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Increasing the carrying capacity of thrust bearings

Ошибки проектирования, несовершенные производственные процессы, изменение технологических режимов работы турбокомпрессоров вызывают осевые сдвиги ротора. Поэтому задача изготовления подшипников высокоэффективных и надежных тяги имеет важное значение в настоящее время. «ТРИЗ» ЛТД Компания имеет опыт в разработке и модернизации подшипниковых узлов, обеспечивающих их высокую грузоподъемность и надежность. В этой статье представлены методы по повышению несущей способности и надежности упорных подшипников скольжения.

Ключевые слова: *упорные подшипники, несущая способность, толщина слоя масла, потребление смазки, максимальная температура гидродинамического клина.*

Помилки проектування, недосконалі виробничі процеси, зміна технологічних режимів роботи турбокомпресорів викликають осьові зрушення ротора. Тому завдання виготовлення підшипників високоефективних і надійних тяги має важливе значення в даний час. «ТРІЗ» ЛТД Компанія має досвід у розробці та модернізації підшипникових вузлів, що забезпечують їх високу вантажопідйомність і надійність. У цій статті представлено методи щодо підвищення несучої здатності і надійності упорних підшипників ковзання.

Ключові слова: *упорний підшипник, несуча здатність, товщина шару масла, споживання мастила, максимальна температура гідродинамічного клину.*

Design faults, imperfect manufacturing processes, change of technological operating modes of the turbocompressors cause axial rotor shifts. Therefore, the task of manufacturing the high-efficient and reliable thrust bearings is important nowadays. TRIZ Ltd Company has an experience in the development and modernization of the bearing assemblies providing their high load capacity and reliability. The methods for increasing the load-carrying capacity and reliability of the thrust sliding bearings are disclosed in this article.

Keywords: *thrust bearings, bearing capacity, the thickness of the oil layer, lubricant consumption, the maximum temperature of the hydrodynamic wedge.*

The constructive deficiencies (errors), the imperfect manufacturing techniques, change of technological modes of operation of turbochargers in the gas, oil and gas, chemical and petrochemical industry led to the axial displacement of the rotors. Therefore, along with an effective balancing of the rotors, the calculation of the axial forces in view of possible operating conditions, improving the system of removing of static electricity, security systems and monitoring of axial thrust, the task of creating a highly efficient and reliable thrust bearing is still relevant today.

"TRIZ" has experience in the development and modernization of the bearing assemblies that provide high load capacity and reliability. Thrust slide lever bearings design TRIZ® used to replace the standard thrust bearings of centrifugal compressors, steam and gas turbines, generators, pumps and other rotating equipment satisfy the requirements of API 617.

This paper considers effective design ways to increase the carrying capacity of thrust bearings used LLC "TRIZ":

1. The two circles of circulation lubricant TRIZ®
2. The system of the rolling load balancing TRIZ®;
3. The hydrostatic compensating suspension TRIZ®;
4. The multifunction scrapers TRIZ®;
5. Individual supply of the lubricant;
6. The individual removal of the lubricant;
7. Extension of the range of the coefficient of efficiency of filling bearing pads TRIZ®;
8. Protectors from the electroerosive destruction TRIZ®;
9. The hydrostatic unloading of the thrust disk TRIZ®;
10. The radial cooling of the thermally loaded zone of the pads;
11. Cooling of the thrust disk TRIZ®;
12. The tangential cooling of the pad periphery to preserve laminar flow TRIZ®;
13. The combined thrust bearing with reversible and non-reversible pads TRIZ®;
14. Reversible bearings with combi properties TRIZ®;
15. Reversible scrapers TRIZ®;

1 Two circles of oil lube circulation

In existing designs, TB oil lube is distributed, as a rule, uniformly on the both sides of the bearing, namely, on the working side and the non-working one. The TB design with two circles of lube oil circulation (Fig. 1) provides delivering fresh oil first to the area of the operating pads in the amount to be required for cooling the same (the first circle of circulation), then the warmed-up oil, through the channels in the bearing housing, is transferred to the non-working side (the second circles of circulation).

Such a circuit of the lube oil feeding provides for 50 % reducing of the lube oil flow rate through the thrust bearing [1].

On the non-working side, the oil is additionally heated much less because of lowering viscosity of the lube oil having been warmed up while passing on the working side. In doing so, the TB load-carrying capacity increases by about 20 percent. This is facilitated by lowering response of the non-working side to the state of the working side, hydrostatic unloading, and reducing strain of the thrust ridge owing to alignment of the temperature fields on its both sides.

2 Aligning system of rolling to increase load-carrying capacity

Uneven loading of the TB pads can result in their cascade failure. At applying traditional lever aligning systems, the temperature difference between the maximum loaded pad and minimum loaded pad reaches 40 °C [2]. Thus, at the temperature of minimum loaded pad 110 °C (maximum admissible temperature for the pads with antifrictional layer of babbit), the temperature of the maximum loaded pad would make 150 °C.

To ensure the even distribution of load between the thrust pads in the bearing unit, there was designed a lever aligning system of rolling characterized by high-compensating properties (Fig. 2), wherein sliding friction between the arms was changed by rolling friction [3, 4]. The maximum temperature difference between the pads of bearings, which were fitted with such an aligning system, decreased from 40 °C to 6°C.

3 Compensating hydrostatic suspension

Most of the thrust bearings operate with the distortions. The distortion reasons are the temperature misalignment of the unit caused by non-uniform elongation of the foundation pillars and different values of the stress and thermal expansions of the unit rotor and stator, the inaccuracies at manufacturing the bearing components, as well as inaccuracy of assemblage at mounting and repairing. The methods of alignment known in the art are not effective. To compensate the temperature and stress strains that result in occurring non-parallelism of the thrust carrying surfaces of the rotor and bearing, there has been developed different versions of the thrust bearings equipped with the hydrostatic suspension (Fig. 3). The lube oil is supplied to the lube oil system of the journal and thrust bearing. From the lube oil system, the oil is directed to each thrust pad through channel *Г* (G) in the bearing housing and the distributive channels. Between the rotating shaft and the bearing pad, there is formed a lube oil layer. From the zone of the maximum hydrodynamic pressure, a portion of the lube oil flows through the hole into the pocket disposed on the back of the shoe, wherein the hydrostatic pressure is created. At the moment, the thrust pad is floating, and lube oil pressure is being throttled over the back of the pad.

From the pocket under the hydrostatic pressure, the portion of the lube oil is supplied through the holes in the bearing housing to the border of the spherical surfaces. As a result, between the outer sphere of the separator and the sphere of the bearing housing, there is formed an oil film. Owing to the oil film at the interface of the spherical surfaces, there is provided uniform receiving of the axial force by the thrust area in the event of any distortions in the system "rotor-thrust collar bearing."

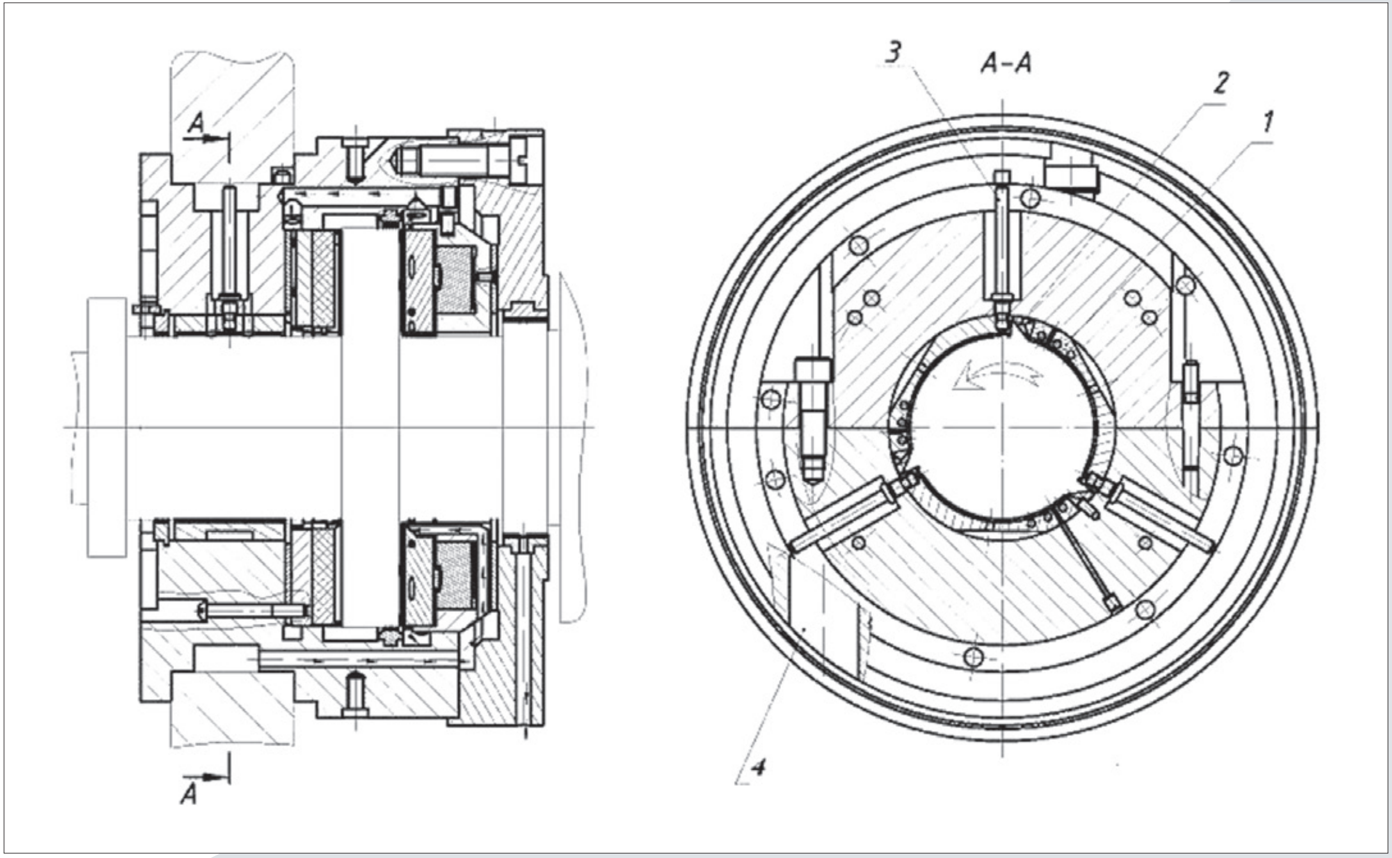

Fig. 1. Journal-Thrust Bearing with Two Circles of Oil Lube Circulation: *1 – journal pad, 2 – scraper, 3 – screw-lock, 4 – lube oil drain from thrust area, 5 – the first circle of lube oil circulation, 6 – the second circles of lube oil circulation*

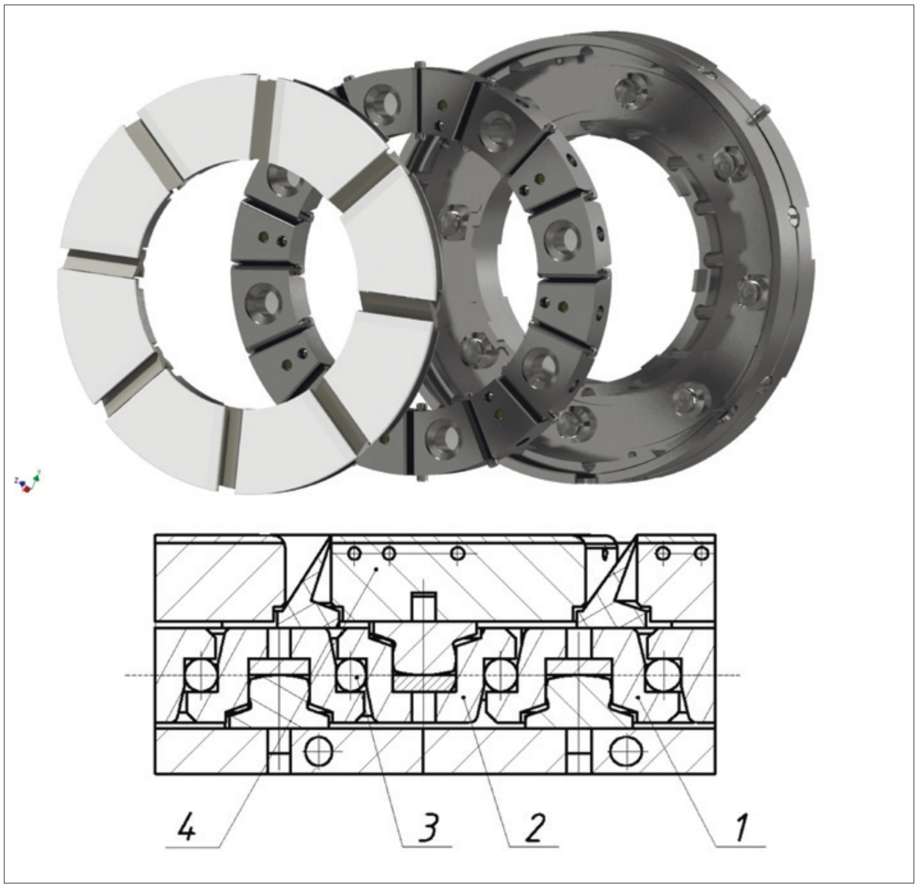

Fig. 2. Lever aligning system of rolling with high-compensating properties: *1 – lower lever, 2 – upper lever, 3 – roller, 4 – thrust pad*

4 Multifunctional oil removing scrapers

Installation of the multifunctional oil removing scrapers at the interpad space of the thrust bearing (Fig. 4) [5] makes it possible to:

– Prevent from transferring of the hot oil film from one pad to another;

– Provide for the individual oil supply into the pads;

– Provide for the individual oil removal off the pads;

– Improve the fill-factor for the pads from 0.6 to 0.9;

– Provide for running static charge off to prevent from erosion destruction of the carrying surfaces of the bearings.

This design reduces the temperature of carrying oil wedge, load-carrying capacity of the bearings and prevents from the pad electroerosive deterioration.

5 Individual lube oil supply into the pads

The oil flow is organized in such a way that due to the special design of the oil removal scraper 12 (Fig. 4), which forms two non-interconnected cavities in the interpad space, there is performed an individual oil supply to the thrust pads. Thus, the oil from the lube oil system flows directly to the pad, not mixing with the hot oil.

6 Individual lube oil removal off the pads

Owing to the special shape of the oil-removal scraper, the hot oil, which was removed off the thrust collar, is diverted into the channels 4 (Fig. 4) after each pad to be drained without being mixed with the oil from the lube oil system.

7 Extending the range of the bearing pads fill factor

The pads fill factor (κ) is the ratio of the working area of the thrust pads to the area of the ring restricted by the inner and outer diameters of the pads, and it has a significant impact on the loadcarrying capacity of the thrust bearings. The bearings of the traditional design withstand the greatest load at $k = 0.6$ [2]. Arranged in the interpad space, the oil removal scrapers prevent the hot oil from transferring from one pad to another by the thrust collar, so in such thrust bearings, the load-carrying capacity of the bearing continues to increase with increasing the area of the bearing pads. At installing the oil removal scrapers at the interpad space, the fill factor of the carrying surfaces of the bearing pads increases from κ=0.6 to 0.9, whereby there is achieved 50 % increase in the load-carrying capacity of the bearing with the same dimensions. This change is illustrated by the graphs in Fig. 5.

8 Protection devices against electroerosive destruction

To prevent the thrust sliding bearings from the electroerosive destruction, there are traditionally used slip rings of various designs. In addition to the existing systems of guard, as protectors of the electroerosive destruction, there are applied the oil removal scrapers installed in the bearings between the pads. The scraper construction is developed in such a way that it constantly contacts with the bearing housing and the machine rotor, even if it wears during operation. Therefore, to prevent the carrying surfaces of the bearings from electroerosive deterioration, there are applied electro conductive oil removal scrapers (Fig. 6).

9 Hydrostatic unloading of the thrust collar

Hydrostatic unloading of the thrust collar is carried out at the expense of the pressure epures difference on the working and non-working sides of the bearing. For this purpose, the entire flow of the lube oil is supplied under pressure onto the working side of the bearing, and then it is throttled in the seal over the thrust collar provided with a specially selected clearance that guarantees the necessary flow rate of the lube oil required for the proper cooling process, and then comes to the state of free draining. When using the scheme of the lube oil supplying with two circles of lube oil circulation (Fig. 1) a portion of the lube oil is transferred to the non-working side through the throttling holes. In other cases, the lube oil is delivered onto the non-working side from the thrust area of the bearing, through the seal between the journal and thrust areas of the journal and thrust bearing. The clearance value in the seal is selected so that, on the one hand, to provide for cooling the non-working side, and on the other hand, substantially, to reduce the pressure thereon. Thus, at operating condition, the working side of the thrust bearing operates under a pressure close to the pressure of feeding the lube oil provided by the lube oil system, and the non-working side operates under the pressure of free draining. Due to this difference of the pressures, there is realized hydrostatic unloading of the thrust collar that reduces the residual axial force and, ultimately, increases the load-carrying capacity of the bearing.

10 Radial cooling of the pad thermally loaded zone

Individual oil supplying to the thrust pads is arranged in such a way that some amount of the lube oil passes through special channels 8 in the thrust pad, which channels are located under the layer of Babbitt, to cool the thermally loaded zone of the pad (Fig. 4). Such a design reduces the temperature of the carrying hydrodynamic wedge and increases the load-carrying capacity of the bearing.

11 Cooling the thrust collar

Another design solution, which increases the load-carrying capacity of the thrust bearing, is further cooling of the thrust collar. Performed within the thrust collar, the channels are adjacent to its working sides. At rotating the thrust collar by the centrifugal forces, the cold lube oil, through supplying channels 4, is entrained into cooling channels 2 (Fig. 7), and along them the lube oil flows out to the periphery of the thrust collar. While flowing along channels 2, the lube oil cools the carrying surface of the thrust collar, and thereby reduces the temperature of the hydrodynamic layer that results in increasing the load-carrying capacity of the bearing. Protector is made of electroconductive material.

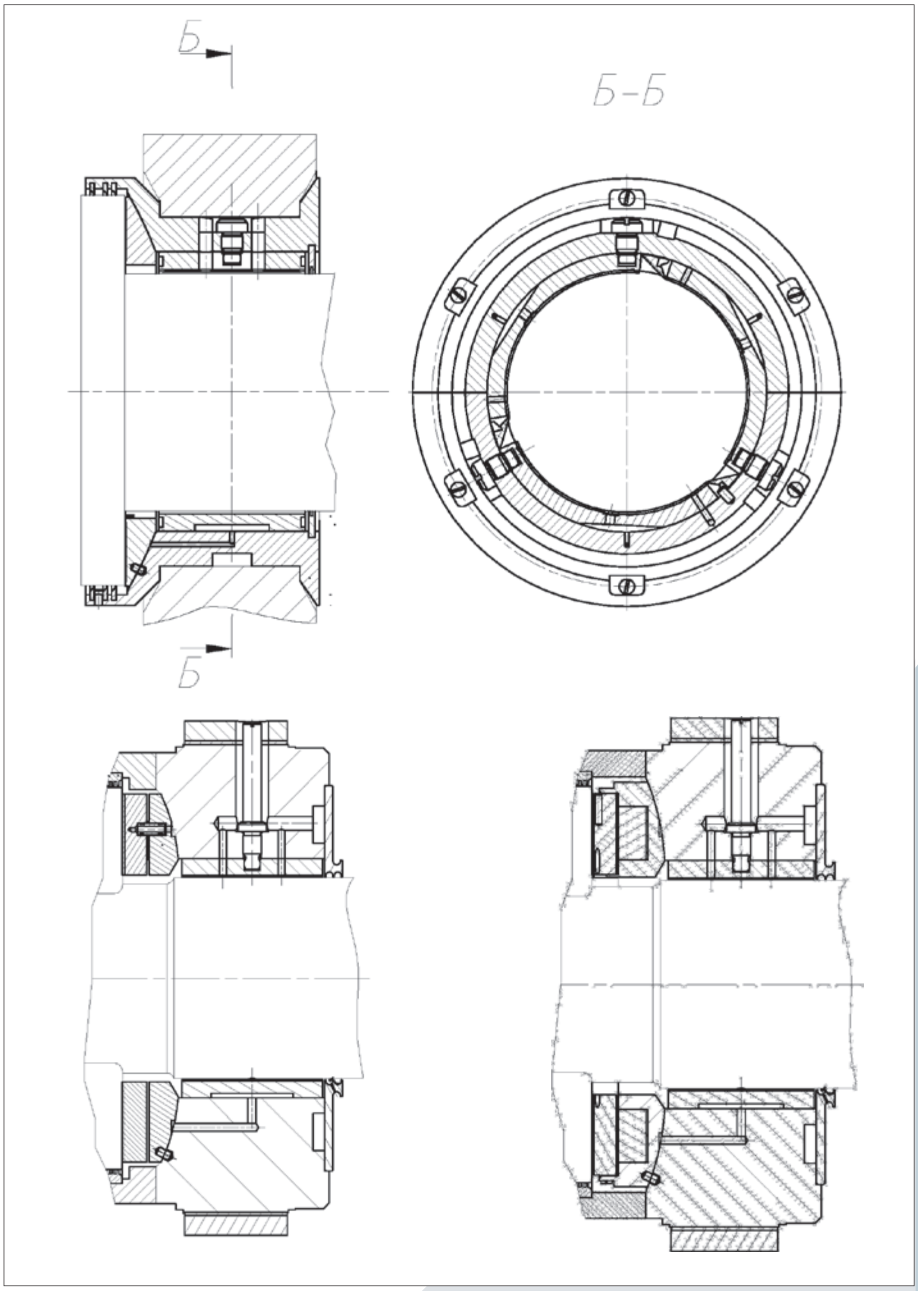

Fig. 3. Versions of the thrust bearing equipped with the compensating hydrostatic suspension

12 Tangential cooling of the pad periphery to maintain laminar flow condition

In the hydrodynamic layer of the thrust bearing operating under conditions of high temperatures and rotational frequencies, there can be occurred a laminar flow condition for the of lube oil due to the lower lube oil viscosity and high circumferential velocities, especially at the periphery of the pad. It is known that under condition of the turbulent flow, there are significantly reduced the load-carrying capacity of the hydrodynamic bearings, increased the power losses, and generated thermal emission as well. To maintain the laminar flow condition for the lube oil at the inlet to the hydrodynamic wedge, on the inlet edge of the thrust pad, there is executed a special incoming hyperbolic surface, which prevents the flow from vortex formation. Also there is specifically provided additional cooling the upper zone of the inlet edge owing to directing a portion of the supplied flow of the cold lube oil through the tangential channels 7 (Fig. 4) and preventing the lube oil from reducing its viscosity at the pad inlet and thereby facilitating the maintenance of the laminar flow condition.

13 Thrust bearing with reversible and non-reversible pads

In practice, there are often occurred operating conditions whereon the turbomachine rotor spins in the reverse direction, and this entails the need in applying the reversible thrust pads. However, sometimes the load-carrying capacity of the bearing composed of only reversible pads is not sufficient for proper perception of the load in the operating direction of rotation. It is known that the non-reversible thrust pads have higher load-carrying capacity as compared with the reversible ones, however, they have virtually zero load-carrying capacity at the reverse (off-design) direction of the rotor rotation, and under such a condition they are not able to provide for the perception of axial force. The way to overcome this situation is to develop the design of the thrust bearing of combined type [5], wherein there are alternately installed the non-reversible and reversible pads (Fig. 8). In such a design, at the working direction of the rotor rotation, the non-reversible and reversible pads operate in conjunction with each other, and the load-carrying capacity of such a bearing is higher than that of the same bearing with the reversible pads. On the condition of the reverse rotation, there are only operated the reversible pads creating the load-carrying capacity to be necessary for this nonstandard situation. Shown in Fig. 8, the thrust bearing has four reversible pads and four non-reversible ones.

Thus, joint installing of the non-reversible and reversible pads in the thrust bearing provides for obtaining a bearing that combines high load-carrying capacity at the straight direction of rotation on the operating conditions with the required load-carrying capacity on the conditions of the reverse rotation in non-standard situations.

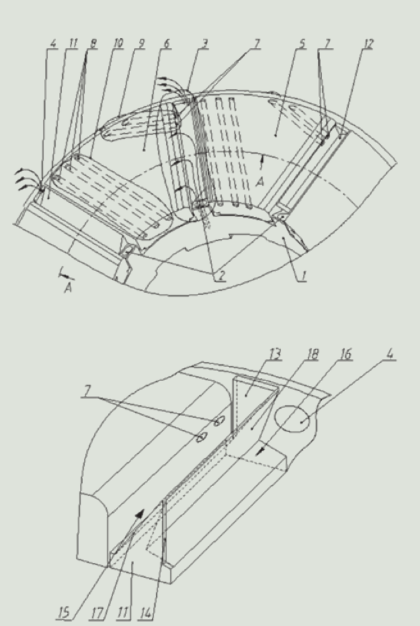

Fig. 4. Tilting pad thrust bearing, TRIZ Ltd: *1 – housing; 2 – oil supply channels; 3 – interpad space; 4 – channels for draining lube oil off; 5, 6 – tilting thrust pads; 7 – oil cooling channels at inlet edge; 8 – oil cooling channels at thermally loaded zone; 9 – pad inlet zone; 10 – thermally loaded zone; 11, 12 – multifunctional oil-removal scrapers; 13 – scraper bridge at drain area; 14 – scraper bridge at the area for cooling oil supply; 15 – cavity to communicate with the cooling oil supply channels; 16 – cavity to communicate with the channels for draining lube oil off; 17 – scraper back; 18 – scraper front surface*

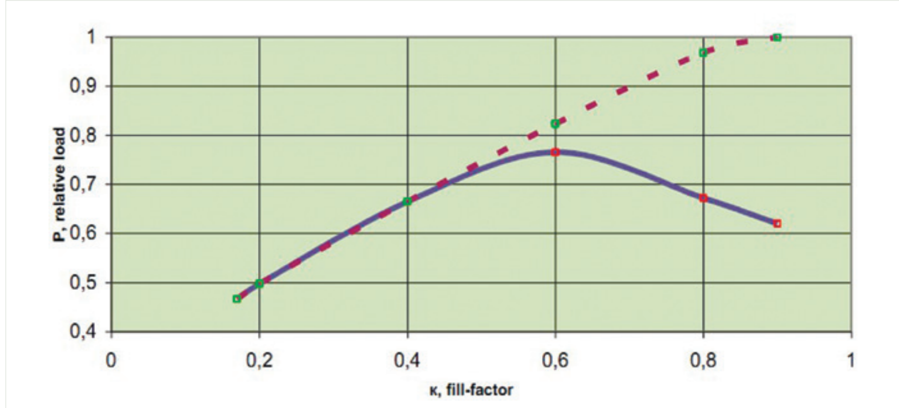

Fig. 5. Maximum load P withstood by the bearing vs. the fill-factor (κ)
———— For the bearings without the oil removal scrapers
– – – – – – For the bearings with the oil removal scrapers

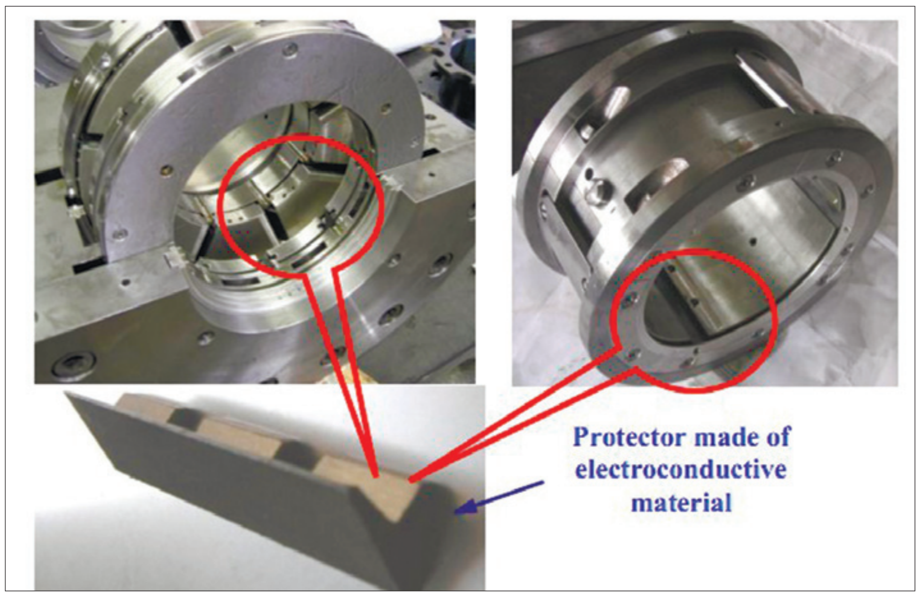

Fig. 6. Bearings equipped with the scraper-protectors to prevent them from electroerosive deterioration

14 Reversible bearings with non-reversible properties

Another way to increase the load-carrying capacity of the reversible thrust bearings is to apply the reversible bearings with non-reversible (combi) properties (Fig. 9).

In these bearings, thrust pads 1 are made of metalfluoraplastic strip and backed by thrust bearing carrier 2, wherein each pad is followed by three symmetrically arranged pockets 3. The pockets are connected to the front side of the pads by holes 4, through which, while operating, the lube oil flows into the pockets from the lube oil hydrodynamic layer. In doing so, the pressure in the pockets is increasing and the pad is floating with leaning in operation onto the hydrostatic oil film. Thus, on the rear side of the pad, there is formed a hydrostatic pressure epure balancing the pressure of the hydrodynamic layer, and the epure resultant point of application represents the pad pivot point. Since the pockets and the holes therein for supplying the lube oil are distributed symmetrically along the length of the pad, the values of the pressure transmitted to the pockets from the epure of the hydrodynamic pressure will be different in various pockets and will increase on a course of the lube oil movement, whereby the coordinate for the resultant of the hydrostatic pressure epure will be displaced in the circumferential direction towards the outlet of the

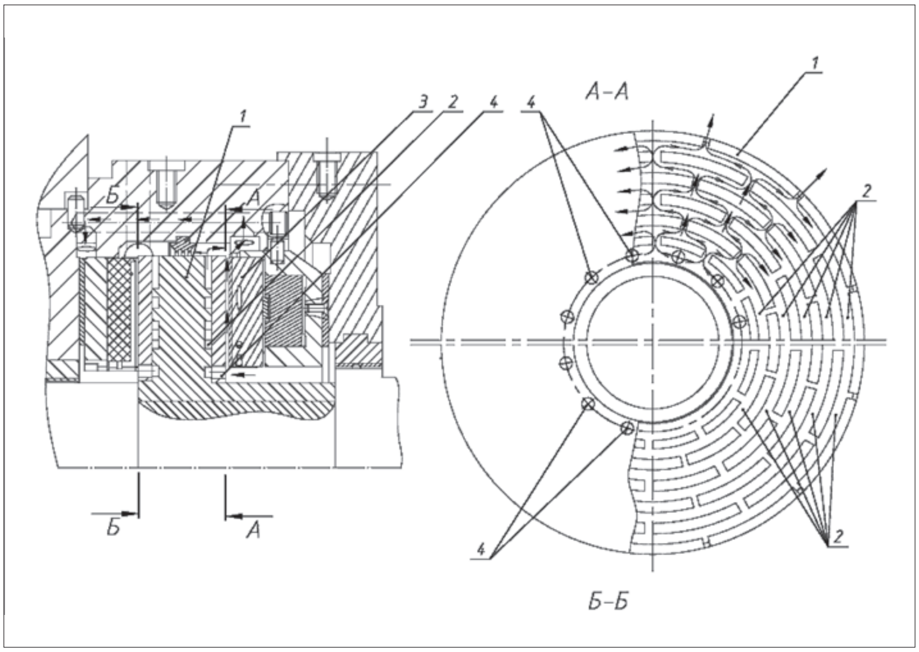

Fig. 7. Axial bearing with inner cooling of the thrust collar: *1 – thrust collar; 2 – cooling channels; 3 – pad; 4 – supplying channels*

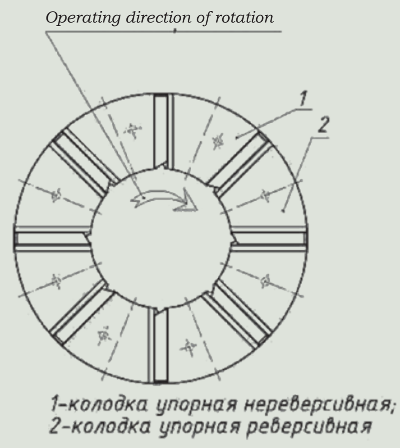

Fig. 8. Thrust bearing with reversible and non-reversible pads:
1 – thrust non-reversible pad;
2 – thrust reversible pad

pad for the relative magnitude of 0.55–0.6, which corresponds to the relative coordinate of the pivot point of the non-reversible pad. Owing to the above said, the bearing obtains high load-carrying capacity, which is inherent to the non-reversible pads. While the rotation direction being changed by the symmetrical arrangement of the pockets, the epures of the hydrodynamic and hydrostatic pressure will be respectively redistributed, the coordinate of the pad pivot point will move in the opposite direction, and the load-carrying capacity of the bearing will remain the same. Thus, the present solution allows combining the reversibility of the bearing with the high load-carrying capacity of the non-reversible pads in the both directions.

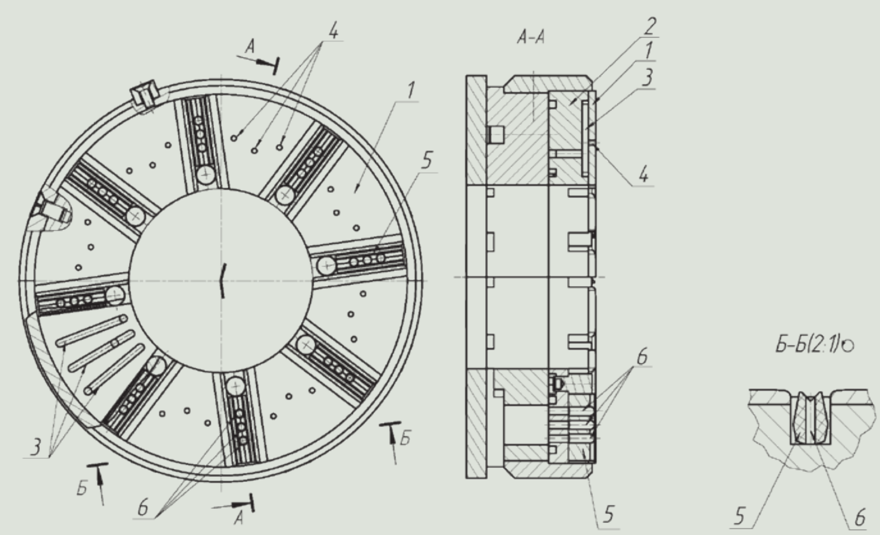

Fig. 9. Thrust reversible bearing with non-reversible (combi) properties: *1 – thrust pad; 2 – thrust bearing carrier; 3 – hydrostatic pockets; 4 – holes for supplying lube oil into hydrostatic pockets; 5 – reversible oil removal scraper; 6 – channels for individual lube oil supply*

15 Reversible oil removal scrapers

To provide for the reverse operation of the bearing, in the interpad space, there are installed reversible oil removal scrapers 5 (Fig. 9), the design of which allows them to carry out their functions independently of the direction of the rotor rotation.

Most of the considered technical solutions have been implemented by TRIZ Ltd while providing modernization of thrust bearings for steam turbines. The detailed results of their implementation for improving the efficiency of steam turbines will be described in the next paper.

References:

1. Inventor's Certificate № 1541442, СССР, 5F16C 17/04 Thrust Sliding Bearing. V. S. Martsynkovskyy, L. V. Cherepov, N. V. Malik, V. I. Yurko, Yu. S. Zinchenko.

2. Serezhkina L. P. Axial bearing for large steam turbines / L. P. Serezhkina, E. I. Zaretsky. – M: Mashinostroenie, 1988. – 175 p.

3. Patent for invention 81026, Ukraine, F16C 17/04. Lever Aligning System for Thrust Bearing. V. S. Martsynkovskyy, Yu. S. Filonenko, V. M. Kucherenko.

4. Patent for invention 2305212, Russia, F16C 17/04. Lever Aligning System for Thrust Bearing. V. S. Martsynkovskyy, Yu. S. Filonenko, V. M. Kucherenko.

5. Patent for utility model 29014, Ukraine, F16C 32/00. Thrust Bearing. V. S. Martsynkovskyy, Yu. S. Filonenko, V. I. Yurko, V. M. Kucherenko.