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Analysis of Load Distribution in Planet-Gear Bearings

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[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

In epicyclic gear sets aimed at aeronautical applications, planet-gears are generally supported by spherical roller bearings with bearing outer race being integral to the gear hub. This paper presents a new method to compute roller load distribution in such bearings where the outer ring can't be considered rigid. Based on well known Harris method, a modified formulation enables to account for centrifugal effects due to planet-carrier rotation and to assess roller loads at any position throughout the rotation cycle. New model load distribution predictions show discrepancies with results presented by Harris, but are well correlated with 1D and 3D Finite Element Models. Several results validate the use of simplified analytical models to assess the roller load distribution instead of more time consuming Finite element Models. The effects of centrifugal effects due to planet-carrier rotation on roller loads are also analyzed. Finally the impact of the positions of rollers relative to the gear mesh forces on the load distribution is shown.

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Introduction

Epicyclic gear sets are known to be power transmission systems that provide high capacity, power density and efficiency. For these reasons, they are widely used in various aeronautical applications such as helicopter main gearboxes and turboprop power gearboxes where the weight is a critical performance criterion. In planetary and epicyclic gearboxes, high loads are transmitted via the planet-carrier which could result in misaligned contacts on gear meshes or planet bearings. Conventional gearbox designs thus include spherical roller bearings to support the planets on the planet-carrier axles. These bearings can cope with misalignment angles up to 1.5 degrees [1] while providing a good radial load carrying capacity. A past study [2] has shown that bearings are a major source of failure in epicyclic gear sets. The authors demonstrated also that the optimization of planet-bearings design can provide significant weight reduction since the saving obtained on one planet is multiplied by the number of planets which is generally greater than four. At the early gearbox design phase, it is thus essential to perform parametric studies in order to find the most optimized design for the planet bearings.

Spherical roller bearings in aeronautical epicyclic gear sets are characterized by two main features:

- For weight saving reasons, the outer-ring of these spherical roller bearings are usually made integral to the planet-gear hub which is, in addition, made as thin as possible. Gear mesh forces induced by the sun-planet and the ring-planet meshes are thus applied directly to the outer-ring at localized points. The conventional assumption of rigid bearing outer-ring submitted to a concentrated load is here not valid. The outer-ring must be considered deformable to determine the roller load distribution.
- In epicyclic gear sets, the carrier is rotating while the ring is stationary (Figure 1). This makes the planet-bearings kinematics rather complex with the inner-ring rotating around the gearbox main

axis while the outer-ring is rotating around the inner-ring (planet-carrier axle). The effect of the centrifugal loads induced by the outer-ring weight could influence the roller load distribution since the ratio of centrifugal loads to accumulated radial gear loads can be as high as 20% for typical turboprop applications.

In this regard, several studies have been conducted to determine the influence of a deformable outer-ring on the bearing loading. An analytical approach has been proposed in 1963 by Jones and Harris [3] and also described in Harris [4]. The main results showed that the outer race distortion modifies significantly the roller load distribution compared with rigid outer race assumption: the number of loaded rollers increases and the most loaded roller is no longer located along gear tangential direction but close to mesh force application. Effects of bearing's diametral and out-of-round clearance were also obtained with the same model by Harris et al. [5]. For this model, though, no finite element (FE) validation exists which could give an idea of the performances of the model.

Liu and Chiu [6] proposed a model that accounts for inertial effects induced by planet-carrier rotation and roller centrifugal forces. The main results showed the influence of the bearing diametral clearance on roller load distribution and fatigue life. Some discrepancies were also observed by the authors compared to Jones and Harris study [3]. Other authors have proposed an FEM approach. Drago et al. [7] studied the effect of planet bearing outer race deformation on gear stresses using a 3D finite element model. The authors demonstrated that the optimization of roller loads can detrimentally affect the gear stresses and that the planet bearing can't be designed without accounting for gear stresses.

The model presented in this paper is based on Jones and Harris [3] approach. In a first part, a recall of Jones and Harris model will be given. A comparison of predicted loads and deformations with 1D and 3D Finite Elements models will show discrepancies that can be explained by the assumptions made in Jones and Harris equations.

In a second part, a new model is proposed that can solve non-symmetric problems to account for centrifugal effects due to planet-carrier rotation. The results analyze the effects of centrifugal effects. The influence of rollers positions with respect to the mesh loads is also studied.

Analysis of state of the art model

Jones and Harris analytical model description

In Jones and Harris approach, the outer-ring flexibility is modeled as a thin elastic ring with a mean radius R and a section moment of inertia I (Figure 1). The effect of gear teeth on ring stiffness is neglected. The loads acting on the bearing outer ring are simplified as two equal and diametrically opposed loads representing respectively sun-planet and ring-gear-planet meshes (Figure 2). The mesh loads are assumed to act along the line of action and on the pitch radius R_p .

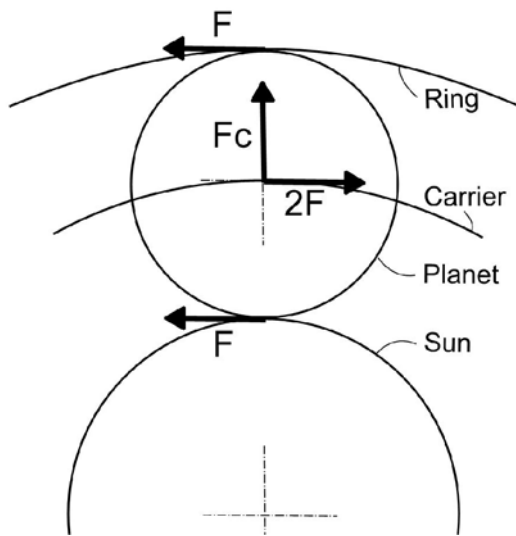


Figure 1. Loads acting on a planet

These loads can be decomposed in elementary radial (F_s) and tangential (F_t) forces and a moment (M) acting on the elastic ring mean radius R . The rollers are assumed to be equally spaced around the outer-ring with the first roller being located along the Ox axis defined in Figure 3. The position of the roller number j is characterized by an angle ψ_j and the reaction force of this roller on the outer-ring is noted Q_j . In summary, the planet-gear outer-ring is submitted to mesh forces F_s , F_t , M and roller contact loads Q_j .

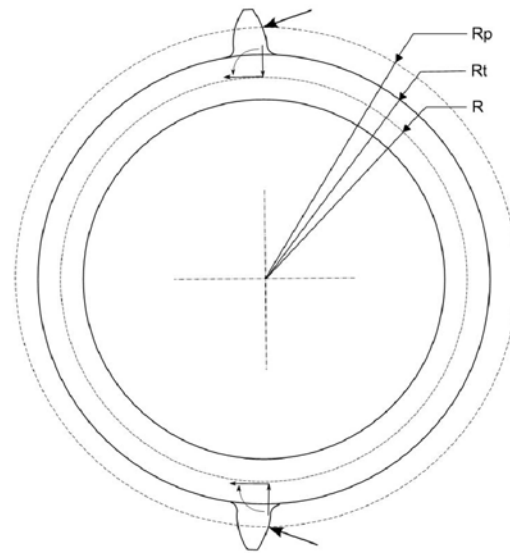


Figure 2. Simplification of mesh loads

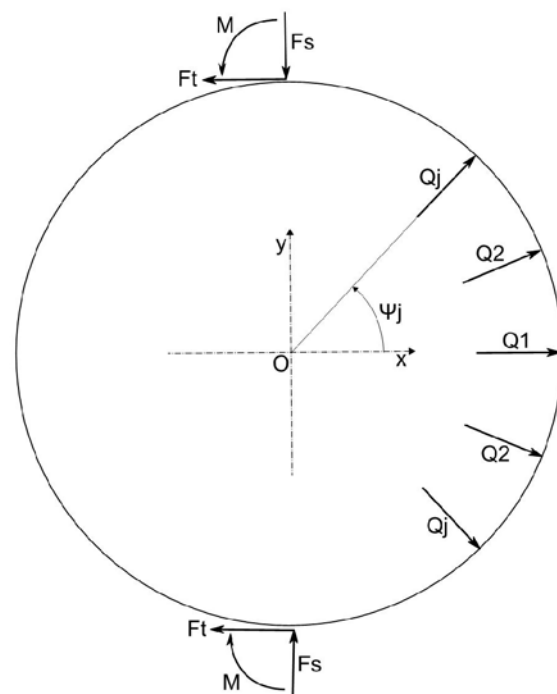


Figure 3. Forces acting on the planet-gear outer-ring

The system studied is thus symmetric around the Ox axis. This makes it impossible to study the influence of centrifugal effects which introduce an asymmetric force acting along the Oy axis, or to study the load distribution with arbitrary roller positions. The radial elastic ring deflection at point i due to a load P is expressed by means of influence