

Research Article

Improvement of the Support Structure of the Working Body for a Vertical Shaft Machine and Its Experimental Test Results

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Abstract

This article presents the structural concept of the shaft support system for vertical shaft machines, describing its design features, manufacturing process, and the functional role of the rubber element positioned between the bushings. The study also examines the improved lubrication system and explains the purpose of shaping the lower inner part of the housing in a hemispherical form, emphasizing the damping function provided by the rubber damper installed in this area. In addition, the paper investigates the twist angle of the helical grooves formed along the shaft in the direction opposite to shaft rotation, the operating rotational speed, and the influence of elastic components within the support assembly on deflection behavior. Experimental test results obtained using weight-based wear measurement techniques are presented to evaluate the durability and performance characteristics of the improved support structure.

Keywords

Housing, Bushing, Bearing, Rubber Damper, Shaft, Base Plate, Helical Grooves, Lubricating Material

1. Introduction

In the fields of machine science and machine design, it is stated that bearings serve as supports for rotating shafts and axles, while these supports receive radial and axial (vertical) loads acting on the shafts and axles, thereby maintaining the necessary position for their rotation [1].

In technological machines, shaft supports are commonly used to reduce friction and wear between relatively rotating

parts. These supports absorb the forces generated in the shafts and transmit them to the machine body, which has been proven to be effective [2].

It is known that vertical shaft supports mainly consist of the following parts: a bushing mounted in the housing, a shaft installed inside it, and a support disc (thrust bearing). These types of shaft supports operate at low speeds and under

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semi-dry or semi-liquid friction conditions [3].

The main drawbacks of the structures currently used in industry are the high load resulting from the large mass of the shaft, the increased friction and wear levels, and the low efficiency of lubrication between the frictional surfaces [4, 5].

Typically, self-aligning bearings are used in spherical supports, which are applied in relatively flexible shafts and housings. The spherical bearing and housing contact surfaces are made of antifriction materials. If the bearing is mounted in a steel housing, it is made of bronze or coated with leaded bronze. Supplying lubricant to the working surface of the support is mandatory, often performed under pressure. For this purpose, oil channels are made on the spherical surface,

ensuring a certain hydrostatic effect that facilitates the self-alignment of the sphere [6].

2. Materials and Research Results

Based on the above, a modernized support structure of the working body for technological machines with vertical shafts has been developed (*Figure 1*) [7]. The improvement aims to increase the operational life of the shaft and its support by reducing friction between the contacting surfaces, damping axial and radial loads, and enhancing the lubrication system.

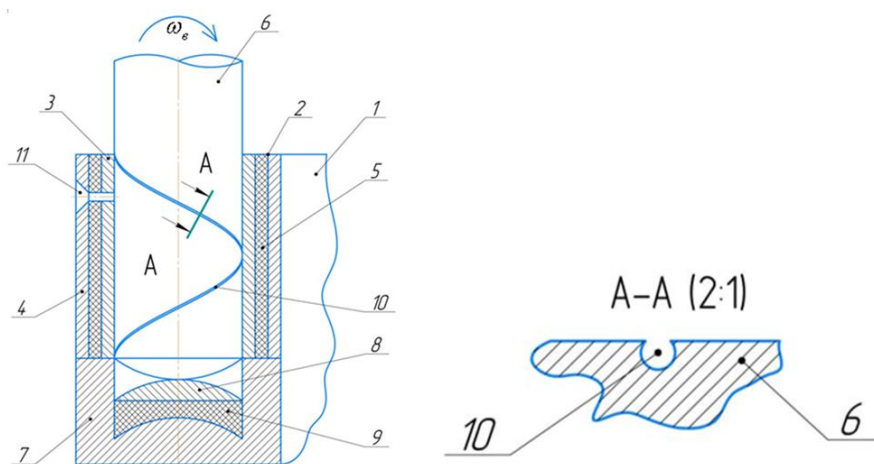


Figure 1. Support structure of the working body for a vertical shaft machine.

The support structure of the working body for a vertical shaft machine consists of a composite bushing (2) installed in the outer casing (1), which houses the entire bearing mechanism. The composite bushing (2) is made up of an inner bushing (3) and an outer bushing (4), with a rubber damper (5) tightly fixed between them. The shaft (6) is placed inside the hole of the composite bushing (2). Its lower end is spherical in shape and contacts the spherical surface of the base plate (8). The base plate, in turn, is installed inside the support (7) and is also fixed through a rubber damper (9).

The rubber damper (9) has a variable thickness — the thinnest part is located at the center, while the thickest parts are along the edges (peripheral surface). This design helps to automatically center the contact between the base plate and the shaft.

The outer surface of the shaft (6) features helical grooves (10) oriented opposite to the direction of shaft rotation. These grooves ensure efficient lubrication. Inside the composite bushing (2), there is a hole (11) for supplying lubricant.

This design is intended to increase the service life of the bearing by absorbing loads, reducing friction, and providing effective lubrication [8].

The proposed structure operates as follows: when the shaft

(6) rotates, friction between the shaft and the composite bushing (2) is reduced due to lubrication through hole (11) and damping of radial forces by the rubber damper (5). Moreover, at the contact zone between the spherical surface of the base plate (8) and the lower end of the shaft (6), the friction force is significantly reduced thanks to the rubber damper (9), which absorbs axial loads. The variable thickness of the rubber damper (9) under the base plate (8) ensures self-centering of the contact between the friction surfaces of the shaft and base plate.

Part of the lubricant flows through the helical grooves (10) into the friction zone between the base plate (8) and the lower end of the shaft (6), leading to a substantial reduction in friction. When applied in industrial conditions, this design allows reducing friction between the contacting surfaces, damping axial and radial loads, and thereby increasing the operational life of the thrust sliding bearing [9].

Experimental research was conducted on the proposed design, for which a test stand was developed.

It is known that the investigated composite support structure of the vertical shaft machine consists of several components. To manufacture the inner bushing of the support structure shown in *Figure 1*, bronze of grade BrO8S12 was

selected. According to the “Materials Science and Engineering Materials Technology” course, this bronze grade is

heat-resistant and wear-resistant. It is shown in Figure 2.



Figure 2. Inner bushing of the working body support structure for a vertical shaft machine.

For the proposed support structure of the working body in a vertical shaft machine, the outer bushing, which serves as an element for fastening to the support housing and holding the spherical surface called the base plate, was made of steel grade 45 containing 0.45% carbon. It is shown in Figure 3.



Figure 3. Outer bushing of the working body support structure for a vertical shaft machine.

At the lower part of the working body support structure, that is, on the bottom of the outer bushing, a spherical surface made of rubber is installed to absorb unbalanced and axial loads. This surface is in contact with the spherical lower part of the base plate. Figure 4. This spherical surface is also made of BrO8S12 bronze.



Figure 4. Spherical surface under the base plate of the working body support structure for a vertical shaft machine.

To securely fix the bronze inner bushing, the steel outer bushing, and the spherical surface at its base, rubbers resistant to dusty environments and high temperatures — grades

10-220MBS, 6308 TMKS, and 7317 MBS [10] — were selected and prepared as shown in Figure 5.



Figure 5. Sliding support bearing assembly.

For the vertical shaft machine, helical grooves were machined on the surface of the shaft that contacts the bushing, forming a kinematic pair with the bushing. Figure 6.



Figure 6. Shaft with helical grooves.

In industrial production, it has been well established that not all the energy consumed by drives during the operation of machines and equipment is used for useful work, and this can now be regarded as an axiom of the process. The main part of the energy losses occurs due to friction between the working elements of machines [11-13].

Scientific studies have shown that the vertical working shaft of hydrogenation machines typically requires maintenance after 720–1440 hours, while its support becomes unserviceable within 1200–1700 hours. After 1000 hours, en-

ergy consumption gradually increases, and by 1700 hours, it rises sharply.

The following common failures were observed in the vertical shaft and its support of the hydrogenation machine:

Conical wear on the surface of the vertical shaft in contact with the support;

Uneven wear of the support due to friction forces generated between the shaft and the support;

Wear of the lower part of the shaft, causing the shaft base to move significantly away from the base portion of the support, which increases downward force and may result in the shaft detaching from the upper portion secured to the coupling by threaded connections; Increased noise and gradually rising energy consumption due to uneven wear between the shaft

and support.

To compare the wear performance of the proposed shaft support structure with the existing one, wear intensity was studied as a function of operating time.

During experimental tests, friction and wear parameters of the vertical shaft and its support in the hydrogenation machine were determined. Several methods exist to measure wear on the contact surfaces of the shaft and support, and among them, the mass measurement (weight loss) method is widely used in laboratory tests because of its simplicity and accuracy. In this method, the amount of material lost due to friction is determined by the difference in weight of the component before and after testing, calculated using the following expression (1) [14, 15].



Figure 7. Load testing of the existing and improved shaft supports.

$$\Delta m = m_{\text{initial}} - m_{\text{next}} \quad (1)$$

where m_{initial} - Weight of the component before testing (g).

m_{next} - Weight of the component after testing (g).

Δm - Mass loss (g).

According to the above procedure, it is necessary to determine the pre- and post-operation weights of the existing and improved shaft support structures (Figure 7).

During the determination of the post-operation weight, the worn part of the component is carefully separated, cleaned thoroughly, dried to remove any moisture, and degreased. After this preparation, the component is repeatedly weighed according to the criteria described below, and the measurements are recorded in a special protocol with assigned reference numbers.

To ensure accurate determination of the actual masses of the shaft supports, high measurement precision, and to minimize measurement errors, each sample is measured at least three times under identical conditions, and the most frequently occurring average value is recorded in the protocol. For this purpose, laboratory scales of model ZEC-21 with an

accuracy of 0.0001 g and industrial electronic scales with an accuracy of 2 g were used.

Experimental tests were conducted on a hydrogenation machine test setup, examining different structural variations of the vertical shaft support working body. The wear characteristics of the shaft support working body were determined.

During the experimental tests, the investigated structures differed in terms of the friction coefficients of the elastic elements of the composite bushing, the helix angle of the grooves on the shaft contact surface, and, during operation, the rotational speed of the vertical shaft.

For each tested structure, the actual weights were measured before and after the test using laboratory scales to obtain values close to the true mass. The wear indicator was then calculated using expression (1). Using the weight measurement method during the tests, the wear rate per unit of time for each structure was determined according to the formula provided in [14].

$$v_t = \frac{\Delta m}{t}; \quad (2)$$

Here, v_t — wear rate of the support (g/hour), Δm — mass

loss (grams) according to expression (1), t — test duration (hours).

To evaluate the accuracy of the experimental results and to compare the determined test outcomes, it is also useful to express the material wear as a percentage. Since the weights of the supports vary, it can be difficult to determine in which case the friction surface has worn more. Therefore, in the weight measurement method for wear, the degree of wear is calculated as a percentage using the following expression (3) [15].

$$\eta_t = \frac{\Delta m}{t} \cdot 100\% = \frac{m_{\text{initial}} - m_{\text{next}}}{t} \cdot 100\% \quad (3)$$

The experimental test results of the wear characteristics of the support working body for the vertical shaft machine, determined using the weight measurement method, are presented below.

3. Results

The experimental test results show that, with an increase in the number of shaft rotations and rotational speed, the wear rate of the inner bronze bushing in the composite support structure for the vertical shaft machine ranged from 1.42% to 1.29% over 150 hours of operation, achieving a reduction of up to 0.13% (Figure 8).

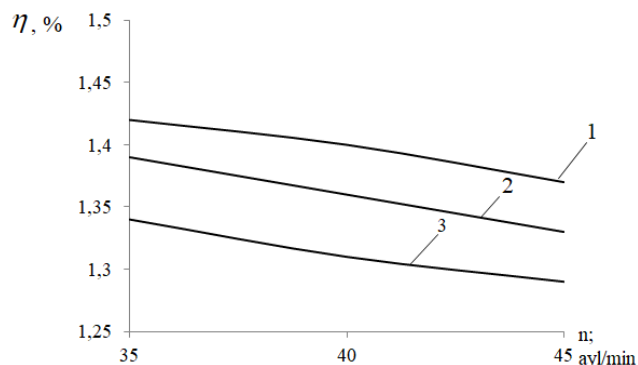


Figure 8. Relationship between shaft rotational speed and wear rate of the inner bushing in the improved working body shaft support structure.

The helix angle of the helical groove on the surface of the vertical shaft in contact with the support ranges from 50° to 70° , that is, $\alpha = \frac{5\pi}{18} \cdot \text{rad}$, $\alpha = \frac{\pi}{3} \cdot \text{rad}$ and until $\alpha = \frac{7\pi}{18} \cdot \text{rad}$. It can be observed that when increased, the wear rate of the inner part of the composite bushing ranged from 1.48% to 1.31%, achieving a reduction of up to 0.17% (Figure 9).

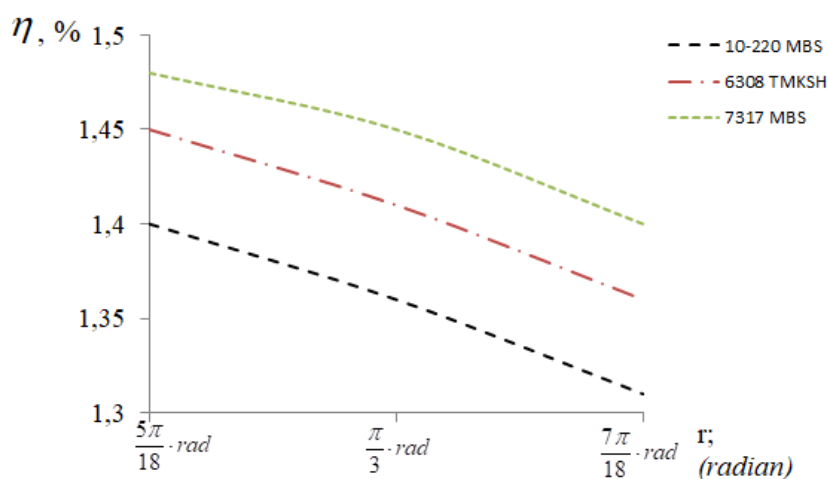


Figure 9. Dependence of wear rate of the improved working body shaft support structure on the helix angle of the groove on the shaft.

When the helix angle of the groove on the shaft's friction surface is $\alpha = \frac{\pi}{3} \cdot \text{rad}$ fixed, and the shaft rotates at 35–45 rpm, an increase in the stiffness coefficient of the elastic el-

ement in the shaft support resulted in the wear rate of the bronze part in the support rising from 1.33% to 1.47% (Figure 10).

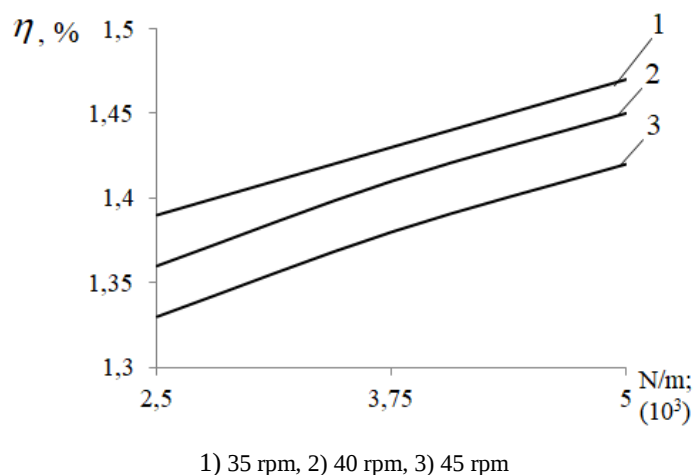


Figure 10. Dependence of wear rate of the improved working body shaft support structure on the stiffness coefficient of its elastic element.

4. Conclusions

Thus, based on the above graphs, it can be concluded that an increase in the shaft rotational speed and the helix angle of the groove on the shaft leads to a reduction in the wear of the support. One of the main reasons is that increasing the helix angle lengthens the total groove length. As is known, a longer groove on the friction surface reduces the contact area with the bushing, which in turn decreases the wear due to the smaller contact surface.

Additionally, it was observed that as the stiffness of the elastic elements in the composite bushing increases, the wear rate of the bushing also rises. This can be explained by the fact that in the proposed design, the rubber dampers sufficiently absorb both radial and axial loads resulting from technological loads, shaft mass, and unbalanced masses. Moreover, the variable thickness of the rubber damper under the base plate ensures automatic centering of the contact between the shaft and the support.

Abbreviations

$m_{initial}$	Weight of the Component Before Testing(g)
m_{next}	Weight of the Component After Testing (g)
Δm	Mass Loss (g)

Supplementary Material

The supplementary material can be accessed at <https://doi.org/10.11648/j.ajma.20251204.15>

Author Contributions

Kenjaboev Shukurjon: Methodology, Project administration, Supervision, Writing – review & editing

Muydinova Nilufar: Methodology, Resources, Validation, Writing – review & editing

Akbarov Alisher: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft

Nishonov Farkhod: Data curation, Formal Analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography



Kenjaboev Shukurjon is a Doctor of Technical Sciences and a professor at the Department of Mechanical Engineering, Namangan State University of Technology. Since May 1, 2020, he has been serving as a professor in this department. He was born on August 23, 1963, in Chortoq district, Namangan region. He holds a higher education degree, having graduated from Tashkent Polytechnic Institute (full-time) in 1985. He holds the academic degree of Doctor of Technical Sciences and the academic title of Professor.



Muydinova Nilufar is currently a PhD student at Namangan State University of Technology. She conducts research in the field of mechanics and mechanical engineering. To date, she has published over 10 scientific articles in international and national journals related to her research area, and she holds a patent for one utility model based on her scientific work.



Akbarov Alisher is a Doctor of Philosophy in Technical Sciences (PhD) and the Deputy Dean for Academic Affairs at the Faculty of Transport, Namangan State University of Technology. He is the author of over 60 scientific and methodological works, including more than 50 articles and conference abstracts. He has 10 years of professional experience in academic and pedagogical activities. His research focuses on the theory of machine mechanisms, their improvement, and issues related to energy-efficient designs.



Nishonov Farkhod is currently a PhD student at Namangan State University of Technology. He conducts research in the field of mechanics and mechanical engineering. To date, he has published more than four scientific articles in international and national journals related to his research area, and he holds a patent for one utility model based on his scientific work.

Research Field

Kenjaboev Shukurjon: Technological machines and equipment, manufacturing technology, machine science, machine parts, theory of machine mechanisms, development of new-generation mechanisms, and the implementation of energy- and resource-efficient technologies in industrial mechanical engineering.

Muydinova Nilufar: Technological machines and equipment, mechanical engineering technology, machine science, machine components, theory of machine mechanisms, creation of new-generation mechanisms, and the application of energy- and resource-efficient technologies in industrial mechanical engineering.

Akbarov Alisher: Technological machines and equipment, manufacturing technology, machine science, machine parts, theory of machine mechanisms, development of new-generation mechanisms, and the implementation of energy- and resource-efficient technologies in industrial mechanical engineering.

Nishonov Farkhod: In the field of transport engineering: transport vehicles and their components, mechanical engineering technology, machine science, machine parts, theory of machine mechanisms, development of new-generation mechanisms, and the application of energy- and resource-efficient technologies in the automotive industry.