test results does not exceed 30%. This indicates sufficient accuracy of the model for practical application at the stage of engineering design.

The analysis of the experimental relationships shown in Fig. 3 indicates a clear trend: the greater the ratio of the roller length to its diameter (l/d), the higher the motor resource of the unit, i.e., the greater the amount of permissible wear until the moment of the roller turning. This allows us to conclude that increasing l/d is an effective design measure to preventjamming of roller bearings.

It should be noted that at large values of l/d = 2…3, in the course of the experiment, in some cases, the critical wear value was recorded at the level of 6…8.5 mm by the moment of the roller turning. This indicates the high stability of rollers with large l/d and the potential for a significant increase in the resource of the unit under conditions of rational selection of parameters.

The influence of treadmill geometry on roller stability

During the research, it was found by visual observations that the rollers during operation are inclined to the axis of rotation, and not placed strictly parallel to it. This phenomenon was observed regardless of the loading mode and design parameters, and is probably due to the presence of an axial component of the friction force and micro-warping of the supports.

In the scientific literature, the main attention is traditionally paid to the ratio of roller length to its diameter (l/d) as a key factor affecting the stability of the bearing assembly. At the same time, the influence of the geometry of the running tracks, in particular their diameter, is not sufficiently covered.

In this regard, a separate series of experimental studies was conducted aimed at assessing the influence of the diameter of the outer raceway (D) on the moment of roller reversal due to wear of the bearing assembly.

According to the results of the experiment, graphically presented in Fig. 4, it is established that:

- maximum service life of the roller bearingobserved at maximum roller length (30 mm);
- The best result is achieved with a minimum diameter of the treadmill (D = 100 mm).

This indicates that excessive increase in the diameter of the treadmill does not always improve the operating conditions of the roller, as it may reduce the support stiffness or worsen the balance of loads acting on the roller at an angle.

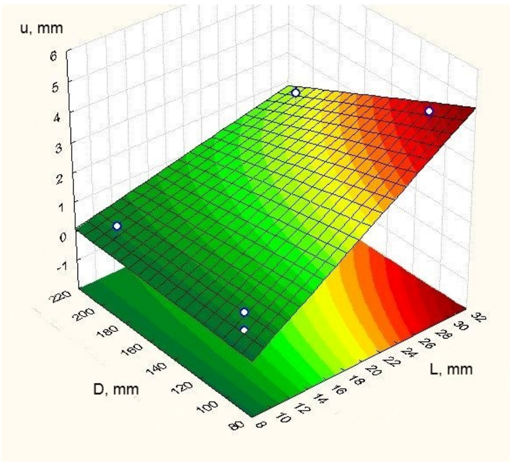


Fig. 4. Dependence of the linear wear value I, mm, on the roller length l, mm, and the outer diameter of the running track D, mm

The graph shows that the lowest wear before the roller turns is observed with a smaller diameter D (100 mm) and a longer roller length (30 mm). This once again confirms the effectiveness of increasing l while maintaining a moderate D as one of the key factors in increasing the wear resistance of the bearing assembly.

The color scale illustrates the wear gradient: the area of lowest values is shown in green, and critical values are shown in red.

The results of the conducted research indicate that to ensure maximum stability of the bearing assembly to the rotation of the rollers, it is advisable to use the minimum possible diameters of the raceways D and rollers of the maximum length l. This configuration reduces backlash, improves the direction of the roller movement and reduces the likelihood of its destabilization under load.

However, the probability of roller reversal increases significantly when large track diameters are used in combination with short rollers. It is with this geometry that the lowest critical wear value was observed before the roller lost stability. The conclusions drawn are fully consistent with the proposed mathematical model (1), which quantitatively reflects the dependence of the critical wear value I on the main geometric parameters of the node (l, d, D) and confirms experimental observations.

Fig. 5 presents the results of experimental studies of the dependence of the linear wear value*I,* mm, from the ratio of the roller diameter d, mm, to the outer diameter of the treadmill D, mm.

The graph illustrates how changing the geometric ratio d/D affects the ultimate wear of the bearing assembly before the moment of the roller turning. The obtained data allow us to draw a conclusion about the nature of the influence of the roller diameter in combination with the dimensions of the running track on the performance of the assembly.

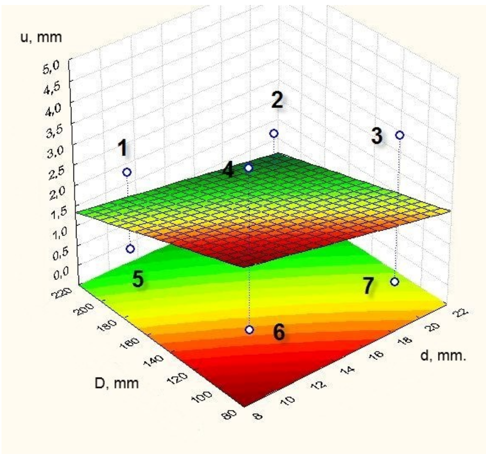


Fig. 5. Dependence of the linear wear value I, mm, on the roller diameter d, mm, and the outer diameter of the running track D, mm.

Based on the obtained experimental data, it was established that the probability of roller reversal is lowest at minimum values of roller diameter d and outer raceway diameter D. Such a geometric configuration provides greater stability of the contact pair and reduces the probability of roller orientation loss during wear.

As can be seen from Fig. 5 (points 1…4), with increasing roller length l, the critical value of linear wear I, at which reversal occurs, increases. This indicates an improvement in the stability of the assembly - the roller maintains the correct position for a longer time even under conditions of intensive wear.

On the other hand, when the roller length is reduced (points 5, 6, 7 in Fig. 5), the turn occurs much earlier - with lower wear values. This indicates a decrease in the resource of the unit due to the instability of short rollers.

The obtained results are consistent with the analytical model (1), which quantitatively takes into account the influence of the geometric parameters of the roller and the running track on critical wear, and once again confirm the feasibility of using long rollers of small diameter at small D to increase the reliability of the bearing assembly.

Table 2

The influence of the geometric parameters of the roller bearing on the wear and probability of the rollers turning

Parameter	Effect on wear	Impact on the probability of reversal	Comment
l	reduces	reduces	Most effectively
d	increases	Increases	Less favorable
D	increases	increases	Increases backlash and distortions

Conclusions

As a result of the research, key geometric factors influencing the occurrence of roller deflection in a bearing assembly have been identified. The ratio of roller length to diameter (l/d) and the diameter of the outer raceway D have the greatest influence.

The most resistant to reversal designs are provided by a combination of a large roller length (l = 30 mm), a small roller diameter (d = 10 mm) and a small running track diameter (D = 100 mm). This configuration provides maximum engine life by reducing backlash and distortion.

It has been experimentally established that with increasing l/d ratio, the probability of roller reversal decreases, and critical wear, which is allowed to lead to loss of stability, decreases. On the contrary, with short rollers (points 5–7 in Fig. 5), reversal occurs much earlier.

The results obtained are fully consistent with theoretical ideas about the nature of wear in rolling pairs, confirm the known provisions regarding the role of l/d, and at the same time expand existing knowledge by taking into account the influence of D, which is insufficiently covered in the scientific literature.

The practical value of the work lies in the possibility of using the results in design and modernization, in particular for selecting the optimal dimensions of the roller bearing, taking into account the maximum wear and service life.

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Маковкін О.М., Диха О.В., Вальчук І.К., Калачинський Т. Дослідження впливу геометрії тіл кочення на зносостійкість підшипників бурового обладнання

У статті представлено результати експериментальних досліджень впливу геометричних параметрів роликів і бігових доріжок на стійкість роликових підшипників до розвороту тіл кочення та заклинювання. Вихід з ладу підшипникових вузлів унаслідок розвороту роликів є поширеною причиною аварійного зупинення обладнання, що супроводжується дороговартісним ремонтом. Метою роботи було визначення оптимального співвідношення довжини ролика до його діаметра (l/d) та впливу діаметра бігової доріжки (D) на критичне зношування, яке призводить до втрати стабільності ролика. Методика досліджень базувалася на математичному плануванні експерименту з варіацією параметрів l, d та D у лабораторних умовах при моделюванні перекосу підшипникового вузла. Встановлено емпіричну залежність, що кількісно описує взаємозв’язок між геометрією ролика, діаметром бігової доріжки та критичним зношуванням. Результати показали, що збільшення l/d підвищує стійкість роликів до розвороту, тоді як надмірне збільшення D сприяє зростанню люфтів і перекосів. Найбільш ефективною виявилась конфігурація з максимальною довжиною та мінімальним діаметром ролика при малому значенні D. Отримані результати можуть бути використані для конструкторського удосконалення підшипникових вузлів, зокрема в буровому обладнанні, з метою підвищення ресурсу та надійності їх роботи.

Ключові слова: роликові підшипники, тіла кочення, зносостійкість, бурове обладнання, оптимізація геометрії, розворот роликів, критичне зношування