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SLIDING THRUST BEARINGS WITH SELF-GENERATED FLUID PIVOTS

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The article discusses the disadvantages of thrust sliding bearings with mechanical supports and mechanical balancing systems similar to the Kingsbury system. Requirements for the design of thrust bearings corresponding to the current level of development of dynamic equipment are formulated. The design of thrust bearings using a hydrostatic suspension is proposed to eliminate the disadvantages of thrust bearings with mechanical supports and balancing systems. The modern design of the bearing developed by TRIZ LTD with mechanical bearings, which meets the requirements of the optimal choice of bearing the best, is given in this article with its advantages and disadvantages inherent in all mechanical systems. The given results of the TRIZ LTD work on the creation of thrust sliding bearings with the replacement of mechanical bearings and mechanical balancing of thrust elements with self-generated fluid elements are used with traditional oil systems. The developed original technical solutions made it possible to reduce the axial subsidence, the number of parts, axial dimensions, noise, axial vibration. Various designs of thrust bearings with self-generated fluid pivots, which most fully satisfy the requirements for the optimal choice of a thrust bearing design and their comparative characteristics in comparison with design of a thrust bearing with mechanical supports of bearing pads and a mechanical alignment system obtained during their testing at the bench are given. Thrust bearings with self-generated fluid pivots are recommended for new developments of rotary equipment, as well as for modernization of equipment operated to increase overhaul mileage, reduce maintenance time, increase reliability and efficiency of equipment due to higher bearing capacity, effective damping and practical axial subsidence from force.

Keywords: *rotary machines, thrust bearing, axial subsidence, damping capacity, fluid pivots.*

Introduction

When choosing thrust sliding bearings, it is necessary to consider the peculiarities of the operation of rotary machines. During the operation of turbine, compressor, turboexpander, pumping and other equipment, conditions of axial instability of the rotor may occur, which may be caused by non-stationary axial load, axial vibration, and off-design operation. At high axial loads on the rotor, there is a significant axial displacement of the bearings due to the pliability of the leveling systems, subsidence of the pads in the places of their contact, which leads to unauthorized stops due to blocking of axial displacements [1]. The axial drawdown of the rotor negatively affects the efficiency and vibration state of dynamic equipment, especially in machines with flow paths with narrow rotor and stator channels and especially with a back-to-back arrangement of steps. The suboptimal position of the rotor relative to the stator accelerates the process of fatigue failure of impellers operating near the surging mode, leads to an increase in axial vibrations and forces and, as a rule, to premature wear and further failure of the thrust bearing and emergency shutdown of dynamic equipment.

Seeing the above, the urgent task is to create thrust bearings to eliminate the disadvantages of mechanical balancing systems.

Literature Review

When designing modern thrust bearings, it is necessary to consider the requirements of technical standards, such as API-617 [2], according to which it is necessary to ensure 2-fold bearing capacity. Typically, during designing, this is achieved by increasing the radial dimensions of the bearings. When modernizing rotary equipment, such an opportunity is absent in most cases, therefore, other approaches and methods are used to increase the bearing capacity of sliding bearings. Some studies and design solutions to increase the bearing capacity are aimed at reducing the transfer of hot oil in bearings and using various methods of supplying oil under the bearing liners [3], using vortex grooves [4], using the structural sliding surface of the liners [5–6], displacement of the support position relative to the center of the insert [7–8], etc.

Usually thrust bearings are misaligned. The reasons for the misalignment can be the temperature misalignment of the unit caused by uneven lengthening of the foundation columns and different power and thermal expansions of the rotor and stator, inaccuracies in the manufacture of bearing parts, as well as inaccuracies in assembly during installation and repair. To balance axial loads, a Kingsbury lever system or a bearing equipped with thrust pads with a spherical support is often used. The Kingsbury bearing is more complex in design and has large axial dimensions, a large axial load on the lever system will lead to axial deformation and subsidence from mechanical abrasion of the bearing elements. [7]. Spherical bearing alignment is ineffective under boundary friction conditions [9].

When an axial driving force occurs, bearings can have large axial vibration and high noise levels. Structural damping of the leveler leveling system or any other mechanical system may not be sufficient to damp axial vibration. Radial bearings use a damping hydrostatic oil film on the back of the liner to reduce radial vibration [10–11]. Such a solution is effective both in transient and nominal operating modes of dynamic equipment.

During the operation of rotary machines, electrical discharge damage occurs to the bearing surfaces of axial and radial sliding bearings [12]. Existing current collectors are not reliable enough and it is not always possible to install them in the equipment that already is under operation [13].

Purpose of Paper

When designing dynamic equipment, there arises the problem of the optimal choice of a thrust bearing design that would satisfy the requirements:

1. Providing 2-fold bearing capacity in accordance with API-617;
2. Small axial and radial dimensions;
3. Providing highly efficient load balancing of load-bearing elements;
4. Providing damping of axial vibrations;
5. Noise reduction;
6. Minimization of axial subsidence from the action of axial forces;
7. Absence of axial subsidence from mechanical abrasion of the bearing element supports;
8. Perception of axial forces during reverse rotation;
9. Protection and signalling in case of electro-erosion effects by electrostatic charges;
10. Minimization of energy consumption;
11. Insurance of a long overhaul period;
12. Simple and fast service.

Since today none of the known designs of thrust sliding bearings fully meets these requirements, the authors set themselves the goal of creating thrust bearings that would most fully meet all the requirements for choosing an optimal design and significantly surpass the characteristics of traditional thrust sliding bearings.

Self-Generated Fluid Pivot and Work Experience with Thrust Bearing

Engineers of TRIZ, which has experience in solving problems of modernization of bearing assemblies, considered the possibility of using part of the oil wedge pressure to form a hydrostatic suspension (fluid pivot) of the pad as a promising direction to prevent subsidence of mechanical bearings and uniform distribution of the load over thrust pads.

Since the 1990s, development of a hydrostatic fluid-supported bearing has begun. Thus, during the modernization of the thrust bearing of the high-pressure housing of the Babetta compressor manufactured by CKD Praha, TRIZ has developed a thrust bearing design with self-aligning pads on a hydrostatic suspension (Fig. 1). The principle of operation of this

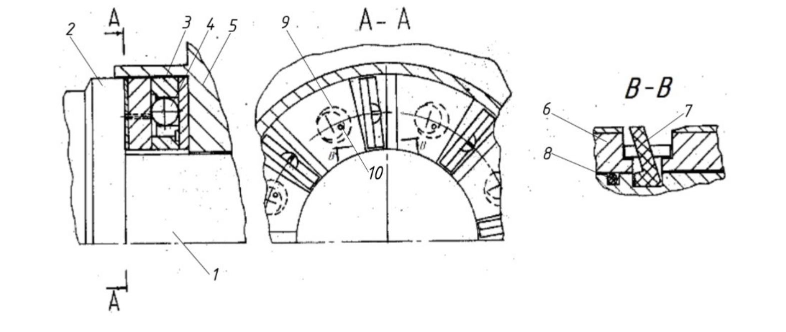

Fig. 1. Thrust bearings with self-aligning pads on hydrostatic suspension: 1 – shaft; 2 – thrust disk; 3 – separator; 4 – safety support; 5 – case; 6 – pad; 7 – scraper; 8 – elastic element; 9 – hydrostatic pocket; 10 – transfer hole

bearing consisted in the fact that during its operation, each thrust pad rests on a self-generated hydrostatic film, which is created as a result of the selection of a part of the lubricant flow of the hydrodynamic lubricating layer on the working surface of the pad. At the same time, hydrostatic pressure is created in the pocket made on the back of the pad.

Since it was not possible to test this design, the development of such a bearing had had to be postponed indefinitely. After the creation of a test bench for sliding bearings, work on the creation of thrust bearings with self-aligning pads on a hydrostatic suspension, which would most fully meet all points of the requirements for an optimal choice, was resumed. Since September 2019, this direction has been intensively developed at TRIZ [14].

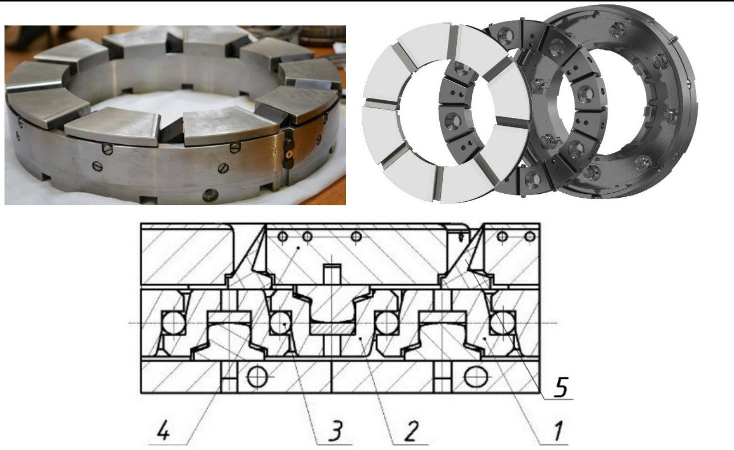

Fig. 2. PUR thrust bearing with leveling lever system:
1 – lower lever, 2 – upper lever, 3 – roller, 4 – thrust pad; 5 – scraper

Nowadays the greatest bearing and leveling capacity is possessed by a thrust bearing design with a PUR leveling lever system (Fig. 2), where rollers are installed between the levers, which allows to replace sliding friction with rolling friction. This constructive solution improves the efficiency of the bearing alignment system [15]. Oil scrapers installed between the pads effectively remove and drain hot oil from the previous pad, as well as direct the supply of cold oil through the scraper into the bearing layer. The scraper is made of wear-resistant, anti-seize and electrically conductive material that allows the electric charge of rotor currents to be transferred through it to the bearing housing, excluding the flow of current through the bearing pads, preventing their electroerosive destruction. Thus, the PUR axial bearing meets the requirements of items 1, 9, 10, 11, partly of items 2, 3, 8, 12 and does not correspond to items 4, 5, 6, 7.

Thrust Bearing with Self-Generated Fluid Pivot and Hydrostatic Load Equalization

To eliminate the disadvantages and preserve all the advantages of a thrust pad bearing with a mechanical support and an equalizing lever system PUR, a thrust damper bearing using the hydrodynamic pressure of an oil wedge to form a fluid (hydrostatic) pivot of the bearing pads – PUD with a fluid pivot was developed [14].

This is realized by the overflow of a part of the lubricant from the hydrodynamic wedge into the pocket on the back side of the pad, which leads to the formation of a hydrostatic pressure plot on it, under the action of which the pad floats up on the fluid pivot and is installed in space in such a way until an equilibrium of forces and moments occurs (similar to a pad with mechanical support).

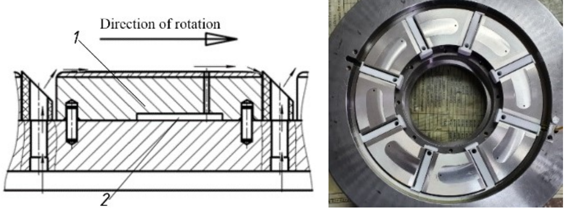

Fig. 3. PUD Thrust bearing with self-aligning pads on a fluid pivot:
1 – pad; 2 – hydrostatic pocket

The use of this bearing design (Fig. 3) eliminates mechanical supports from the bearing design, thereby eliminating additional axial subsidence due to crushing of the contacting bearing surfaces. The elimination of mechanical supports also reduces the axial and radial dimensions of the assembly.

The formation of a hydrostatic layer of oil in the bearing on the back of the pad provides additional noise suppression and damping, which reduces axial vibration and rotor swing.

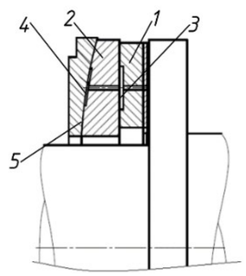

Fig. 4. PUDS thrust bearing with self-aligning pads with a spherical thrust on a fluid pivot:
1 – pad; 2 – bearing ring; 3 – hydrostatic pocket;
4 – annular groove; 5 – spherical surface

To ensure stable operation of the rotor, under the condition of uneven load on the bearing elements and the elimination of axial force subsidence of the mechanical alignment system of the bearing, TRIZ engineers have developed a thrust damper bearing supported on a bearing ring with a spherical stop on the bearing housing through a hydrostatic support – PUDS with fluid pivot (Fig. 4).

Between the spherical surfaces of the bearing ring and the body, grease is supplied from a pocket on the back of each of the pads. When the bearing receives axial force, part of the oil from the hydrodynamic wedge flows through the hydrostatic pocket of the pad into the annular groove on the spherical surface of the bearing ring. A hydrostatic pressure plot is formed between the spherical surfaces, which allows the spherical surface of the bearing ring to float on the bearing oil layer and establish (turn) in the desired position when exposed to uneven load on the pads. This design allows to assure even greater noise reduction and greater damping, as well as the ability to equalize the load between the bearing pads, which has no analogues, while the unevenness of the temperature field on the bearing pads is up to 2 ºC.

In comparison, the perfect PUR mechanical leveling system achieves unevenness up to 6 ºC (for comparison, in the Kingsbury mechanical leveling system, unevenness reaches 40 ºC). When using traditional lever leveling systems, the temperature difference between the maximum loaded and the minimum loaded pad reaches 40 ºC [9]. At a temperature of the minimum loaded pad of 110 ºC (the maximum allowable temperature for pads with an antifriction Babbitt layer) [16], the temperature of the maximum loaded pad can be 150 ºC.

Thus, the choice of a PUDS pad bearing with a fluid pivot will more effectively reduce axial vibration, ensure the axial stability of the rotor, and effectively redistribute the force on the bearing pads when the axial load is uneven.

To ensure stable operation of the rotor under the condition of uneven load on the bearing elements, as well as an additional reduction in the axial size of the axial support, engineers of TRIZ have developed an annular segment thrust damper bearing with an abutment of the support ring against the bearing housing through a spherical surface on a hydrostatic support – PUDSK with fluid pivot (Fig. 5).

The spherical surfaces of the bearing ring and the body are lubricated from the wedge-shaped segments. When the bearing accepts axial force, part of the oil from the hydrodynamic wedge of the bearing segments flows through the holes in the bearing ring into the hydrostatic pockets on the spherical surface of the bearing ring. A hydrostatic pressure diagram is formed between the spherical surfaces, which allows the spherical surface of the bearing ring to float on the bearing oil layer and establish (turn) in the desired position when exposed to uneven load on the pads.

This design, like the fluid pivoted PUDS pad design, provides the assembly with additional noise reduction and additional axial damping, as well as the ability to equalize the load between the bearing wedge segments.

All three types of liquid-seated thrust bearings have 2 to 3 times fewer parts than a mechanically-seated PUR linkage bearing, which simplifies and shortens assembly time (Fig. 6).

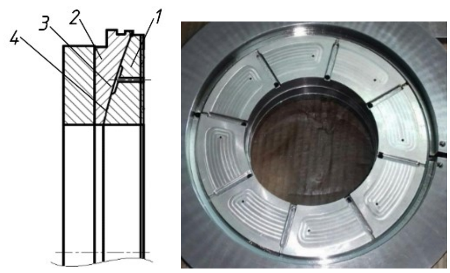

Fig. 5. PUDSK annular thrust damper bearing with a spherical thrust on a fluid pivot:
1 – bearing ring with segments; 2 – bearing housing; 3 – hydrostatic pocket; 4 – spherical surface

a b

Fig. 6. PUDS bearing on a fluid pivot (a) and PUR bearing with mechanical support and lever levelling system (b):
a – 51 parts; b – 109 parts

Bench Tests of the Bearing

At the bench of the TRIZ LTD company (Fig. 7), tests of 3 types of design of bearings with fluid pivots were carried out. For comparison, a thrust bearing with a PUR leveling lever system was also tested in the same overall dimensions.

Bench parameters during the experiment:

– Rotation speed – 1500-5000 rpm;
– Oil supply pressure – 1.2 bar;
– Oil consumption through the bearing – 75 l/min;
– Oil supply temperature: 40–43 ºC;
– Axial force on the bearing: 5–70 kN;
– The place of installation of the temperature sensor in the pad/segment is a thermally loaded zone near the exit from the pad, in the direction of rotation;
– The place of installation of the pressure sensor is the cavity of the hydrostatic pocket on the back side of the thrust pad;
– The location of the shaft end displacement sensor is the thrust bearing end cover.

Additionally, bench tests were carried out under conditions of increased vibration caused by a radial displacement of the axes of the bearing rotor shaft and the drive shaft by 0.2 mm. In conditions of increased vibration, the vibration velocity was measured on the bearing housing.

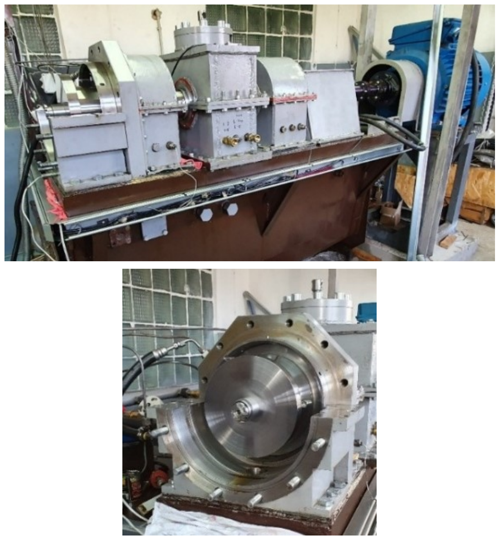

Fig. 7. Bearing bench

Experiment results graphs are presented in Fig. 8–11.

As can be seen from the test results, the temperature conditions of the bearings are comparable (Fig. 8). The small temperature difference at high load conditions of 60–70 kN is due to the presence of additional damping in the PUD, PUDS, PUDSK bearings and the conversion of the absorbed energy of axial vibration into heat. The axial displacement (axial settlement) of the three liquid-supported bearings is significantly less than that of a mechanical-supported bearing with a lever leveling system, due to the absence of this system in liquid-supported bearings. (Fig. 9). The minimum axial displacement is observed in the annular segment thrust damping bearing PUDSK with a fluid pivot. This is due to the lack of self-aligning pads and additional liquid (hydrostatic) support on the back of the pads. Recordings of the pressure in the hydrostatic pockets/groove (Fig. 10), as well as the movement of the shaft (Fig. 9), confirm that on the reverse side of the PUD bearing pad and on the spherical surfaces of PUDS and PUDSK bearings, a hydrostatic pressure plot is formed, under the action of which the ascent and installation of bearing elements (pads and rings) when rotating the thrust disk occurs. Tests

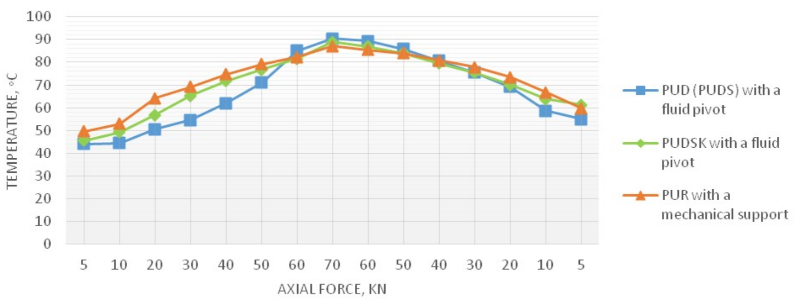

Fig. 8. Comparison of bearing temperatures

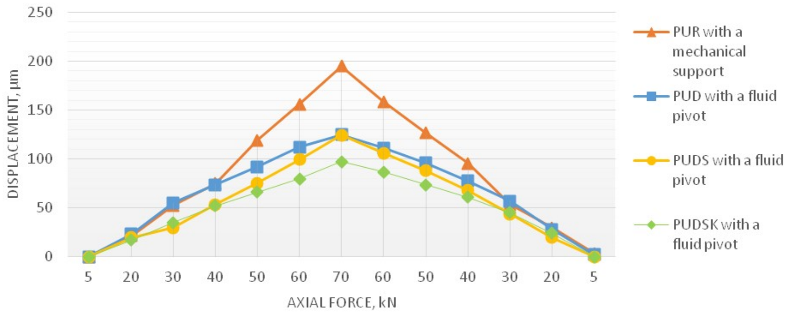

Fig. 9. Comparison of axial displacement of bearings

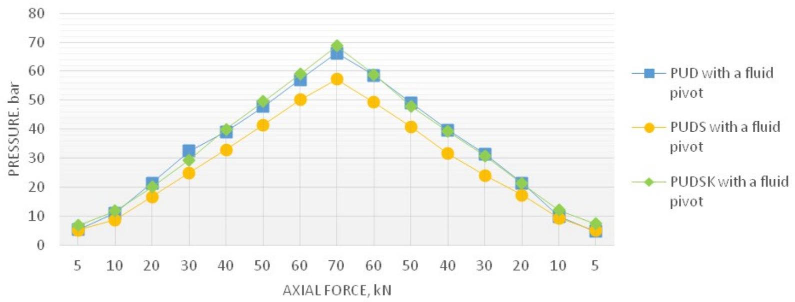

Fig. 10. Comparison of pressure in hydrostatic pocket/groove

under high vibration conditions (Fig. 11) showed that the vibration velocity in the direction of the bearing axis, measured at the housing, is lower for all three fluid-seated bearings than for a mechanical-seated bearing with a PUR linkage system. Below is a table of the reduction in the level of axial vibration velocity for bearings with a fluid pivot compared to a bearing with a PUR lever system (Table 1).

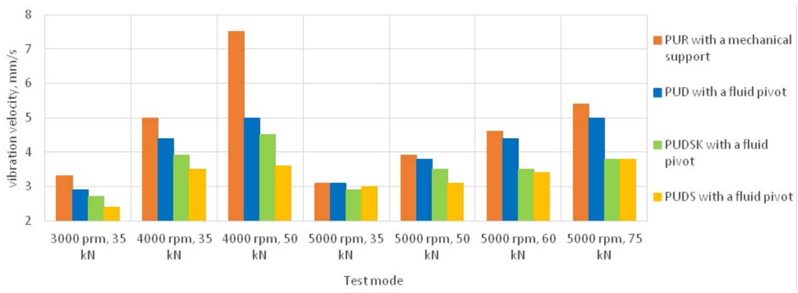

Fig. 11. Comparison of the values of vibration velocity measured on the bearing housing

Table 1. Decrease in the level of axial vibration velocity in comparison with PUR

PUD	PUDS	PUDSK
1–1.5 times	1.03–2.1 times	1.07–1.67 times

The decrease in the level of vibration velocity is associated with the presence of additional damping in the liquid bearings. This is especially observed in modes of increased vibration (system resonance) with a high axial force. The most effective damping is observed in the PUDS bearing, which is associated with the presence of two fluid pivots: on the back side of the pads and on the spherical thrust surface.

Repeatability of experimental results was ensured by numerous tests. The differences between the results of individual experiments were 1–6 percent.

Thrust sliding bearings with self-generated hydrostatic supports are recommended for use in new designs of rotary equipment, as well as in the modernization of operated equipment in order to increase the overhaul, reduce the time of routine maintenance, improve the reliability and efficiency of equipment due to a higher specific bearing capacity, effective damping, the practical absence of axial drawdown from force action.

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Conclusion

To meet the requirements for selection of the optimal thrust bearing design, PUD, PUDS and PUDSK fluid-pivoted thrust bearings have been developed, manufactured and successfully tested using the hydrodynamic pressure of an oil wedge to form a liquid (hydrostatic) support of the bearing and load-balancing elements. Such designs best meet the requirements for choosing the optimal thrust bearing. They eliminate the disadvantages of mechanically supported thrust bearings with a PUR mechanical leveling system. The developed original technical solutions made it possible to reduce: subsidence (axial displacement under load), the number of parts by 2–3 times, axial dimensions, noise, axial vibrations up to 2 times, while maintaining a high bearing capacity, raised to a high operational the level of reliability, efficiency, turnaround time of dynamic equipment.

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Упорні підшипники ковзання з самогенерованими гідростатичними опорами

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У статті розглянуті недоліки роботи високонавантажених упорних підшипників ковзання з механічними системами врівноваження, аналогічними системі врівноважування Кінгсбері. Сформульовані вимоги до конструкції упорних підшипників ковзання, що відповідають сучасному рівню розвитку динамічного обладнання, і розроблені способи й методи їх вирішення з метою вибору оптимальної конструкції упорних підшипників для усунення недоліків упорних підшипників із механічними системами врівноваження. Запропоновано конструкції упорних підшипників із використанням гідростатичної опори. Розглянуто сучасну конструкцію підшипника, розроблену фірмою ТОВ «ТРІЗ» ЛТД із механічними опорами несучих колодок, що найбільше відповідає вимогам оптимального вибору підшипника, з її перевагами й недоліками, притаманними всім механічним системам. Представлені результати робіт ТОВ «ТРІЗ» ЛТД із створення упорних підшипників ковзання із заміною механічної опори й механічного врівноваження упорних елементів на самогенеровані гідростатичні опори з використанням традиційних штатних маслосистем. Прийняті й реалізовані оригінальні технічні рішення дозволили, при забезпеченні несучої здатності сучасних упорних підшипників, зменшити просідання (осьове зміщення під навантаженням), збільшити демпфування осьових вібрацій до 2-х разів, зменшити як кількість деталей у 2–3 рази, так і габарити, знизити шум. Наведено конструкції розроблених упорних підшипників ковзання, що найбільше задовольняють вимогам оптимального вибору конструкції упорного підшипника, і порівняльні характеристики, отримані при їх випробуванні на підшипниковому стенді. Упорні підшипники ковзання з самогенерованими гідростатичними опорами рекомендується використовувати при нових розробках роторного обладнання, а також при модернізації устаткування, що експлуатується з метою збільшення міжремонтного пробігу, скорочення часу регламентного обслуговування, підвищення надійності й ефективності обладнання за рахунок більшої питомої несучої здатності, ефективного демпфування, фактичного осьового зміщення від силового впливу.

Ключові слова: *роторні машини, упорний підшипник ковзання, осьове просідання, демпфуюча здатність, гідростатична опора.*

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