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Technical solution for improve the efficiency of the steam turbines

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Abstract

This paper presents effective ways to increase the carrying and reliability of thrust bearings. Technical solutions implemented by TRIZ Ltd have been considered. In comparative characteristics of the bearing took into account such factors as: capacity, peripheral speed at the average radius, speed at the periphery, specific pressure, specific lubricant consumption. Comprehensive analysis of the working conditions of bearing was aimed to protect against electroerosion.

Keywords: Two-tier stage; Two-tier low pressure cylinder; Fork-shaped blade

1 Introduction

The constructive deficiencies (errors), the imperfect of manufacturing techniques, change in 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

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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.

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

1) Two circles of circulation lubricant.
2) System of the rolling load balancing.
3) Hydrostatic compensating suspension.
4) The multifunction scrapers TRIZ.
5) Individual supply of the lubricant.
6) 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.
9) Hydrostatic unloading of the thrust disk.
10) Radial cooling of the thermally loaded zone of the pads.
11) Cooling of the thrust disk.
12) Tangential cooling of the pad periphery to preserve laminar flow.
13) Combined thrust bearing with reversible and nonreversible pads.
14) Reversible bearings with combi properties.
15) Reversible scrapers.
16) Regular profil the supporting surface.
17) Peripheral sealing zone.
18) Technology of electroerosive alloying.
19) Demagnetization – workflow of service of the dynamic equipment.

A typical problem during the operation of synthesis gas turbocharger is an axial shift of the turbine rotor 103-JT [15]. It is accompanied by wear of the thrust pads of the staff bearing, the rotor and stator damage of turbine parts. Analysis of the structure of the bearing of the turbine, as well as the nature of the wear thrust pads led to the conclusion that the thrust bearing is at the limit of its load-carrying capacity, component, according to the calculations of 5.5 t.

In order to prevent accidents in the most loaded starting and transients states TRIZ Ltd. Company (rus. Tovarishchestvo Realizatzii Inzhenernyh Zadach – Engineering Problems Realization Company) was developed modernized thrust turbine bearings 103-JT extra load – 12.5 tonnes, corresponding to the requirements of standards API, providing twice the reserve on the bearing capacity of the whole range of possible modes of operation of the unit, not only in rated operation. Compared with the staff thrust bearing a modernized bearing not only has a high load-bearing capacity, and lower power loss and the cost of the grease.

In 2006, the company was designed and manufactured, journal and thrust bearings for the turbine of the upgraded synthesis gas compressor poses 103J with capacity of the thrust part 20 t from the operating side and 10 t from broken out and receiving the load when the rotor rotates in the opposite direction up to 6 t. This problem was solved by using of combined thrust bearing from broken side, which establishes the irreversible and reversible pads. For uniform load distribution between thrust bearing pads in the system used of the rolling load balancing with increased compensating properties in which the sliding friction between the arms is replaced by rolling friction. To provide the necessary of heat removal and organization of sufficient flow of lubricant in the bearing is organized two rounds of circulation of lubricating oil to the thrust pads and implemented individual supply and drainage of oil from them, in addition, some of the oil passes through special channels in the thrust pads under the babbitt metal layer for cooling of the thermally loaded zone of the pads. To comply the conditions of the laminar entrance of the oil into the hydrodynamic wedge on the front edge of thrust pad is formed the front surface close to the hyperbolic. In addition, the leading edge cooling performed, preventing a decrease of viscosity and facilitate the expansion of the range of laminar flow.

Adopted and implemented at the operated units technical solutions have allowed to increase the carrying capacity by several times and to reduce the specific consumption of lubricating oil while maintaining the size of the binding to the turbine.

Design faults, imperfect manufacturing processes, change of technological operating modes of the turbocompressors in gas, petroleum, chemical and petrochemical industry cause axial rotor shifts. Therefore, the task of manufacturing the high-efficient and reliable thrust bearings (TB) is important nowadays along with effective rotor balancing, methods of axial forces calculation considering possible operating modes, improvement of static electricity elimination system, protective and monitoring systems of the axial shift.

TRIZ Ltd. Company has an experience in the development and modernization of the bearing assemblies providing their 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.

In this paper, there are disclosed the methods for increasing the load-carrying capacity and reliability of the thrust sliding bearings.

2 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 nonworking 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 nonworking 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].

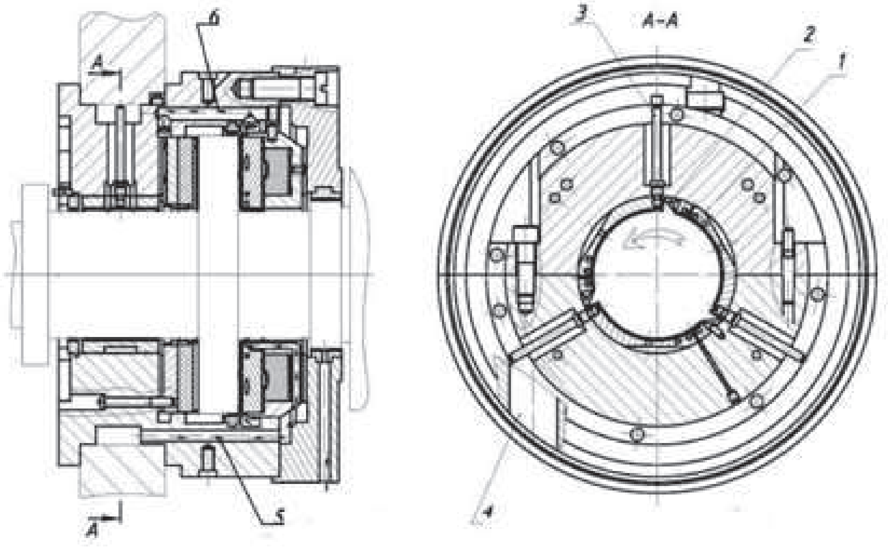

Figure 1: Journal-thrust bearing with two circles of oil lube circulation: 1 – journal pad, 2 – scraper, 3 – screw-lock, 4 – lube oil drain from thrust area, 5 – the first circle of lube oil circulation, 6 – the second circles of lube oil circulation.

On the nonworking 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%. This is facilitated by lowering response of the nonworking 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.

3 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.

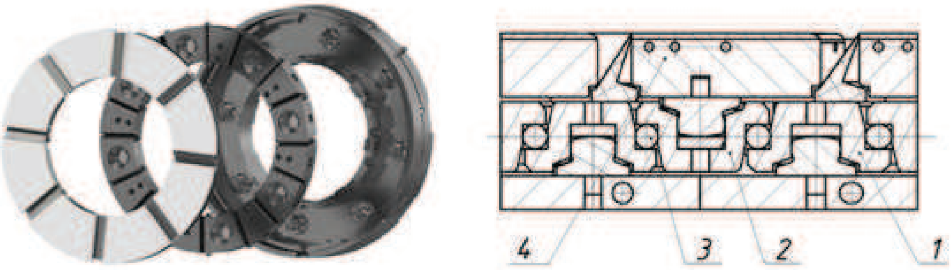

Figure 2: Lever aligning system of rolling with high-compensating properties: 1 – lower lever, 2 – upper lever, 3 – roller, 4 – thrust pad.

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.

4 Compensating hydrostatic suspension

Most of the thrust bearings operate with the distortions. The distortion reasons are the temperature misalignment of the unit caused by nonuniform 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 nonparallelism 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 (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.

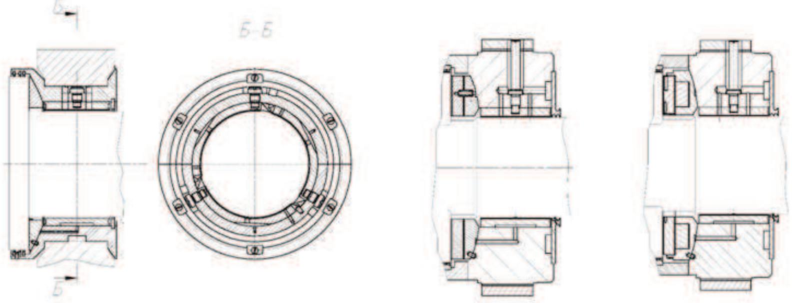

Figure 3: Versions of the thrust bearing equipped with the compensating hydrostatic suspension.

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 collarbearing’.

5 Multifunctional oil removing scrapers

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

- 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.

6 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 noninterconnected 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.

7 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.

8 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 $\kappa = 0.6$ [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

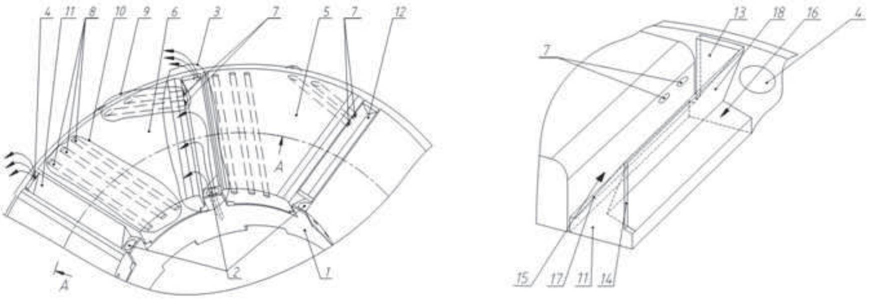

Figure 4: Tilting pad thrust bearing: 1 – housing; 2 – oil supply channels; 3 – interpad space; 4 – channels for draining lube oil off; 5, 6 – tilting thrust pads; 7 – oil cooling channels at inlet edge; 8 – oil cooling channels at thermally loaded zone; 9 – pad inlet zone; 10 – thermally loaded zone; 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.

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 $\kappa = 0.6$ 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.

9 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).

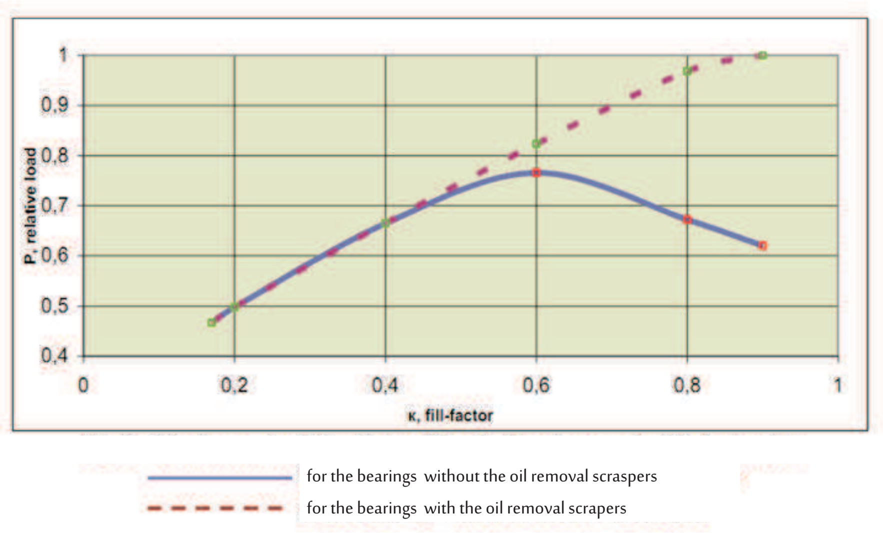

Figure 5: Maximum load, P, withstood by the bearing vs. the fill-factor, κ).

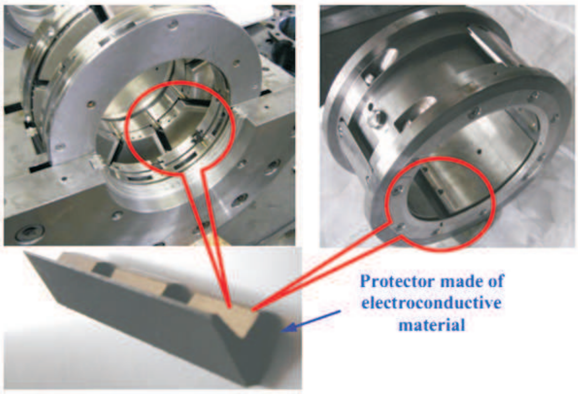

Figure 6: Bearings equipped with the scraper-protectors to prevent them from electroerosive deterioration.

10 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 nonworking 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 nonworking side through the throttling holes. In other cases, the lube oil is delivered onto the nonworking 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 nonworking 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 nonworking 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.

11 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.

12 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 made of electroconductive material.

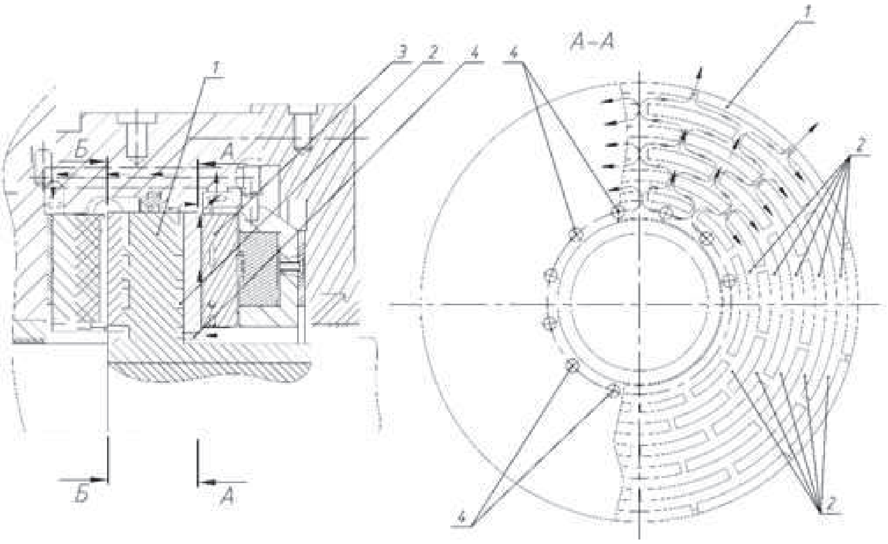

Figure 7: Axial bearing with inner cooling of the thrust collar: 1 – thrust collar, 2 – cooling channels, 3 – pad, 4 – supplying channels.

13 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.

14 Thrust bearing with reversible and nonreversible 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 nonreversible 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 nonreversible and reversible pads (Fig. 8). In such a design, at the working direction of the rotor rotation, the nonreversible 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 nonreversible ones.

Thus, joint installing of the nonreversible 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 nonstandard situations.

15 Reversible bearings with nonreversible properties

Another way to increase the load-carrying capacity of the reversible thrust bearings is to apply the reversible bearings with nonreversible (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

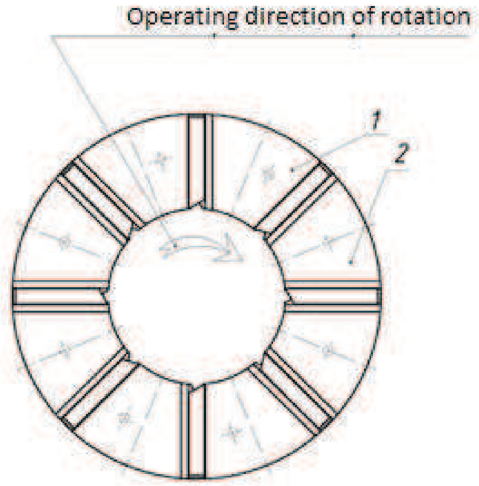

Figure 8: Thrust bearing with reversible and nonreversible pads: 1 – thrust nonreversible pad, 2 – thrust reversible pad.

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 pad for the relative magnitude of 0.55–0.6, which corresponds to the relative coordinate of the pivot point of the nonreversible pad.

Owing to the above said, the bearing obtains high load-carrying capacity, which is inherent to the nonreversible 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 nonreversible pads in the both directions.

16 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.

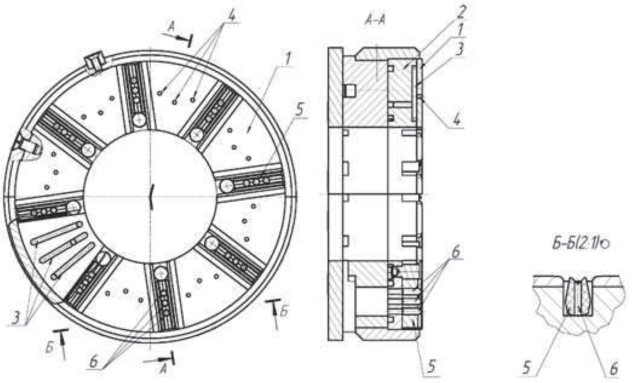

Figure 9: Thrust reversible bearing with nonreversible (combi) properties: 1 – thrust pad, 2 – thrust bearing carrier, 3 – hydrostatic pockets, 4 – holes for supplying lube oil into hydrostatic pockets, 5 – reversible oil removal scraper, 6 – channels for individual lube oil supply.

17 Regular profile for the bearing surface

In [6], there is proposed a new process based on the electroerosive alloying (EEA) method that is designed to form a special relief on the friction surfaces of the bearing pads (inserts), which relief increases the bearing reliability at the expense of increasing its load-carrying capacity. For this purpose, the load-carrying surface of the sliding bearing pad (insert) is covered with special layers provided in different directions by means of a tool-electrode using the EEA method. Besides, on the lateral and outlet edges, there are formed strips of the additional microrelief (Fig. 10). It should be noted that the formation of the regular microrelief is provided by the EEA method itself.

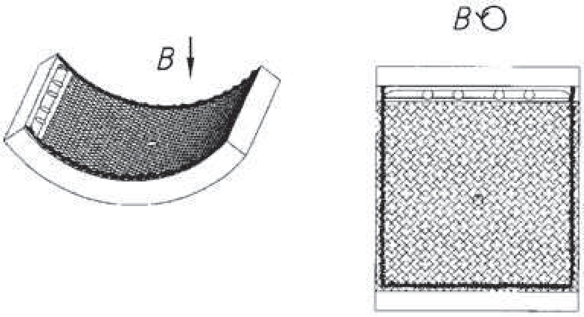

Figure 10: Bearing pad with the microrelief and the additional strips of the surface microrelief.

18 Peripheral sealing belt

The peripheral sealing belt (Fig. 11) is formed on the inner, outer, and outlet edges of the thrust pad using the EEA method. Such sealing belt reduces the lateral oil leakages from the hydrodynamic wedge in the radial and also in the circumferential directions. This facilitates filling of the hydrodynamic pressure epure thereby increasing the load-carrying capacity of the oil film.

Figure 11: Bearing pad with the microrelief and the additional strips of the surface microrelief.

19 The processes based on the electroerosive alloying method

Basing on the analysis of the process for manufacturing the bearings pads, examination of their operating conditions and reasons of their failure, it has been proposed to apply an intermediate layer of copper on a steel substrate before tinning. This will ensure a stronger bond of the steel substrate with the layer of Babbitt, as well as more intensive removal of heat from the friction zone [7]. There are a lot of different methods for applying soft metals on the steel items (electroplating, metallization by spraying, EEA, etc.). Comparison of their advantages and disadvantages made it possible to identify the EEA process as the most promising one to provide for the strong bond of the applied metal with the substrate. This feature is a determining factor in choosing this technology. Analysis of the results obtained for the test samples showed that the use of the copper transition layer applied by EEA process makes it possible to increases the bond strength between the steel substrate layer and the anti-friction layer of Babbitt (steel 20 + EEA copper + tinning + babbitt) by 35% if compared to the conventional technology (steel 20 + tinning + layer of babbitt). The proposed process [10], providing the strongest bond of the layer of babbitt with the steel substrate, is relevant for thrust and journal sliding bearings, floating seals, supporting fingers for the planetary multipliers gears, etc.

20 Degaussing process is a necessary technological process for dynamic equipment maintenance

The process of bearing electroerosion is provided by running electrostatic discharges off onto the ground at bypassing the ground loop rotor-current collecting brushes – 'earth' with formation of a new ground loop rotor – bearings – 'earth' (case). The reason for such a situation is the violation of the contact between the current collecting brushes and the rotor. As the bearings represent the units, which are most closely located to the rotor, they become the most vulnerable spots for the flow of currents in this circuit [11]. In newly developed TRIZ bearing, there is foreseen installation of scrapers-protectors made of an electrically conductive material (Fig. 6). While operating, the scrapers-protectors are in constant contact with the bearing housing and spaced by a minimum clearance from the load carrying surfaces of a machine rotor, with wear compensation in the course of operation. Based on practical experience on protection of load carrying surfaces against electroerosion in the course of operation the following measures can be recommend:

- to ensure reliable contact of current collecting devices with the rotor, and reliable operation of the ground loop of the machine, for example, turbine unit;
- while repairing, to inspect bearings, seals, couplings for the presence of electroerosive damages;
- if damaged to check the residual magnetization of parts, determine the points of locking current loop and clean the corresponding units, pockets,

clearances, and cavities of intoxicated oils and metallic dust that appeared as a result of ectroerosion;

- restore the quality of the surfaces for necks, inserts, ridges, pads of bearings and seals as the roughness of the above mentioned parts contributes to the concentration of the electric field and the breakdown of the oil film in the respective units;
- to take into account that conducting repair work associated with the use of strong magnetic fields (electric welding, magnetic particle testing, the use of magnetic racks, etc.) requires monitoring of the residual magnetization of parts and components;
- to perform demagnetization in the case of excessive magnetization; at operating machine, to provide for the absence of working nearby welding generators, emergency welding cables, and other extraneous sources of electric fields;
- it is necessary to use oil and gas seals reducing flooding with water and dissolving gases in oil;
- lube oil systems of the compressor units should have effective systems for cleaning lube oil;
- before starting up the machine, the lube oil should pass through the process of cleaning;
- compressor units should be protected against axial shift as electroerosive destruction of the layer of Babbitt occurs without any significant changes of the bearing temperature, and if the value of the rotor axial run-up in the direction of loading is less than the thickness of the bearing antifriction layer (1–2 mm), the rotating rotor will touch the stator elements.

The above mentioned recommendations are deficient since the measurement of the magnetization should be performed for rotor, bearings, flowing parts and cases. In this regard, degaussing is necessary to make at carrying out overhaul of disassembled machine.

21 Conclusion

Most of the considered technical solutions have been implemented while providing modernization of thrust bearing for turbine of synthesis gas compressor, 103-JT, in ammonia production (Fig. 12). Table 1 shows the factors of increasing the load-carrying capacity of the above said bearing in their absolute and percentage terms.

Table 1: Factors of increasing the load-carrying capacity.

Parameter	Value
Load-carrying capacity of bearing with six nonreversible pads, kG	9580
Increasing load-carrying capacity due to changing the amount and form of pads, kG	4630 (48%)
Increasing load-carrying capacity due to installation of scrapers, kG	1875 (13%)
Increasing load-carrying capacity due to additional cooling thermally loaded zone of pads, kG	1425 (10%)
Increasing load-carrying capacity due to applying lever aligning system with high-compensating properties, kG	2840(20%)
Increasing load-carrying capacity due to distribution of pressure epures on thrust collar (hydrostatic unloading), kG	800(6%)
TOTAL: load-bearing capacity of upgraded bearing, kG	21150

As it can be seen from the Tab.1, owing to the use of the technical solutions, the load-carrying capacity of the bearing was more than twice increased at keeping the overall dimensions of the bearing. Application of these innovative technologies has made it possible to increase the load-carrying capacity of the thrust bearings and reduce the specific flow rate of the lube oil while keeping the overall dimensions of the bearing.

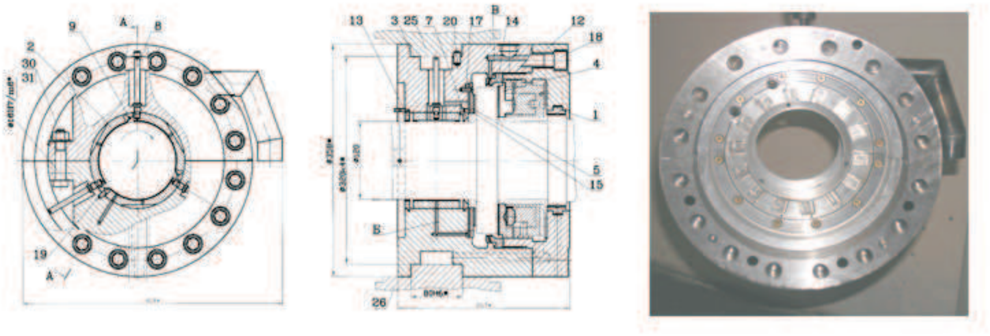

Figure 12: Journal-thrust bearing TRIZ.

By present time there have been no remarks to the operation of the bearings, axial shifts of the rotors have not been observed. Thus at the expense of rational system of supplying lubricant and decreasing common expenditure of lubricant per a bearing, installation of the modernised thrust bearing at the turbine 103-JT allows to diminish power losses for pumping lubricant by 736.5 W.

In 2006, TRIZ Ltd. Company developed and manufactured the journal bearing and the journal-thrust bearing for the modernised turbine of the synthesis-gas compressor, 103J [15], for the customer OPZ, Odessa (Fig. 13). Modernising the turbine for the purpose of increasing productivity of the shop for ammonia production was performed by corporations ALSTOM Power Sp. z o.o. and UTE Sp. z o.o..

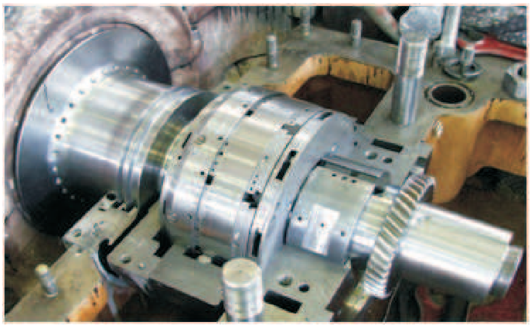

Figure 13: Journal-Thrust Bearing PDU –120/260 for Modernized Turbine 103JT.

According to the Technical Specification, the bearing ability of the thrust portion of the journal-thrust bearing should make 20000 kG on the operating side and 10000 kG on the nonoperating side at working rotational speed of the turbine of 11200 rpm. Based on the optimisation computations, diameter of the thrust disk has been restricted by value of 260 mm. Thus the pressure on the babbit surface of the thrust bearing shoe that was generated by the axial force makes 60 kG/cm^2 at the maximum sliding speed of 152 m/s at working rotational speed.

To provide for uniform loading distribution over the thrust bearing shoes, in the bearing there is applied a lever aligning system having increased compensating properties wherein the sliding friction between levers is substituted by rolling friction [12]. To provide for necessary heat-take off as well as to organize an architecture of channels for sufficient flow of lubricant, in the bearing there are performed two circles of circulation for lubricant oil and there is practically realized individual oil supply to thrust bearing shoes; besides, to cool the thermoloaded zone of the bearing shoe, some oil portion passes through special channels in the thrust bearing shoe which are fulfilled under babbit layer.

To observe proper condition for laminar oil flow entering hydrodynamic wedge, on an input edge of the thrust bearing shoe there is formed a special surface which configuration is close to the hyperbolic one. There is provision for cooling the input edge to prevent lowering oil viscosity and promote execution of a condition for the laminar oil flow.

In the course of development of the bearing design, it had been clarified that at the machine shut down, there would occur a condition when the turbine rotor would start rotation in the opposite direction, the rotational speed in this case could reach 4000 rpm, and the value of axial force could achieve 6000 kG and would be directed towards nonoperating bearing shoes. This problem has been solved by application of the combined thrust bearing on the nonoperating side in which irreversible and reversible bearing shoes are mounted. While rotating in a working direction with rotational speed of 11200 rpm, the bearing has bearing ability of 12000 kG, and at inverse rotation with rotational speed of 4000 rpm it has bearing ability of 6000 kgf. The reversible thrust bearing shoes have been developed for operation of thrust bearings under condition of inverse rotation (Fig. 14). Their bearing ability and damping properties are the same as at the traditional irreversible bearing shoes of the TRIZ design.

Thanks to the technical solutions incorporated in the design of the thrust bearing assembly, made possible the modernization of turbines, aimed at improving its effectiveness, as a result of which the steam consumption decreased by 12 t/h. In 2009, it was carried out similar to the modernization of another turbine at Odessa Port Plant and OAO ‘Kuibyshev Azot’. In 2010, two modernized turbines of ‘Akron’ and JSC ‘Kemerovo Azot’.

An important criterion for assessing the effectiveness of the thrust bearing is the specific consumption of lubrication or the ratio of oil consumption to the carrying capacity of the bearing. As can be seen from the table, bearing TRIZ exceed several times staff not only load-bearing capacity, but also according to this criterion, which confirms the effectiveness of the technical solutions to increase the carrying capacity of the bearing. The most effective from this point of view is a set of technical solutions implemented in the newly developed turbine bearing modernized PDU-120/260. This bearing is superior staff of the bearing capacity of almost 4 times, and the specific consumption of lubricant is almost 3 times less than that of full-time.

The second example of increasing the carrying capacity of the thrust bearing – improving axial stability of the turbine T-50/70–6.8/0.12 (Fig. 15).

Table 2. Comparative characteristics of the bearing.

	Bearing	Direction of rotation	Bearing capacity, kG	The peripheral speed at the average radius, m/s	The speed at the periphery m/s	Specific pressure, P, kG/cm^2	Factor PV $kG/cm^2 \cdot m/s$	Specific lubricant consumption, 1/min/t
Operating side	POU-120 (Staff reverse)	Operating	5500	102	131	24	2448	33
	PDU-120-TZ (modernized not reversible)	Operating	11700	102	131	51	5202	17
	PDU-120/260 (developed not reversible)	Operating	20000	113	153	56	6328	12
Nonoperating side	POU-120 (Staff reverse)	Operating	2630	102	120	4,9	500	690
	PDU-120-TZ (modernized not reversible)	Operating	263	102	120	4,9	500	355
	PDU-120/260 (developed not reversible)	Operating	12000	113	153	33	3729	20
		Reverse	6000	40	55	17	680	40

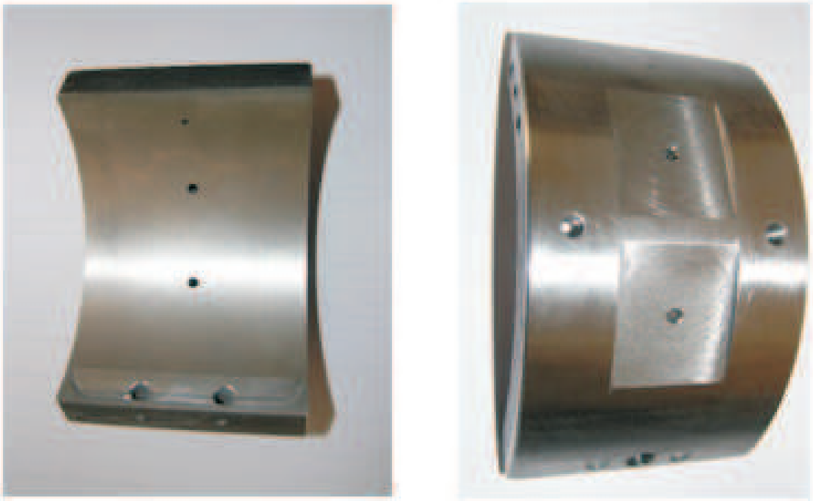

Figure 14: Reversible thrust bearing shoes with irreversible properties.

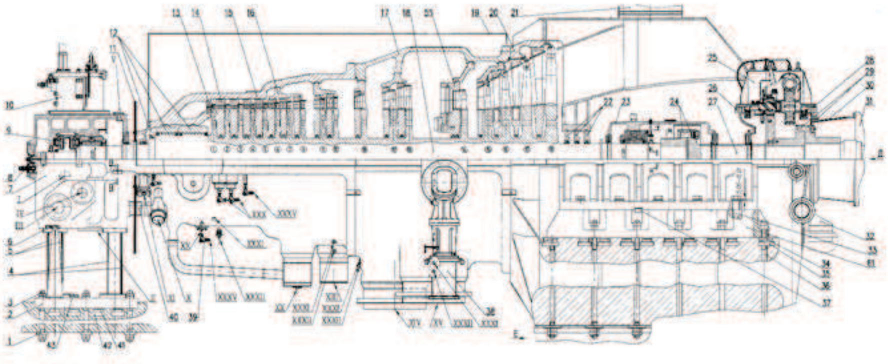

Figure 15: The steam turbine T-50/70–6.8/0.12.

During operation of the steam turbine there was a gradual increase in axial thrust of the turbine, which led to the destruction of babbit layer thrust pad (Fig. 16). In order to eliminate the reasons for the decision was made to modernize the steam turbine T-50/70–6.8/0,12 ALSTOM Power Sp. z o.o., as well as the replacement of the original thrust bearing thrust bearing lever, produced by TRIZ, with increased load capacity and protection against electroerosion.

After a comprehensive analysis of the working conditions of bearing assemblies

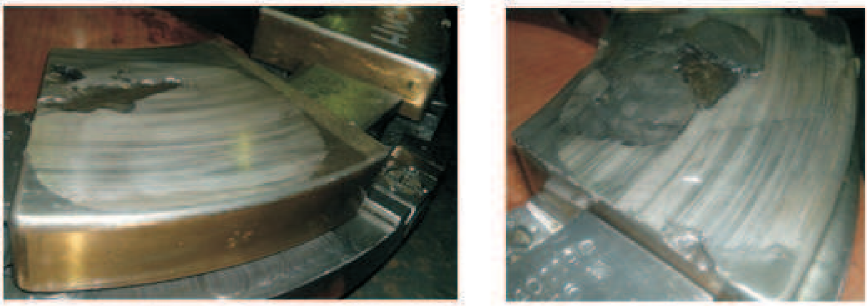

Figure 16: Destruction of the regular thrust pads.

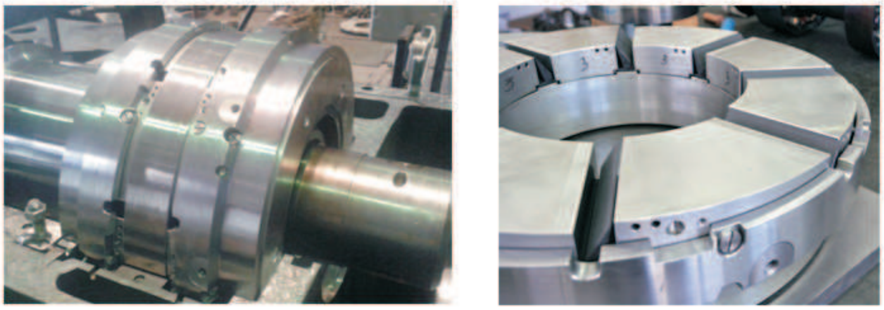

Figure 17: Journal-thrust bearing PUR-430.

the thrust lever bearing was designed to with increased load capacity 36700 kG compared with the standard design of 24000 kG and protection against electroerosion.

Parameters	Staff thrust bearing	Thrust lever bearing TRIZ
Bearing capacity, kgf	1400	36700
Sliding speed, m/s	67	67
Specific pressure, kG/cm^2	225	480
The specific consumption of lubricant, l/min	150	95
Protection from electric erosion	–	+
Fill factor (κ)	0.6	0.82
Operating temperature, °C	68	56

Thus it is necessary to mark that the second component of economic benefit that is understood as saving operation expenditures connected with technical maintenance of the compressor package and repair work, is capable to make a powerful part of total economic benefit at the expense of essential increasing of reliability of operation and prolongation of between-repairs cycle for the compressor equipment.

However, the quantitative estimation of this component is hampered in view of heterogeneity of data for a regular variant and should be spent for each concrete package taking into account specificity of its maintenance. The considered solutions are base at holding modernization of synthesis-gas turbocompressor. In practice, each package demands the decision of variety of additional problems, careful individual inspection, analysis, execution of a complex of engineering computations and work out, supervision of manufacture and adjustment. Experience of modernising of the dynamic equipment that is available in the TRIZ arsenal allows solving problems of any complexity with high technical and economic benefit [13, 14].

It is necessary to underline once again that all things stated above are realized and checked up in practice.

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