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# Basic Classification of the Gas-lubricated Bearings

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**Abstract:** Air bearings with forced supply of the working fluid in the gap between the surfaces of the stator and the rotor (gas-static) are designed for advanced oil-free transmissions of gas-turbine plants. Increasing the pressure at which the working fluid is supplied leads to the gap increases the load capacity and stiffness of the compressed layer, suppresses vibration. But the consumption of the working fluid increases as well and the efficiency of the construction lowers. The task of the design is to achieve a minimum working body consumption for the given load capacity. The comparison of the gas-static and gas-dynamic bearings is given. It is shown that the drawback of the first type is high air consumption that decreases the engine's efficiency and of the second type – the fire risk and low resource. To overcome this contradiction, the turning segments are used. Such bearings are called hybrid, with self-adjusting inserts. They combine the best qualities of gas-dynamic and gas-static bearings. A classification of air bearings by several criteria is given.

**Key words:** Gas lubrication · Gas-static bearing · Gas-dynamic bearing · Hybrid gas bearing · Radial bearing, axial bearing · Rayleigh's equation.

## INTRODUCTION

In this paper the development gas-static bearing (GPB) with a forced supply of gas in the lubrication layer between the stator and the rotor is described. The lack of contact during the working regimes and hence, the absence of contact friction, no necessity of oil lubrication, ability to provide high rotation speed, the relative simplicity and low weight of construction make these supports very attractive for those industries, where lightness, compactness and the long and reliable operation without maintenance is required. The efficiency of using gas-lubricated bearings instead of ball bearings in aviation and power gas-turbine engines (GTE) is linked to increased fire safety, engine weight reduction, increase of it's resource as well as reduction of operating and life-cycle costs.

### Classification of Gas-lubricated Bearings

**Radial, Radial-axial and Thrust Bearings:** The bearing prevents the shaft from displacement. There are three types of bearings: radial, radial-thrust and thrust (axial).

As the name implies, the radial bearing prevents displacement of the rotating shaft in the transverse (radial) direction. Respectively, thrust (axial) bearing prevents the displacement in the longitudinal (axial) direction and the radial-thrust bearing - in both directions simultaneously.

**Basics of Classification by the Principle of Lift Force Creation:** In theory of gas lubrication there are three principles of creating excessive pressure in the gas layer of supports, which are called the principles of gas lubrication:

- The wedge effect;
- The effect of the external lubrication pumping;
- The effect of the oscillating wall.

Having these three principles significantly broadens the field, where the supports with gas lubrication can be used. Combining these principles creates the hybrid supports, such as:

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Table 1: Comparative characteristic of GSB and the GDB

| GDB | Uncontrollable GSB | Controllable hybrid GSB |
|---|---|---|
| Used in small high speed rotating devices. | Used in gyroscopes, coordinating tables, measuring devices. | Haven't found their use due to control system performance problem |
| Advantages: efficiency | Advantages: load capacity depends only on the supplying pressure and area of interaction | Advantages: potentially perfect light supports for high-speed rotors. |
| Disadvantages: low resource, difficult manufacturing, fire risk. | Disadvantages: high consumption of the working fluid | Disadvantages: combines the virtues of both GSB and GDB, which virtually compensate all disadvantages, linked to the necessity of control system. |

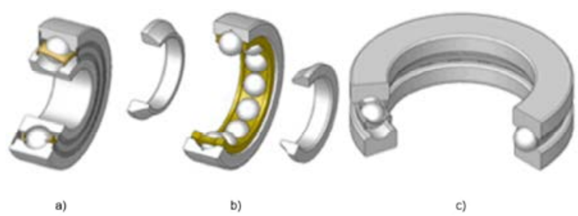


Fig. 1: Principle scheme of traditional ball bearings, a) - radial, b) radial - thrust c) thrust (axial).

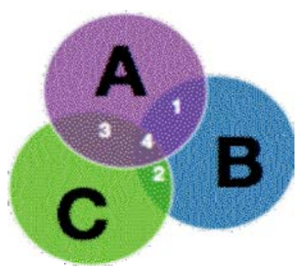


Fig. 2: Gas-lubricated sleeve bearings. Classification criteria: A- blowing system, B- moving inserts, C- rotor. 1 - gas-static bearing with self-adjusting inserts, 2 - gas-dynamic bearing, 3 - uncontrollable gas-static bearing, 4 - hybrid gas-lubricated bearing.

- The external pumping plus the wedge effect and b) the oscillating wall plus the wedge effect (Fig. 2).

**Air Bearings – Gas-static (GSB) and Gas-dynamic (GDB):** As previously stated, all bearings are divided by the principle of a lifting force creation. There are gas-static (lift force is created by the air, supplied by an external device under excessive pressure), gas-dynamic (lift force is created by the interaction between the shaft and bearing moving parts with a viscous thin layer) and hybrid (both effects are used) bearings. When the shaft rotates, the lift force always arises, due to viscous friction forces (the Bernoulli effect).

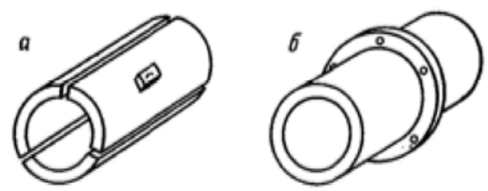


Fig. 3: The radial gas bearings. a) Segmental. b) full-scope.

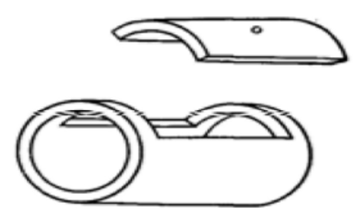

Fig. 4: Full-scope radial GSB with a segment cutout.

**Classification by the Form of the Supporting Surface:** Radial bearings can be segmental (Fig.3) and a cylindrical with 360° scope (Fig.3b). The last is called full-scope.

Sometimes segment cutouts are made in full-scope GSB (Figure 4).

This is done to increase the critical shaft rotation speed, at which instability, known as the "half-speed vortex" occurs (not to be confused with the critical frequencies of the forced oscillations). This phenomenon is typical for gas-dynamic bearings (GDB), but at very high speeds arises in full-scope GSB as well. In the segmental GSB such instability does not arise [1]. Segments can be made turning (Fig. 5). Then they will adjust themselves at an angle of attack to the oncoming gas flow during the rotation, i.e. wedge effect will occur, increasing the lift force [2-5]. If the axis of rotation is chosen properly, the segment will turn at the predetermined angle of attack by itself depending on the speed and load of the shaft and keep this position.

The segments may be fixed still or made in the form of wedges on the inner surface of the cylindrical shell. These bearings are called multi-wedge (Fig. 6). Segmental and

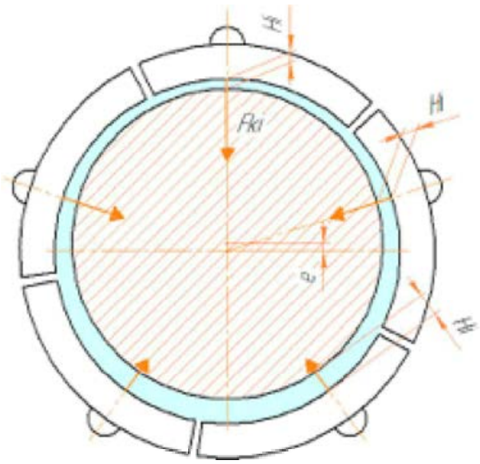

Fig. 5: Bearing with turning segments.

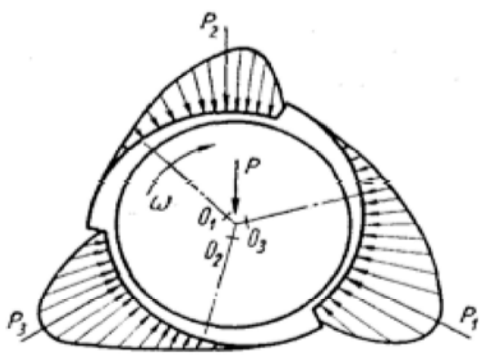


Fig. 6: Multi-wedge gas bearing with self-adjusting petals. P - axial load , P1, P2 , P3 - the pressure distribution on the surface of the petals, [omega] - rotation direction, O1 , O2 , O3 - shift of the petals.

multi-wedge bearings shows their advantages at their fullest when the hybrid method of lift force creation is used. At low shaft rotation speed they work as GSB and at high speed - as GDB. Thus, we achieve a combination of both bearing types' best qualities.

**Classification of GSB by the Method of Throttling:** The pressure in the gas supply system should not depend on the load. The change of the lubrication layer thickness under the load causes pressure redistribution in the gap. If the pressure drop at the supply hole is subcritical, i.e. the speed of the gas flowing out of it is less than the local speed of sound, the pressure disturbance enters the working fluid supplying system as well. If the pressure were supplied directly from the pump to the holes, the redistribution would cause the gas to flow mostly through the holes where the gap is currently the largest, therefore the pressure near the holes with smaller gap will be insufficient.

If the gas flows directly from the pump to the gap through the simple cylindrical holes, the change of the minimum gap size hmin under the influence of external load and, correspondingly, of the pressure will cause the change of the pressure in the pump. To avoid this various pressure throttling systems are added to the supply system. Their design is usually linked with the development of optimal bearing surface form to achieve the maximum possible stiffness of the gas layer.

Working fluid supplying system may be composed of different combinations of supply canals, grooves (undercuts) and cavities. The solution of the variational problem of maximizing the functional J = Ffr / F (where F- bearing capacity of the profile, FTP – friction force value), shows that the optimal gap is described by a piecewise continuous function.

The solution differs from the classic Rayleigh's profile [6] by the appearance of the intermediate section [7], the support surface is defined by the function.

$$H(\overline{x}) = \begin{cases} H_1 & 0 \le \overline{x} \le \overline{x_1} \\ \varphi(\overline{x}) & \overline{x_1} \le \overline{x} \le \overline{x_2} \\ H_2 & \overline{x_2} \le \overline{x} \le 1 \end{cases}$$

This solution is corresponded by the gas-static support with the "groove" (Fig. 7) of $B_{ch}$ x $L_{ch}$ size. The gas is supplied under high pressure through the hole with the diameter of $d_j$ and length of $l_j$, then into the groove and only then flows into the annular gap. The pressure throttling in such bearing occurs when the high-pressure gas passes through two resistances (hole - groove, groove - annular gap).

It is known [8] that GSB with grooves have significantly greater bearing capacity than the bearings where the gas is supplied directly into the gap through the holes. However, unlike them, they are apt to non-stationary regimes occurrence.

When supplied via system of simple holes the instability does not occur [9, 10]. To throttle the supply pressure in such GSP the holes are made stepped (Fig.8).

In fluid sleeve bearings the supply of lubrication from one of the bearing's end directly into the gap between the stator and the rotor can often be found (Fig. 9). This can be used in the gas bearing with a very high elongation, where l - shell length and d - its diameter.

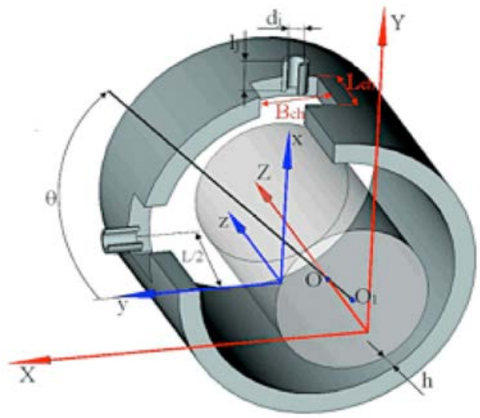


Fig. 7: Radial GSB with grooves.

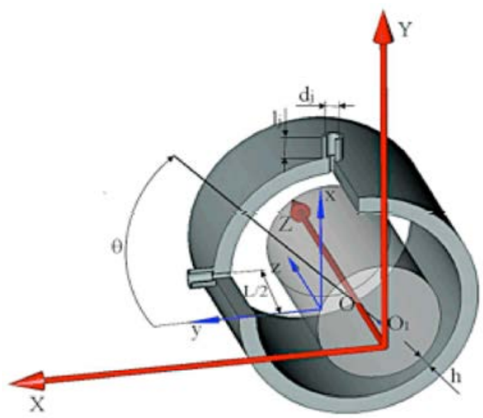


Fig. 8: Radial GSB with the high-pressured gas supplied through the stepped holes directly in the annular gap.

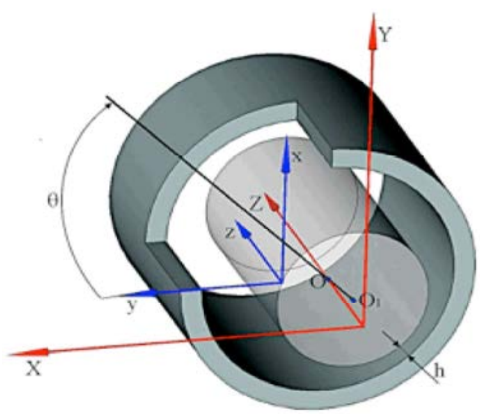


Fig. 9: Radial GSP with axial lubrication supply.

**Classification by the Form of Nozzles That Supply the Gas into the Gap:** By the geometry of the system of the gas distribution over the surface of the support GSBs are divided on:

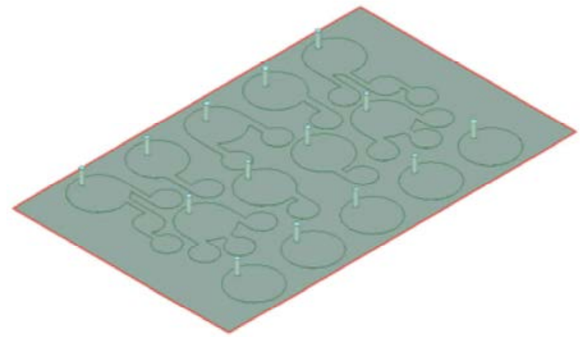

Fig. 10: Working fluid distribution system with cylindrical nozzles and grooves of complex shape.

- Bearings with simple and cylindrical holes. In the ultimate case a whole bearing surface can be covered with holes;
- Bearings with a slotted nozzles (flutes);
- Bearing in which the holes are connected as closed loops;
- Bearings with grooves (undercut), grooves can have a quite complex geometry (Figure 10).

## CONCLUSION

The classification of gas bearings is discussed above. The main classification criteria is the following:

- A vector of the force: radial, radial-axial (thrust), axial (thrust);
- A way of lift force creation: gas-static, gas-dynamic, hybrid, oscillating;
- The bearing surface form: full-scope, full-scope with cutout, segmental, multi-wedge;
- The method of pressure throttling the in the gas supply system: with simple cylindrical holes, with stepped cylindrical hole, with grooves, with working fluid supply from the end of the bearing.
- The shape of the nozzles: a simple holes, with a slotted nozzles, with gas supply to a closed loop, with gas supply to the grooves (undercut).

**Findings:** The design of gas bearings is very diverse and allow to solve most engineering problems arise.

The choice of a design concept must be preceded by a parametric analysis and optimization according to the chosen criterion of optimality. Most often it is the minimization of the working body consumption and the energy costs for a given load capacity, rotation speed and resource. There are also operational restrictions: the temperature and humidity of the working fluid, its pollution, the primary operation regime, etc.

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