APPLICATION OF SPHERICAL BEARINGS IN TURBOFAN AIRCRAFT ENGINE

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Abstract: *Spherical bearings have a very common application in machine and aircraft industry where rotational flexibility is required at joint connection. In an aircraft the application of spherical bearings plays an important role since they are used in critical interfaces of aircraft or aircraft engine structure. The article presents different types of spherical bearings with their applications, typical materials used for the bearings and bearing life calculation method.*

Keywords: SPHERICAL BEARING, TURBOFAN ENGINE

1. Introduction

Spherical bearings have a very common application in machine and aircraft industry where rotational flexibility is required at joint connection. In an aircraft spherical bearings have applications in different places starting from the aircraft structure, finishing on the turbofan engine. Figure 1 shows typical locations of spherical bearings in turbofan engine.

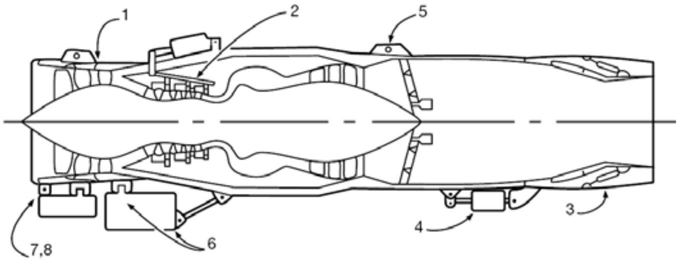

Fig. 1 *Spherical bearings application in turbofan engine:* ***1)*** *Fan, variable geometry actuator bearings,* ***2)*** *Compressor, variable geometry actuator bearings,* ***3)*** *variable nozzle, actuator bearings,* ***4)*** *thrust reverser and blocker door actuator and support bearings,* ***5)*** *engine mounts,* ***6)*** *gearbox mounts,* ***7)*** *oil tank mounts,* ***8)*** *oil cooler mounts*

Figure 2 shows typical locations of spherical bearings in an aircraft structure.

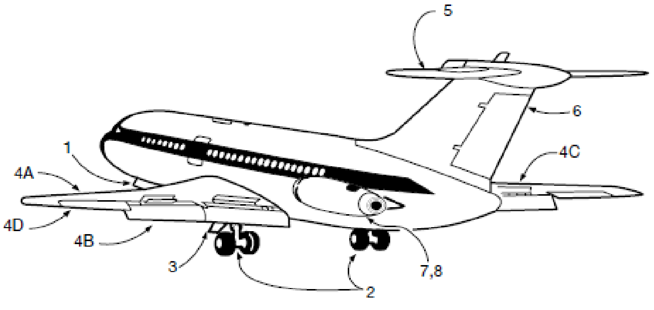

Fig. 2 *Spherical bearings application in aircraft structure:* ***1)*** *Nose landing gear actuator, steering and support bearings* ***2)*** *main landing gear actuator and support bearings,* ***3)*** *door and canopy actuator and support bearings,* ***4A)*** *leading edge slat actuator and support bearings,* ***4B)*** *trailing edge flap actuator and support bearings,* ***4C)*** *spoiler actuator and support bearings,* ***4D)*** *aileron actuator and support bearings,* ***5)*** *horizontal stabilizer actuator and support bearings,* ***6)*** *vertical stabilizer actuator and support bearings,* ***7)*** *thrust reverser actuator bearings,* ***8)*** *pylon and engine mount bearings*

2. Discussion

Variety of bearings application enforced different types of design like: swaged bearings, loader slot bearings, split ball bearings, split race bearings, bearing with teflon insert and the seal.

2.1 Swaged bearing

The bearing is manufactured by swaging a ductile race around a hardened ball. The race is machined and the assembly released to obtain proper clearance between spherical ball outer diameter and race inner diameter. Swaged spherical bearings have from 80 to 100 % contact between race inner diameter and ball outer diameter. The large contact area between ball and race allows to take very high static loads. The disadvantage of this type of bearing is the lack of exact control of bearing radial clearance.

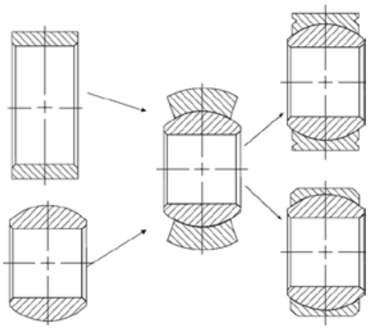

Fig. 3 *Swaged spherical bearing*

2.2 Loader slot bearing

Loader slot bearing is a non-swaged bearing type. The spherical race inner diameter is fully machined, case hardened and lapped. Lapping operation enables to achieve very exact dimension tolerances which give a very good control of internal radial clearance and contact area of mating surfaces. On the front face of the race there are machined entry slots which facilitate an assembly of the ball. At the assembly of the bearing in dedicated part it’s important that the loader slots will be positioned in the angle of 90 deg to the load which will be acting on the bearing. It’s important since the loader slot cross section is the weakest portion of the bearing.

An advantage of loader slot bearing is the fact that a ball is exchangeable without the need of bearing race removal from the next higher assembly. These types of bearings support static and dynamic loads.

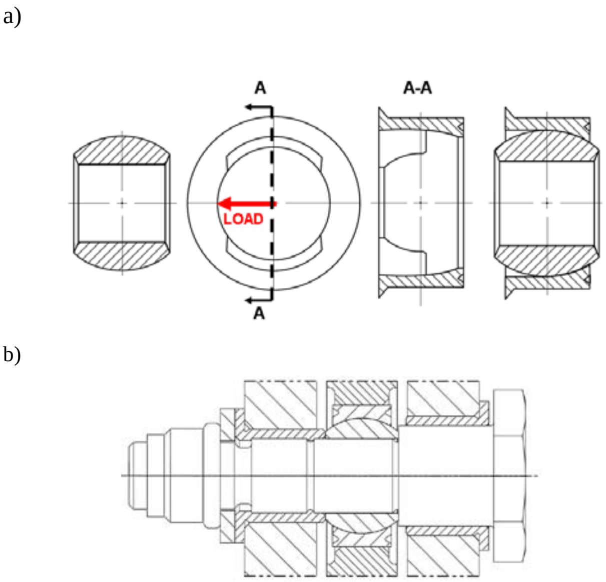

Fig. 4 *Loader spherical bearing: a)Spherical ball and outer race with loader slot, b) Example arrangement of loader slot bearing*

2.3 Split ball and split race bearing

Split ball spherical bearings are designed to offer similar advantages like slot bearings. In the split ball bearing there is no loss of bearing area due to the entry slot. The split ball is machined and ground in matched sets with zero gap at the separation plane. The ball is typically a copper alloy. Just as the load slot bearing, the race is fully machined, wear surface hardened, then finished with a lap operation. Because the race is the harder member, the wear is intended to occur on the ball. The split ball design allows to replace the ball without the need of replacement of all bearing assembly. Split ball designs are intended for applications only where pin rotation will occur. There are no clamping force on the ball faces.

Split race bearings have a race that is circumferentially or transversely split. The resulting two half races are placed around the ball and retained by a housing. Split race designs are used principally on larger bearings when installation in the applications is difficult.

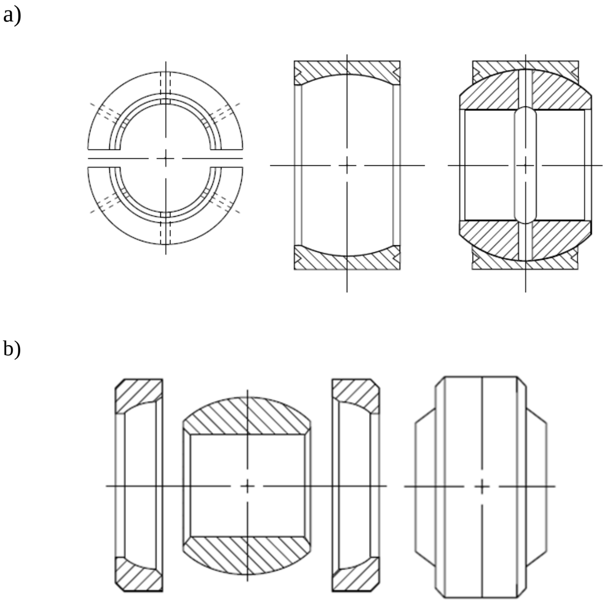

Fig. 5 *Split spherical bearing: a)Split ball bearing, b) Split race bearing*

2.4 Sealed bearing

For applications in which there is dirty environment sealed bearing is required. The seal is a mixture of rubber and silicone, which is secured by metal shield welded to the outer race. Teflon liner is used for bearings working in high load conditions. An example of bearing application can be aircraft landing gear and wing flap actuator.

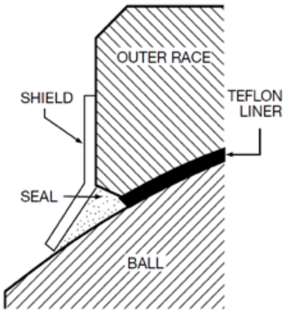

Fig. 6 *Sealed spherical bearing*

2.5 Typical materials for spherical bearings

Materials used for spherical bearings can have different ball-race configurations which depend on an application, working conditions, maximum loads and maintenance criteria. Table 1 shows common used materials.

Table 1: *Materials for spherical bearings*

Application	Corrosion resistant steel	Nickel based alloy	Cobalt based alloy
Ball	303 440C PH13-8Mo 15-5PH 17-4PH A-286 BG42 Greek Ascoloy	Inconel 718 InconelX-750 Rene 41 Waspaloy	Stellite 3 Stellite 6 Stellite 6B L-605 MP35N
Race	303,304 410,416,422 431,440C PH13-8Mo 15-5PH 17-4PH A-286 Greek Ascoloy	Inconel 718 Inconel X-750 Monel 400 Monel K500 Rene 41 Waspaloy	L-605

3. Results of discussion

Boundary dimensions of spherical joint depend on ball diameter in function of contact stress:

$$D = \sqrt{\frac{\dfrac{F_r^2}{A_r^2} + \dfrac{F_a^2}{A_a^2}}{\pi * \varphi * p_a}} \qquad (1)$$

$$\bar{A}_r = \frac{4A_r}{\pi D^2} \qquad (2)$$

$$\bar{A}_a = \frac{4A_a}{\pi D^2} \qquad (3)$$

$$\varphi = \frac{A_a}{A_r} \qquad (4)$$

where: F_r – radial load, F_a – axial load, A_r – nominal area of contac*t*, A_a – effective area of *contact*, φ - the ratio between the effective and nominal area, p_a – maximum contact pressure.

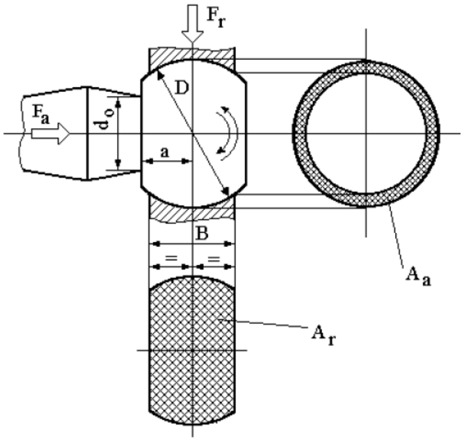

Fig. 7 *Spherical joint loading scheme*

The stress in the dangerous section of the spindle is calculated by the following equation:

$$\sigma_{\max} = \frac{4F_a}{\pi d_0^{\ 2}} + \frac{32F_r a}{\pi d_0^{\ 3}} \qquad (5)$$

where: d_0 – diameter of the spindle in the weakest area.

The safety calculations are performed in terms of contact pressure:

$$\frac{4\sqrt{\frac{F_r^{\ 2}}{\bar{A}_r^{\ 2}} + \frac{F_a^{\ 2}}{\bar{A}_a^{\ 2}}}}{\pi * \varphi * D^2} \le p_a \qquad (6)$$

Calculations of spherical bearing taking axial and radial load are performed with taking under consideration static and dynamic loads.

Contact pressure p_e for dynamic load conditions is calculated from equation (7):

$$p_e = \frac{F_r^{\ 2} + 6F_a^{\ 2}}{F_r * B * D} \qquad (7)$$

where: B – width of the bearing race, D – spherical diameter of the ball.

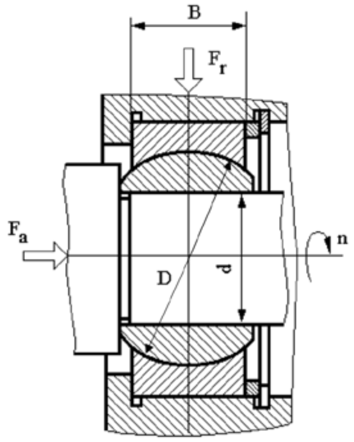

Fig. 8 *Spherical joint radial-axial loading scheme*

Knowing the contact pressure it can be calculated the durability of the bearing expressed in the number of cycles:

$$L_0 = f_0\left(\frac{p_0}{p_e}\right)^3 * 10^5 \qquad (8)$$

where: f_0 – *bearing lubrication factor,* p_o – dynamic permissible contact pressure for $L_{0=}10^5$ number of cycles.

For static calculations of spherical bearing it is considered the condition:

$$p_e \le p_{as} \qquad (9)$$

where: p_{as} – admissible static contact pressure.

Nominal bearing life is calculated by the following equation:

$$L = a_1 * a_2 * (a_3)^3 * \left(\frac{C}{P}\right) * 10^5 \qquad (10)$$

where: a_1 - the coefficient of the direction of acting of the load, having values a1 = 0.015÷5, as a function of the kind of load and kind of material pair, a_2 - coefficient of maintenance having values *a2=1* or *a2=15*, as a function of the existence or non existence of lubrication and the kind of material pair, a_3 - coefficient of temperature of the bearing having values *a3=0.3÷1*, as a function of the working temperature and the nature of the material pair, C – dynamic loading capacity factor, P – equivalent load

In many cases spherical bearings are working under radial, radial-axial and axial load conditions. Then dynamic loads for the bearings are calculated by the equation:

$$P = X * F_r + Y * F_a \qquad (11)$$

where: X - the coefficient of radial load (for radial bearings X=1, for radial axial ones X=1 if $\frac{F_a}{F_r} \le 0.8$ and X = 0.6 if $\frac{F_a}{F_r}\rangle 0.8$, for axial ones X=1.2), Y - the coefficient of axial load (for radial bearings Y=1÷6 as a function of the ratio Fa/Fr=0.2÷1.6 and the nature of the material pair, for the radial axial bearings Y=0 if $\frac{F_a}{F_r} \le 0.8$ and Y=0.7 if $\frac{F_a}{F_r}\rangle 0.8$, for axial ones Y=1).

Working conditions of the spherical joint include also rotational movement of the ball in the race (yawing movement) which has an influence on bearing life. To establish an allowable limit for ball sliding speed it's necessary to establish *p*V* factor:

$$p = \frac{F_r}{D * B} \qquad (12)$$

where: p – contact pressure [N/mm^2], F_r – radial load [N], B – width of the bearing race [mm].

Sliding velocity is calculated by the equation:

$$V = \frac{\pi * D * \beta * f}{90 * 60} \qquad (13)$$

where: V – sliding velocity [mm/s], β – half angle of turn of ball in the race , f – frequency of yawing motion of the ball in the race.

Factor $p*V$ needs to meet following criteria”

$$pV < pV_{allowable} \qquad (14)$$

An example value of $pV_{allowable}$ factor for material steel on steel is 400 [N/mm^2*mm/s].

4. Conclusions

The weight of the gearbox is the basic criteria used in aircraft industry. Gearbox arrangement at the early phase of the design has a serious impact on the gearbox weight. An application of the gearbox ratio share methodology for specific gearbox stages allows to minimize gearbox weight.

5. References

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