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Research Article

HIGH PRECISION MANUFACTURING TECHNIQUES REQUIRED FOR BEARINGS OF AIRCRAFT APPLICATION

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ABSTRACT

The paper focuses on the manufacturing processes associated with antifriction rolling element bearings. Rolling element bearings with higher precision class of ABEC 5 to ABEC 9 or RBEC 5 to RBEC 9 as per American bearing manufacturing association (ABMA) standard find application in aircraft engine main shaft, gearbox, accessory gearbox and precision-machine tool applications. These bearings operate at high speeds ranging from 0 rpm to 60,000 rpm with extreme temperature range between -54°C to 150°C. Bearings used in aircrafts require life of 99% reliability (i.e., 1% failure). Manufacturing processes and procedures play vital role in bearing's life. Manufacturing procedures in context of high speed, high precision bearings are considered here for discussion.

INTRODUCTION

Aircraft Bearings are designed and developed with higher precision class of ABEC 5 / RBEC 5 onwards as per ABMA Standards. To meet the requirement of aerospace quality standards, the bearing components are need to be manufactured with stipulated manufacturing processes. There are many macro level processes involved in manufacturing aircraft bearings. Rolling element bearings have different components such as outer race, inner race, rolling element, cage and rivets. Detailed process sheet to be prepared by the manufacturers for stage by stage machining of bearing component to achieve the dimensional and geometrical tolerance specified in the drawings both in component level and in assembly level.

The quality and reliability of the bearings used in the aircraft demands suitable surface integrity characteristics thus calling for appropriate manufacturing technologies viz., Ring rolling, vacuum hardening, cryogenic treatment, dynamic balancing, silver plating etc., which are not in vogue in the Indian bearing manufacturing industries. However they are required to maintain the metallurgical specification in the high precision aircraft bearings. These technologies are identified and effectively utilised to develop aircraft bearings.

Ring rolling

Design Ring rolling has evolved from an art into a strictly controlled engineering process. Seamless rolled rings are produced on a variety of equipment. All give the same product, seamless section with circumferential grain orientation. These rings generally have tangential strength and ductility, and often are less expensive to manufacture than similar closed die forgings. All in all, the ring rolling process offers homogeneous circumferential grain flow, which is one of the parameters that is required in any type of bearing (Harris, 2002).

In the ring rolling process, a pre-form, is heated to forging temperature and placed over the idler roll of the rolling machine. Pressure is applied to the wall by the main roll as the ring rotates. The cross-sectional area is reduced as the inner and outer diameters are expanded. Equipment can be fully

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automated from billet heating through post-forge handling. Advanced ring rolling equipment can roll contours in both the inner and outer diameter of the ring, allowing for excellent weight reductions, material savings, and reduced machining cost. There are infinite variety of sizes into which rings can be rolled, ranging from roller bearing sleeves to rings of 25 ft in diameter with face heights of more than 80 in. Various profiles may be rolled by suitably shaping the drive and idling rolls (Fig. 1).

Starting stock cut to size by weight is first rounded, then upset to achieve structural integrity and directional grain flow (Fig. 2).

Work piece is punched, and thenpierced to achieve starting "donut"shape needed for ring rolling process (Fig. 3).

Completed pre-form ready forplacement on ring mill for rolling. Ring rolling process begins with theidler roll applying pressure to the preformagainst the drive roll (Fig. 4).

Ring diameters are increased as thecontinuous pressure reduces the wallthickness. The axial rolls control theheight of the ring as it is being rolled (Fig. 5).

The process continues until the desired size is achieved.

Heat treatment furnace selection

Several standards list, detailed heat treating requirements including precise temperatures requiredheating and cooling, allowable differences in part surface and core temperatures, the method oflocating thermocouples in the charge and the methods to be used to perform mechanical tests to evaluate material strength. In the heat treatment of tool steel, the industrial practice of heating to the austenitising temperature and soaking for the appropriate time iswell known. New generation vacuum-furnace control system is capable of isothermal quench controlled cooling. After reaching pre-transformation temperature, (Ms), the work piece is held for a finite interval of time necessary to equalize the core and surface temperature hen cooled further in the transformation region without being subjected to thermal stresses due to temperature gradient between the core and surface. Increasing the cooling gas pressure from 6 to 12 to 15 bars proportionally increases the cooling rate also. The process sequence is as follows; keeping bearing rings in trays with sufficient gap for quenching airflow, close the doors and ensure tight. Preheat to 840°C, equalize then superheat to 1110°C vacuum environment at the pressure level of 10^{-2} bar. Immediately, followed by quenching through opening inert gas under 6-10 bar pressure (Fig. 6). Quenching rate is 40°C/min. After reaching to room temperature, the first tempering has to be carried out without opening the furnace. Between the tempers one sub-zero treatment has to be carried out ensure

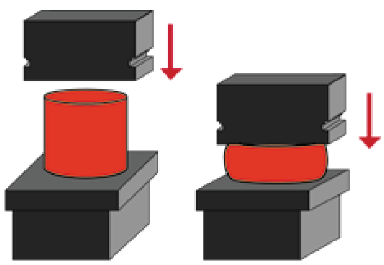

Fig. 1 Starting stock cut.

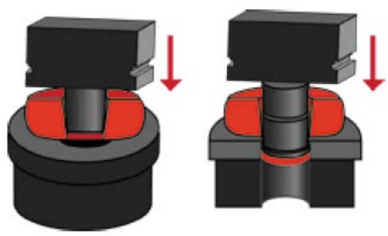

Fig. 2 Work piece is punched.

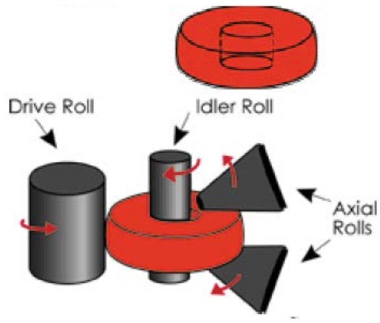

Fig. 3 Pre-form.

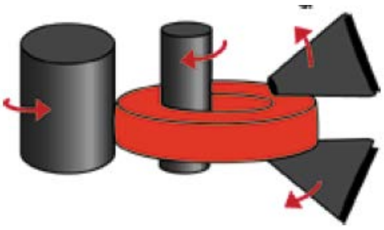

Fig. 4 Ring diameter sizing.

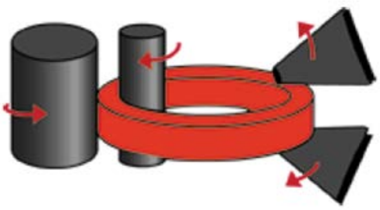

Fig. 5 Finished product.

the reduction of retained austenite. TTT cuvre as of (Fig. 7) shows martensite finishing temperature below 0°C.

Development of hard turning and hard milling process for bearing rings

By establishing the hard machining technologies the high energy grinding process is totally eliminated. Hard turning refers to the process of single point cutting of hardened pieces within the 2 µm range with hardness between 58 and 62 HRC. Hard turning has proven to be worthy alternative to the more expensive and cost consuming grinding process. This not only reduced the cost but also ensured the precision profile geometry that was required on the rings, where the grinding wheel is not easily accessible. In aircraft quality bearing development, some of the bearings are having customised geometrical shapes. The flanged type bearings are having holes on the flanges for positive locking of bearings with softer housing materials. These flanges are to be finished after heat treatment. Hence hard turning and hard profile machining concepts are adapted (Fig. 8) (Janusz, *et al*., 2004)

Development of dynamic balancing technology for bearing cages

As the bearing used in the aircraft are running at higher rpm (16000-56000 rpm), they have to be

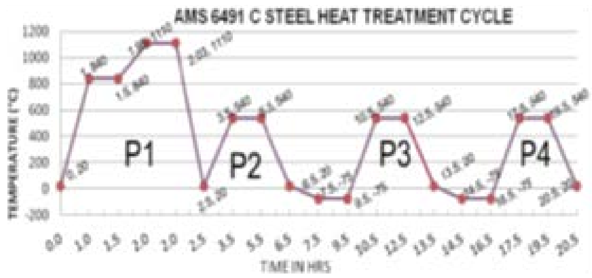

Fig. 6 Heat treatment cycle.

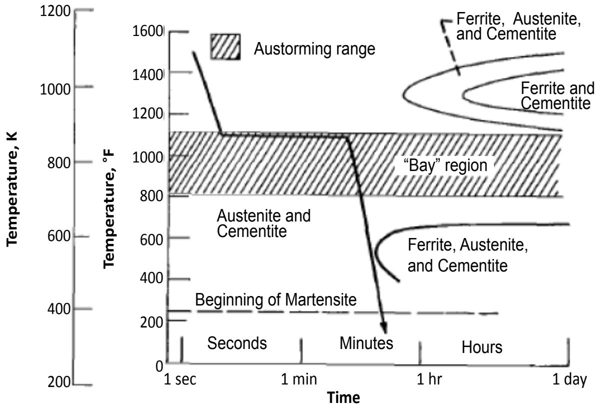

Fig. 7 TTT curve for AISI M50.

Fig. 8 Hard turning.

dynamically balanced which otherwise induce non uniform load conditions that ultimately impairing the service life. Balancing is a process of aligning principal inertia axis with the geometric axis of rotation through the addition or removal of excess material. By doing so, the centrifugal forces are reduced, minimizing noise, vibration and associated wear.

The mass moment of inertia is the rotational counterpart of mass and is a measure of mass distribution about an axis. For a particle, it is the product of mass (m) times the square of the distance (r) from the axis to the particle, $I = mr^2$. Since the mass moment of inertia is calculated with respect to an arbitrarily specified axis, it can have just about any value depending on the axis chosen. It turns out that all rigid bodies have at least one set of axes about which the body is perfectly balanced. These axes are known as the principal axes. They are mutually orthogonal and have their origin at the mass centre.

RESULTS AND DISCUSSION

General motion of the cage in a ball bearing is correlated to the level of cage unbalance. Unbalance levels at which the cage interactions become quite excessive are determined from the parametric runs. The increasing mechanical interactions are indicated by increasing forces at the guide lands and also in the cage pockets. The highly transient and very short time collisions, underflow unbalance, tend to become almost steady contacts at high unbalance level. This leads to excessive wear of the cage both at the guide lands and in the cage pockets. The cage contact forces and the resulting wear rates are correlated to cage unbalance for both outer and inner race guided cage with a combined thrust and rotating radial load on the bearing. Also the corresponding power losses in the bearing are evaluated as a function of cage unbalance. Although the solutions are similar for both outer and inner race-guided cages, guidance on the stationary outer race appears to be somewhat more favourable in terms of both power loss and cage wear. For each of the prescribed unbalances the overall mechanical interaction of the cage, at any time T, is defined by a tie-averaged wear rate W(T), which is expressed as

$$W(T) = \frac{1}{T}\int_0^T \frac{KQ(t)V(t)}{H}dt$$

where K is a wear coefficient, H is the hardness of the cage material, Q(t) and V(t) are respectively the contact load and sliding velocity at instant t. Under stable conditions such a time averaged rate stabilizes to a well-defined steady-state value while a definite positive gradient with respect to time is developed in the event of instability.

When a rotor rotates at a speed, if the unbalance mass m is located at a radius r then the magnitude of the centrifugal force is $mr\omega^2$. If it is two planes then the force will be F1 (Fig. 9),

$$F1 = \frac{a_2}{l}mr\omega^2, F2 = \frac{a_1}{l}mr\omega^2$$

The magnitude of A_w can be computed using the law of cosines.

$$A_w = [A_u^2 + A_{u+w}^2 - 2A_u A_{u+w}\cos(\phi - \theta)]^{1/2}$$

Since the magnitude of the trial weight W and its direction relative to the original unbalance are known, the original unbalance itself must be at an angle α away from the position of the trialweight. The angle α can be obtained from the law of cosines:

$$\alpha = \cos^{-1}\frac{A_u^2 + A_w^2 - A_{u+w}^2}{2A_u A_{u+w}}$$

The balancing requirement grade G2.5 was selected based on ISO 1940. (ISO 76:1987(E)) The permissible unbalance was calculated by using equation

$$e_{per} = 2.5\left[2.5\frac{30}{\pi * N}*10^3\right]g.mm/\mathrm{Kg}$$

$$U_{per} = m * e_{per} g.m$$

Where

e_{per}: Residual specific unbalance

Fig. 9 Cage balancing.

U_{per}: Numerical value of the permissible residual balance

m: Numerical value of the rotor mass

G: Balance quality grades

N: rpm

By dividing the result by correction plane radius will give the amount of material to be removed or added to balance the cage (Edward and Paul, 2000; Pradeep, 1991; Pradeep; 1991).

Silver plating technology development for cage

When a part is in sliding or rolling contact with another engineering component then, even if it is lubricated, there is the likelihood of adhesive wear. Adhesive wear can occur in many engineering situations; for instance shafts, journals, pistons and rings, cams, bearings, pads, gears, seals, slideways, etc., as well as in metal cutting, drawing and forming. In general, if mating parts are metallic, the softer of the two, suffers greater wear and therefore components are to be surface engineered (Rao, 2004; ISO 281:1990 (E)).

Silver gives excellent anti-fretting properties as well as providing a corrosion resisting surface. Thicknesses are typically between 10 and 25 μm. The bath composition contains a small amount of brightener additive which prevents effective deposit thickness in excess of 50 μm. Silver plating on steel, zinc and zinc-based alloys should have anunder coat of nickel over copper. As aircraft bearings are made from steel, aluminum bronze or silicon bronze requires undercoat. Silver plating on copper and copper alloys should have a nickel undercoat. Copper and copper alloy material on which a nickel undercoat is not used, and other base metals where a copper undercoat is employed, should not be used for continuous service at a temperature in excess of 149°C. Adhesion of the silver plating is adversely affected because of the formation of weak silver and copper inter-metallic layer.

Silver in its purest form is a soft, white, lustrous metal which is extremely malleable and ductile and capable of taking a high polish. It may be electrodeposited in either a soft dull finish or a hard-semi-bright finish, suitable for use in the aerospace industry and the electronic and electrical industries. The two types of finishes available are: Dull Silver and semi-bright silver. In a current bearing development, dull silver coating is used as it is more versatile than semi-bright silver. This silver is in its purest form (99.9%) and therefore a very efficient electrical conductor. The finish is also very lubricious which makes it suitable

Fig. 10 Vacuum packed bearing.

for use in aerospace components where resistance against rubbing wear is essential.

Bearing packing and preservation technology

In the vacuum packing process, all air is evacuated from the pack. It is then hermetically sealed in order to maintain the vacuum and protect the contents from environmental influences. A vacuum pack protects these products from environmental influences such as dust, moisture and oxidation. The vacuum pack also fixes the pack contents in position and reduces the volume of products containing air, such as foams, fabrics, etc. Chamber sealers require the entire product to be placed within the machine Like external sealers, a plastic bag is typically used for packaging. Once the product is placed in the machine, the lid is closed and air is removed. Once the air is removed, the bag is sealed and the atmosphere within the chamber is returned to normal. The lid is then opened and the product removed (Fig. 10).

CONCLUSION

Based on available facilities and technologies in India it is possible to manufacture higher class of accuracy bearings in flexible manufacturing mode. However, it's difficult to produce bearings in mass production mode with minimum rejection rate. Establishment of dedicated manufacturing system to produce higher precision class bearings in India is essential to reduce the production cost of bearings.

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